CHAPTER 4: OVERVIEW OF THE TAXONOMIC GROUPS

For consistency when comparing Species of Greatest Conservation Need (SGCN) lists across states, accepted or official taxonomic standards for plant and animal species were used by consulting recognized sources for naming conventions. These are listed in Box 4-1. Species undergoing active genetic research or having taxonomic discrepancies utilized the latest literature so as not to have to wait on a publication's revision cycle. Many existing conservation plans and initiatives exist for members of these taxonomic groups and are listed in Appendix 1.

Box 4-1: Taxonomic Standards Sources

- **Reptiles & Amphibians**: The Society for the Study of Amphibians and Reptiles (SSAR) is the official taxonomy source for North American amphibians and reptiles north of Mexico.
- **Birds:** The American Ornithologists' Union Checklist of North and Middle American Birds is the official source on the taxonomy of birds found in North and Middle America, including adjacent islands.
- **Mammals**: The American Society of Mammalogists Mammal Diversity Database is used for mammals.
- **Freshwater, Diadromous, & Marine Fishes:** The Common and Scientific Names of Fishes from the United States, Canada, and Mexico, 8th edition, published by the American Fisheries Society (AFS), has the recommended list of common and scientific names of fishes from the United States, Canada, and Mexico.

  Page, L.M., K.E. Bemis, T.E. Dowling, H. Espinosa-Perez, L.T. Findley, C.R. Gilbert, K.E. Hartel, R.N. Lea, N.E. Mandrak, M.A. Neighbors, J.J. Schmitter-Soto, & H.J. Walker Jr. 2023. Common and scientific names of fishes from the United States, Canada, and Mexico, 8th edition. American Fisheries Society, Special Publication 37, Bethesda, MD.
- **Mussels & Snails:** The Freshwater Mollusk Conservation Society has the recommended list of common and scientific names of mussels and snails.
- **Crayfish & Freshwater Shrimp:** The latest edition of Thorp and Covich's Freshwater Invertebrates: Ecology and General Biology has the recommended list of common and scientific names.

  James H. Thorp and D. Christopher Rogers, eds. 2015. Thorp and Covich's Freshwater Invertebrates: Ecology and General Biology, 4th edition. Academic Press. 1148 pp.
- **Marine Invertebrates, Leeches & Freshwater Sponges:** World Register of Marine Species (WoRMS) is referenced for the latest information and taxonomy for marine invertebrates, leeches, and sponges. Sponges also utilize the World Porifera Database associated with WoRMS.
- **Insects & Allies:** NatureServe Explorer and the primary literature are utilized for these invertebrates.
- **Plants**: NatureServe Explorer is used for non-vascular plants. The latest edition of Weakley's book is used for vascular plants:

  Weakley, A.S. 2024. *Flora of the Southeastern United States*. University of North Carolina Herbarium, North Carolina Botanical Garden, Chapel Hill, North Carolina, USA.

Fifteen main taxonomic groups were evaluated in this edition of the State Wildlife Action Plan (SWAP) and each of these is discussed in this chapter, including their current status, challenges faced, and conservation opportunities available to address these threats. Chapter 5 discusses overarching threats and stressors that impact multiple taxa groups. Likewise, Chapter 8 discusses actions that can be taken to mitigate for those threats for the benefit of multiple species and habitats across many taka groups. Additionally, those taxa groups with all or part of their life cycles in freshwater aquatic systems face a particular subset of threats and stressors.

Herpetofauna: Amphibians and Reptiles

Currently, 148 species of amphibians and reptiles are known to occur in South Carolina. The State's rich herpetofaunal diversity is likely due to the diversity of habitat in the state. Though small in land area, South Carolina comprises portions of three major physiographic provinces: the Blue Ridge, Piedmont and Coastal Plain. Within each of these provinces, numerous sub-provinces or distinct ecological regions occur. A variety of unusual or rare habitats are found within these regions, and many support populations of unusual or rare amphibians and reptiles. The Blue Ridge, Upper Piedmont (referred to colloquially as the Foothills) and Coastal Plain are collectively rich in herpetofauna. Rock outcrops in the Blue Ridge and Upper Piedmont provide habitat for the Southern Gray-cheeked Salamander, the Green Salamander, and the Timber Rattlesnake. Bogs in this same region may provide habitat for Bog Turtles, Four-toed Salamanders and Wood Frogs**.** Several species of amphibians and reptiles found in South Carolina's Blue Ridge are peripheral to the state as the core of their geographic range is farther north.

The Piedmont of South Carolina is not as rich in herpetofauna as the other physiographic provinces, but there are areas of this province that are significant. The Savannah River Valley, for instance, is home to the Webster's Salamander, a rare species endemic to this region (at least in South Carolina). Numerous species that are found primarily in the Coastal Plain intrude into the Piedmont along the Savannah River.

The Coastal Plain is a very important region overall for herpetofauna in South Carolina, with high species diversity, habitat diversity, and multiple rare, threatened and endangered species. Of the 148 species of amphibians and reptiles found in the State, 120 (81%) can be found in the Coastal Plain. Within this province, the Longleaf Pine ecosystem plays a vital role in the life history of many species, including such rarities as the Pine Snake, Southern Hognose Snake, and the Gopher Tortoise. Isolated, temporary wetlands such as Carolina bays, flatwoods, ponds, and lime sinks provide breeding habitat for numerous amphibians, including the Flatwoods Salamander, Tiger Salamander, and Gopher Frog. Seeps and shrub bogs, embedded in xeric Longleaf Pine habitat in the Fall Line/Sandhills, are home to the Pine Barrens Treefrog.

Challenges

As is the case with most wildlife species, amphibian and reptile populations are impacted by habitat loss. In particular, the loss of rare, uncommon or vulnerable habitats, such as isolated freshwater wetlands, Longleaf Pine communities, and freshwater seepage wetlands is taking a toll on herpetofauna. One of the most significant challenges impacting amphibians and reptiles in

South Carolina is loss of habitat. Wetland habitats, which are critically important to many members of this taxonomic group, have been destroyed by draining and filling throughout the State. Even small alterations to wetlands can make the habitat inhospitable for reptiles and amphibians, which are known to require adequate upland habitat around breeding wetlands. Wetland best management practices (BMPs), that suggest wetland buffers of 50-100 ft, are inadequate for long-term persistence (Semlitsch and Bodie 2003; Buhlmann and Gibbons 2001; Litzgus and Mousseau 2004; Powell and Babbit 2015). Populations of amphibians may be extirpated by the elimination of adequate upland habitat despite the protection of the breeding wetland. Conversely, the drainage or alteration of wetlands in an otherwise unaltered forest may result in the extirpation of local amphibian populations due to removal of appropriate breeding habitat. Many wetlands that still exist are now unsuitable for breeding because they have been left isolated on the landscape as a result of careless farming, development, or timber operations.

Conversion of habitat for agriculture represents a significant challenge to reptiles and amphibians. For example, Longleaf Pine habitat has been greatly reduced both in extent and in quality subsequent to European settlement of the Southeast (Noss 1989). Vast acreages of Longleaf Pine have been converted to agriculture, solar farms, and/or loblolly pine plantations in South Carolina. The loss or degradation of Longleaf Pine habitat results in the loss of key components necessary for success of the animals that live in that habitat.

Underground refugia, such as this Gopher Tortoise burrow, are critical habitat components for some herpetofauna species. Photo by Andrew Grosse, SCDNR

One often overlooked component important for reptiles and amphibians is underground refugia. Gopher Tortoises provide important refugia in the form of their burrows, but their range is limited in South Carolina. In the absence of Gopher Tortoises, many species rely on stump holes and/or small mammal burrows to escape extreme temperatures and predators. These habitats are vitally important for the persistence of many reptiles and amphibians, yet removal of stumps remains a common management practice, leaving little to no refugia for the species that remain.

Fire suppression and exclusion contributes to habitat loss for many amphibian and reptile species. Many species in this taxonomic group require an understory that contains a diverse herbaceous plant layer that is maintained by routine burning. However, increased development and changing weather patterns in recent years have resulted in a decrease in adequate fire frequency in many areas of the State, which has resulted in successional changes that render the habitat unsuitable for some species.

Habitat can also be lost to urban development. Nesting habitat for marine turtles and Diamondback Terrapins is lost as coastal development expands. Even if a suitable habitat is available, nesting can be aborted because of human disturbance near nest sites. Further, lighting in coastal areas can result in nesting failure from disorientation of nesting females and

hatchlings. Road mortality is also a significant threat as urban development requires additional roadways. These roads are frequently constructed through amphibian and reptile habitats, and mortality occurs as animals attempt to migrate across roadways.

Disease can lead to severe population crashes or even localized extinctions. Chytridiomycosis is a fungal disease caused by *Batrachochytrium dendrobatidis* that affects the skin of amphibians, compromising water and electrolyte uptake. Because amphibians rely on their skin like humans do their lungs, the hyperkeratosis caused by the fungus can also impact respiration. A closely related pathogen, *Batrachochytrium salamandrivorans*, or *Bsal*, is an emerging pathogen capable of causing significant mortality in salamanders. Though currently only detected in captive salamanders outside of the US, the rate at which captive amphibians are imported for the pet trade–coupled with the potentially devastating impacts *Bsal* would have on native salamanders – make it a significant concern for South Carolina salamanders. Amphibian Perkinsea is an alveolate protist that is responsible for amphibian mass mortality events throughout the US. Amphibians in South Carolina have been severely impacted by this disease in recent years. Another disease in South Carolina, Ranavirus, causes hemorrhaging and ulcers and has been documented in reptiles and amphibians. Eastern Box Turtles are especially susceptible to Ranavirus and are a common vector of the disease. Snake Fungal Disease or SFD (*Ophidiomyces ophiodiicola*) continues to be documented throughout South Carolina. SFD causes swelling, scabs, and lesions. In October 2013, an infected Copperhead was found in Spartanburg County, SC, making it the first confirmed case in the State. Since then, many other species have been documented with SFD throughout the State. Studies on Eastern Diamondback Rattlesnakes, Rainbow Snakes, and Brown Watersnakes have shown extreme susceptibility to SFD, so that the disease continues to be a threat to the snakes of South Carolina.

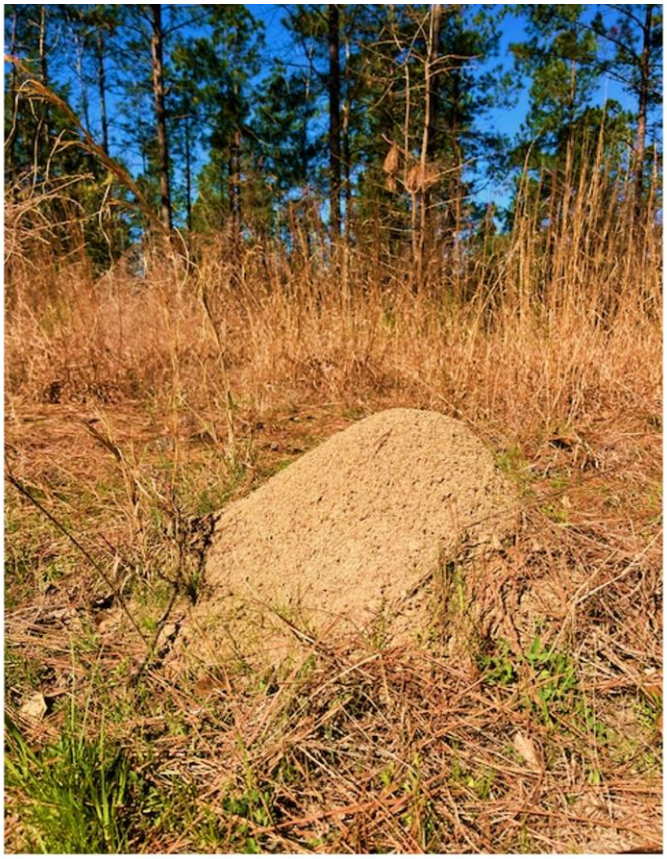
Previously, unregulated harvest was a significant challenge for reptiles and amphibians in South Carolina. In 2019, the South Carolina Department of Natural Resources (SCDNR) passed new regulations that added significant protections for all reptiles and amphibians native to South Carolina from commercial exploitation. Specifically, no native species can be exported from South Carolina, and transfer of possession (buying, selling, trading, etc.) is prohibited. A major component of these regulation changes was increased protections for turtles, which, in addition to prohibiting export and transfer of possession, also added possession limits for individual species as well as in aggregate. Despite these restrictions, several species of reptiles and amphibians in South Carolina continue to be collected for the domestic and international pet trade. This illegal collection increases the risk of drastic population declines for several species in the State, especially turtles.

Spotted Turtles are a species threatened by illegal collection for the domestic and international turtle trade due to their striking appearance, making them attractive to collectors. Photo by Andrew Grosse, SCDNR.

Introduced species can adversely affect South Carolina's reptiles and amphibians. Sightings of nonnative herpetofauna continue to increase. Legislation passed in 2019 protecting all native species from commercial exploitation also included regulations that prohibited the release of wildlife that is not native to South Carolina. In 2021, further legislation passed that allows SCDNR to promulgate regulations to prohibit or restrict certain species of nonnative wildlife in South Carolina that 1) have the potential to become established in the State in sufficient numbers to become a nuisance and/or 2) pose a demonstrable deleterious and widespread threat to wildlife, agriculture, or human health and safety. Due to a rise in confirmed sightings throughout the State, established populations in adjacent states with similar habitats and climate, and documented impacts on similar native species in other states in the Southeast, Argentine Black-and-White Tegus and their hybrids were the first species added to this "Restricted Nonnative Wildlife List".

Red-eared Sliders (*Trachemys scripta elegans*) impact the population stability of Yellowbelly Sliders through hybridization. This nonnative species has been released in South Carolina resulting in concerns about the genetic integrity of the Yellowbelly Slider as established Red-eared Sliders interbreed with this species, shifting the genetics of local populations.

The presence of nonnative fire ants throughout the Southeastern United States has been implicated as a potential reason for the apparent decline of the Southern Hognose Snake (Tuberville and Jensen 2008). Fire ants may also be adversely affecting populations of other fossorial and egg-laying snakes. Further, fire ants are suspected to affect the probability of turtle hatchling survival and are responsible for mortality of released head-started Gopher Tortoises and Gopher Frogs.

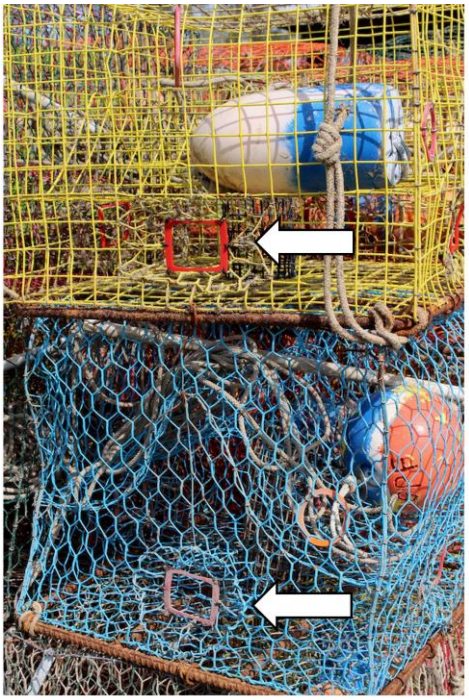


Red Imported Fire Ants can invade sensitive habitats, preying on ground-nesting birds and terrestrial herpetofauna.
Photo by Anna Smith, SCDNR

Feral pig populations continue to be a threat to reptiles and amphibians. Pigs are opportunistic omnivores and eat a variety of plants and animals. A recent DNA metabarcoding study (Canright et al. 2023) found that while vertebrates are consumed less than plant matter, the majority of the vertebrates that were consumed were amphibians, suggesting amphibians may be more vulnerable to feral pig predation than previously thought. In addition to direct mortality, feral pigs also negatively impact reptiles and amphibians when "rooting," especially in sensitive habitats.

Hook-and-line entrapment is a threat to turtles, like this Florida Softshell, when they take fishing bait. Photo by Anna Smith, SCDNR.

Entrapment in fishing devices, including hook-and-line, trawls, and crab pots represents a significant challenge to turtle species throughout the State. Florida Softshell and Spiny Softshell turtles are often captured incidentally on hook-and-line and are either killed to retrieve the tackle or later die due to complications from the ingested hook. Major challenges to the Diamondback Terrapin in the marine environment include recreational, commercial, and abandoned/ghost crab pots. Progress has been made to reduce this bycatch through turtle excluders for crab pots, and efforts have been made to educate crab fishermen about the importance of removing old pots and using these turtle excluders over the openings.



Diamondback Terrapin exclusion devices affixed to crab pots. Photo provided by Erin Weeks, SCDNR.

Incidental take of Loggerhead Sea Turtles from boat strikes and commercial fishing operations constitutes a major challenge to this species. In a 1990 study, the National Academy of Sciences estimated that between 5,000 and 50,000 Loggerheads were killed annually by the shrimping fleet in the Southeastern Atlantic and Gulf of Mexico (National Research Council 1990). In 1988, South Carolina was the first to enact a law to require Turtle Exclusion Devices (TEDs) on shrimp trawls to reduce incidental take of sea turtles. By 1991, TEDs were required everywhere by the National Marine Fisheries Service. The size of TEDs was adjusted in 2003 to accommodate Leatherback Sea Turtles. The shark longline fishery, which operates all year long off the south Atlantic, may still impact Loggerheads in the neritic environment (Lewison et al. 2004). Turtles are still at risk from entanglement in longlines, float lines, and other ropes and cables (NMFS & USFWS 1991). In addition, sea turtles may mistake floating plastic for jellyfish and ingest it, causing gut obstructions or the absorption of toxic chemicals (NMFS & USFWS 1991).

A juvenile Loggerhead Sea Turtle exits a TED. Photo by NOAA.

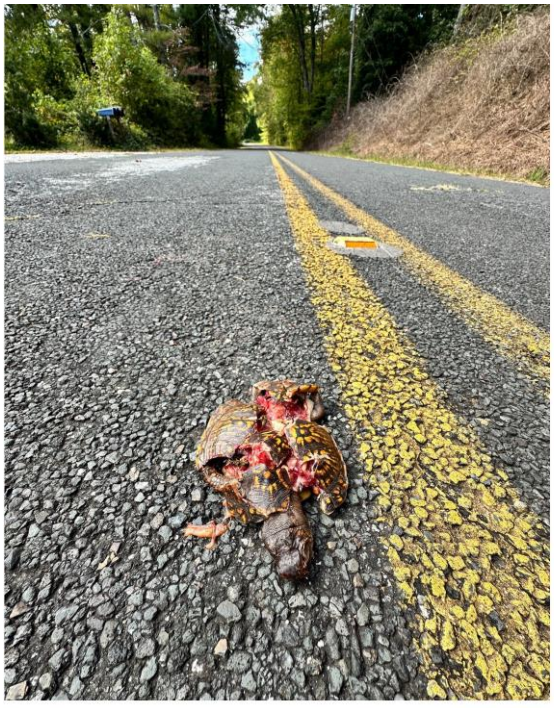
A silent threat to some herpetofauna is the lack of knowledge about the species and thus the uncertainty of their status. There are a number of amphibian and reptile species in South Carolina for which adequate data on their status is lacking, but there is no immediate indication that they are threatened. Several of these species have been

added to the SWAP and categorized as data deficient. Adding these species is important to ensure they are not overlooked due to their cryptic nature.

Despite recent advances in genetics, controversy over the taxonomic status of certain species, or species complexes, continues to result in a lack of certainty in giving a truly fixed number of species for the State. Additionally, new species have been recently discovered or described, which results in a dynamic species list. To emphasize the way in which the species list can change, consider the following recent additions. Within the last 25 years, Chamberlain's Dwarf Salamander (*Eurycea chamberlainii*), Patch-nosed Salamander (*Urspelerpes brucei*), and Dwarf Black-bellied Salamander (*Desmognathus folkertsi*) were identified in South Carolina and added to the SWAP. In addition, and most recently, the *Desmognathus* salamander genus was investigated, with eight (8) newly described and/or renamed species in South Carolina (Pyron and Beamer 2022, 2023). Other taxonomic issues that still remain include the milk snake/scarlet kingsnake relationship.

Conservation Opportunities

Conservation for most wildlife starts with protection and connectivity of habitat, which includes microhabitats that are essential for species persistence (i.e. breeding, nesting, foraging, and overwintering habitats). Prioritizing habitats based on connectivity, rare and sensitive species habitats, and watersheds should continue to be taken into consideration when new properties are being purchased or otherwise obtained and/or protected. Collaborating with adjacent states, non-governmental organizations (NGOs), and non-profits to protect habitats—as they relate to an overall species range and/or corridors—should be prioritized as it increases the opportunities for additional funding and resources to mitigate costs and better conserve the target species and/or habitats.



A road-killed Eastern Box Turtle (SGCN High) on a rural mountain road in the Upstate of South Carolina. Photo by Keith Bradley, SCDNR

Similarly, exploring opportunities for connectivity of habitats by utilizing “developed” land may allow for alternatives that benefit wildlife. Several reptile and amphibian species are known to occur in green space in and around developments. Habitats such as solar, sand mines, and parks typically leave “green” space that varies in suitability; however, each development type has different requirements for long term management. Better understanding these requirements, keeping an open dialogue with developers, and thinking “outside the box”, should provide future opportunities to work cohesively to benefit wildlife and habitats in these locations.

Increased urban development requires larger and additional roadways. Roads are frequently constructed through amphibian and reptile habitats and pose a significant threat to the longevity of adjacent populations. Mortality

occurs as animals attempt to migrate across roadways. Depending on the number of lanes, traffic volume, and speed limit, some animals may cross safely. However, many reptiles and amphibians have high site fidelity to nesting, breeding and overwintering sites and will likely return year after year, significantly increasing the likelihood of mortality. Additionally, as existing roads increase in traffic volume and/or are widened to accommodate residential growth, they become barriers to gene flow between populations. Finally, road mortality of reptiles and amphibians is not only detrimental to the long-term persistence of populations but it is also a safety hazard for drivers. Hitting large turtles or alligators or attempting to avoid them on the roadway can cause severe damage to vehicles and injuries to drivers. Wildlife crossings have gained popularity and have been successful at reducing mortality when installed and maintained appropriately. Wildlife crossings consist of bridges, culverts and/or tunnels, with fencing that guide wildlife to a particular area to cross roads safely. These crossings have been successful in several other states but have yet to be used in South Carolina and rarely in the Southeast. With the continued increase in development and need for increased infrastructure, there are numerous opportunities for wildlife crossings. All new roads or widening projects should consider wildlife crossings for driver safety, as well as to increase the likelihood that species will persist in adjacent habitats.

Protected lands provide both large- and small-scale restoration and/or habitat enhancement opportunities. Historical aerial maps provide a snapshot of habitats decades earlier and can help inform where restoration opportunities are most appropriate. Similarly, a significant amount of habitat in South Carolina is privately owned. Education on the importance of specific microhabitats should be provided to private landowners as well as management/enhancement techniques for habitats that better represent historical landscapes and is more conducive for increased biodiversity.

Population augmentation and/or re-establishment of historical populations has grown in popularity over the last decade. Population augmentation can differ depending on the species and overall goals and can include different age and size classes as well as head-started individuals. Head-starting, or the process in which hatchlings are raised in captivity to attain a larger size more quickly and thus become more likely to escape naturally high levels of predation once they are released into the wild, has become common practice for Gopher Tortoises and Gopher Frogs in South Carolina. While there are many opportunities to augment existing populations or reestablish historic populations, the overall goals and risks involved should be considered prior to any action to ensure the desired outcomes.

Gopher Tortoise hatchlings await release during a telemetry project.
Photo by Andrew Grosse, SCDNR

SCDNR Herpetologist, Andrew Grosse, releases a head-started Gopher Frog into its natural habitat. Photo by Jessica Egan, SCDNR.

Nonnative species continue to be problematic for native reptile and amphibian populations in South Carolina. Feral hogs, red imported fire ants, Red-eared Sliders, and Argentine Black-and-white Tegus have been studied throughout the southeast and their negative impacts to native wildlife and habitats are well known. Even so, more survey, research and/or management opportunities exist to better manage these species in South Carolina. Similarly, the increasing number of new and emerging nonnative species provides an opportunity to proactively evaluate their status and potential impacts prior to invasion. Increasing our knowledge of how nonnative species function in our habitats and interact with our native species allows us to make more informed conservation and management decisions.

Illegal collection of native reptiles and amphibians in South Carolina continues to be a problem. New regulations, passed in 2019, increased protection from commercial exploitation and provided the tools needed to better protect South Carolina's native reptiles and amphibians. Surveillance on public lands indicate illegal collection continues to occur, providing opportunities to utilize these new regulatory tools to enforce regulations and increase education and awareness regarding protections of our native reptiles and amphibians. Additionally, law enforcement should be vigilant to current reptile and amphibian markets. Changes in specific species demand create opportunities to proactively intervene and reduce species and ecosystem impacts before they become detrimental.

Birds

As of 2024, 445 species of birds have been documented in South Carolina. Approximately 181 of these are classified as breeders, though this number may be higher due to some species being considered provisional (CBC 2024). The total number of species present is comprised of resident and migrant birds with the majority of taxonomic orders of birds found in the United States

represented in the State (Sibley 2000). South Carolina supports a high diversity of birds during breeding, wintering, and migration, likely due to the State's varied environments and habitats (Cely 2003). The National Audubon Society lists 45 sites in the State as Important Bird Areas (IBAs), 16 of which are recognized to be of global importance.

Three different Bird Conservation Regions (BCRs) transect South Carolina: the Appalachian Mountains, Piedmont, and Southeastern Coastal Plain. Bird Conservation Regions are a single application of a scale-flexible hierarchical framework of nested ecological units based upon the Commission for Environmental Cooperation. BCRs were adopted to provide a single map of biological units for all bird initiatives to use to attain a regional-based approach to bird conservation (US NABCI 2000). BCRs can be partitioned into smaller ecological units to facilitate finer scale planning and implementation or aggregated to facilitate greater cooperation and partnerships across political boundaries in order to recognize the migratory nature and vast annual ranges of certain species.

The Appalachian Mountain BCR spans the Blue Ridge, the Ridge and Valley Region, the Cumberland Plateau, the Ohio Hills, and the Allegheny Plateau and contains the headwaters of several major river systems (US NABCI 2000). A portion of the Blue Ridge transects three counties in the northwestern corner of South Carolina; this diverse temperate forest ecosystem supports habitats found nowhere else in the State (Barry 1980). Several bird species are primarily found only in this portion of South Carolina including Ruffed Grouse, Common Raven, Black-throated Blue Warbler, Chestnut-sided Warbler, Red Crossbill, and Dark-eyed Junco (Cely 2003). This region also supports some of the highest breeding densities of Scarlet Tanager, Louisiana Waterthrush, Worm-eating Warbler, and Black-throated Green Warbler in the State (Cely 2003).

The Piedmont BCR is geographically part of Southern Appalachia and makes up the transitional area between the mountains and the flat Coastal Plain spanning from New Jersey to Alabama (US NABCI 2000). Approximately one-third of South Carolina is comprised of this ecological unit (Cely 2003). This area is best characterized by oak-hickory dominated forests with associations of Shortleaf and Loblolly Pine, Black Gum and Sweetgum (Barry 1980). The once fertile and highly productive soils have been reduced due to past mismanagement, and the area is now subject to intensified agriculture and forest management practices (Barry 1980). The Piedmont is the primary breeding area in South Carolina for several grassland and scrub/shrub birds such as Killdeer, House Wren, American Goldfinch, Song Sparrow, Field Sparrow, and Grasshopper Sparrow (Cely 2003). Interior wetlands, reservoirs, and riverine systems provide migration and wintering habitat for waterfowl and some shorebirds (US NABCI 2000).

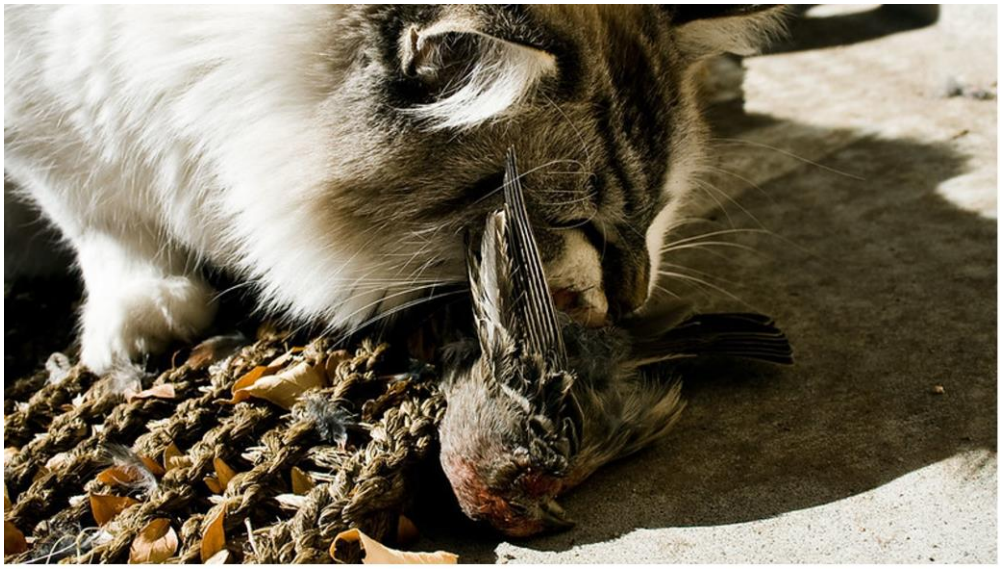
The Southeastern Coastal Plain is a huge area composed of both the South Atlantic Coastal Plain and the East Gulf Coastal Plain physiographic areas (Pashley et al. 2000). In South Carolina, the western boundary is at the Fall Line marking the edge of the hilly Piedmont; the eastern boundary is the Atlantic Ocean (Pashley et al. 2000). The major habitat types include Longleaf and Loblolly Pine interspersed with Carolina bays and pocosins, bottomland hardwoods and maritime forests (Barry 1980). Priority species dependent upon pine habitats include Red-cockaded Woodpecker, Bachman's Sparrow, Brown-headed Nuthatch, Henslow's Sparrow, and Painted Bunting (Pashley et al. 2000). Bottomland forests support high breeding densities of

many Neotropical migrants including Acadian Flycatcher, White-eyed Vireo, Prothonotary Warbler, Hooded Warbler, and Northern Parula (Cely 2003). The coastal intertidal habitats provide critical staging, wintering, and breeding areas for species such as American Oystercatcher, Short-billed Dowitcher, Dunlin, and Red Knot (US NABCI 2000). Offshore islands and coastal areas provide important nesting and foraging habitats for seabirds, waterfowl, herons, egrets, ibis and other species (US NABCI 2000). Impounded wetlands (old rice fields) and backwaters are particularly important for nesting and foraging waterbirds. Many impoundments are managed for waterfowl but also benefit marsh birds, wading birds, and shorebirds. Most wading bird rookeries (excluding the Great Blue Heron) are located in the Coastal Plain, and wading birds utilize a variety of types of wetlands in this region.

A Yellow-crowned Night Heron rests in tidewrack along the shoreline. Photo by Anna Smith, SCDNR.

Challenges

One of the major challenges to birds in South Carolina is outright loss, fragmentation, and/or alteration of habitat. Land use changes and urban development are often to blame. Roads into forests bring native and non-native predators such as rodents and feral cats. Nest parasites, such as the Brown-headed Cowbird, can also move into the forest interior via forest-edge habitats and clearings (Kilgo and Moorman 2003). Birds in the State depend upon varied habitats from the mountains to the coast; changes to habitats can result in loss of feeding or nesting habitat for these species. Wetland habitats, which are important to many members of this taxa, have been destroyed by draining and filling throughout the State. Even small alterations to wetlands can make the habitat unsuitable for nesting and foraging as water levels change and prey species disappear.



Cats allowed to roam outside are non-native, invasive predators to a variety of small animals like birds.
Photo by Will Keightley, Flikr 2007, Creative Commons

Conversion of prime habitat to agricultural fields poses another challenge to birds. For example, Longleaf Pine habitat has been greatly reduced both in extent and in quality; vast acreages of Longleaf Pine have been converted to agriculture and/or Loblolly Pine plantations in South Carolina. The loss or degradation of Longleaf Pine habitat results in the loss of key habitat components necessary for the success of the animals that live there.

Fire suppression contributes to habitat loss for bird species that require an understory with a diverse herbaceous plant layer that is maintained by routine burning. In recent years, the use of prescribed fire as a management tool has decreased in the State due to an increase in housing density. This has resulted in successional changes that render the habitat unsuitable for some animal species.

Human disturbance represents a significant challenge to birds in South Carolina. Nesting success of many birds can decrease when people frequent breeding bird congregation areas. Further, wakes from boats can destroy coastal bird nests and interrupt feeding for many shorebirds. Because there are a limited number of coastal islands that can be utilized for shorebird and seabird nesting purposes, disturbances are often profound since the birds cannot simply relocate. In addition, pelicans, terns, and skimmers nest colonially, so many nests can be affected each time the colony is disturbed.

Chemical contamination often threatens many carnivorous bird species, particularly those that consume fish and other aquatic organisms. Persistent organo-chlorine pesticides and heavy metals, such as lead and mercury, can result in poisoning. Barbiturate poisoning of Bald Eagles has also been an issue in South Carolina and elsewhere. Phenobarbital, which is used to euthanize animals, can be ingested by eagles that feed on carcasses that have been disposed of in landfills. The Center for Birds of Prey in Awendaw, SC, has treated several Bald Eagles for such poisoning in the past. New regulations require disposal of euthanized animals in a dedicated section of landfills and then they are covered to a certain depth in order to minimize scavenger

deaths. Neonicotinoids, the most widely used insecticides on Earth, are lethal to birds. A single seed coated with a neonic can kill a bird, and one tenth of a corn seed per day during egg-laying season can affect reproductive success (Mineau and Palmer 2013).

Black Vulture mortality event in Charleston County, SC from a H5N1 avian flu outbreak in 2022. Photo by Anna Smith, SCDNR

Several diseases and parasites can affect bird populations directly. These include West Nile Virus, Avian Vacuolar Myelinopathy (AVM), cholera, botulism, high pathological Avian Influenza (H5N1), and soft tick infestation. Indirect effects on bird populations include disease outbreaks in important nesting substrates or forage plants. Examples include Sudden Oak Death and Hemlock Wooly Adelgid infestations, which greatly alter the characteristics of the forest type and therefore bird habitats. Non-native predators can also decimate bird populations. In particular, predation by domestic and feral cats is problematic for songbirds. In 2013, researchers reported that an estimated 1.4-3.7 billion birds are killed each year in the United States (Loss et al. 2013.)

Additionally, an over-population of White-tailed Deer can be detrimental to bird habitat. In areas of high densities (greater than 7.9 deer/km^2), herbivores browse the understory such that nesting and foraging substrates are greatly reduced (NatureServe 2004).

> *"I now suspect that just as a deer herd lives in mortal fear of its wolves, so does a mountain live in mortal fear of its deer. And perhaps with better cause, for while a buck pulled down by wolves can be replaced in two or three years, a range pulled down by too many deer may fail of replacement in as many decades."*
>
> ***-Aldo Leopold, Thinking Like a Mountain***

Renewable energy production can also have a marked impact on bird populations. Wind turbines kill or maim approximately 700,000 to a million birds every year (ABC 2021). Nighttime migrants and raptors are especially vulnerable. It is estimated that by 2030, the total number of wind turbines in the United States could grow to more than 100,000, essentially doubling the number of bird strikes (ABC 2013). Wind farms themselves also destroy habitat as vegetation is removed and towers are erected. By 2030, 20,000 mi.^{2} of terrestrial habitat and 4,000 mi.^{2} of marine habitat may be impacted. Solar energy facilities, which are rapidly increasing in number in South Carolina, also have the potential to destroy critical habitat if not planned or constructed

with wildlife impacts in mind. Currently, the State is projected to double its solar production to over 5,000 megawatts in the next five years (SEIA 2024).

Window strikes in both city and residential settings kill millions of songbirds annually. Photo by Anna Smith, SCDNR

Collisions with glass buildings claim around 365 million to 988 million birds each year in the United States (Loss et al. 2014). It is estimated that 592 million birds collide with low rise buildings and homes, plus an additional 0.5 million collisions with high-rise buildings (Loss et al. 2014). During the day, birds perceive reflections in glass as habitat they can use. At night, migratory birds are drawn to, and confused by, artificial light. This increases the chance of colliding with windows, and also mortality from exhaustion. Communication tower strikes take an additional 7 million birds per year (ABC 2013). Nocturnal migrants often become confused by the red lights of communication towers and hit the guy wires or the towers themselves.

Migratory species like songbirds and shorebirds will be highly affected by climate change. Migrations and breeding are timed to coincide with abundant prey. If the timing of spawning and/or insect hatching is decoupled from the arrival of the birds along the migration routes, these birds could face higher mortality during migration and lower productivity on the breeding grounds (Robertson et al. 2024, Youngflesh et al. 2023). Breeding grounds are also in trouble. Breeding bird ranges have begun to shift north as is evident by tropical species establishing themselves along the Gulf Coast. As temperatures increase, it's predicted that long-distance migrants, populations at high latitudes, and forest species will be at high risk (Youngflesh et al. 2023). Bird species in remnant boreal forests will have less habitat. In addition, sea level rise will destroy foraging habitat used by wading birds by altering salinity levels and aquatic plant species composition. A multitude of nesting shorebirds and marsh birds will be affected by sea level rise as nesting habitat is inundated. As sea level rises and storm intensity increases, coastal impoundment infrastructure may become more difficult to maintain. Many marsh birds, wading birds, and waterfowl may experience a reduction in nesting and foraging habitats if impoundments can no longer be managed in a way that creates suitable conditions.

Wading birds will be affected by drought conditions as prey abundance in nontidal wetlands diminishes. When wading birds are required to fly greater distances to find food, droughts can result in nesting failures or lower productivity. In addition, lower water levels can make nests vulnerable to mammalian predators, especially when aquatic vegetation becomes established. Unusually high-water levels, as seen during floods, can result in prey being dispersed. Heavy rainfall during the chick-rearing period is an issue for tactile foragers such as the Wood Stork, who require concentrated prey in shallow water to feed efficiently. Coastal areas, where both tidal and nontidal foraging areas can be utilized, will become increasingly important to wading birds if prey availability becomes diminished or unpredictable farther inland. Managing

impounded wetlands near Wood Stork colonies to concentrate prey at critical times during the nesting season can counteract some of the negative effects of droughts and floods on prey availability and improve the survival rates of nestlings.

Conservation Opportunities

Habitat loss is considered the main threat to birds and other taxa. Protection and restoration of habitat should include aspects that are essential for breeding, foraging, and roosting, as well as considerations for variable habitat needs throughout the annual life cycle (i.e. breeding, migration, wintering). Prioritizing habitats based on connectivity and occurrences of rare and sensitive species should be considered when new properties are protected or restored. Habitat protection and restoration should be considered at multiple scales from territory size up to landscape scales. Partnering with other states, federal agencies, NGOs, and non-profits should make conservation efforts more effective.

Other ways to optimize habitat protection is by utilizing already disturbed land for development, minimizing fragmentation, and maintaining habitat management regimes. For example, SCDNR has developed a Solar Siting Tool to help inform large solar development projects about areas of lower environmental sensitivity that could be suitable for solar. Additionally, a Solar Habitat Guide was developed to improve habitat for wildlife at solar developments. Forest fragmentation is one of the biggest problems for forest interior birds. As forest habitat shrinks, bird species that are area-sensitive may abandon smaller woodlots altogether. Identifying and protecting unbroken forest interior tracts, developing habitat corridors, and minimizing the frequency of roads and power line rights-of-ways that bisect those habitats will help maintain those bird populations. Historically, fire, floods, windstorms, and herbivores maintained habitat conditions conducive to disturbance-dependent species (Askins 2001). Specific management regimes differ depending on the habitat, species guild, and also individual species (e.g. early successional, deciduous forest, pine savannah, forested wetland, marsh bird, wading bird species guilds).

Seabird and shorebird nesting habitat is limited along South Carolina's coast, but management of important nesting sites can increase reproductive success. Closures, demarcated with signs and symbolic fencing, can reduce human and dog disturbance to nesting birds. Strategic predator and avian tick control reduce the loss of eggs and

Posting of nesting beaches can help reduce damage to eggs and chicks from people and pets. Photo by Felicia Sanders, SCDNR, of pelicans nesting on Crab Bank in Charleston Harbor.

chicks and minimize nest abandonment.

SCDNR's Bird Conservation Coordinator, Amy Tegeler, demonstrates bird banding of Painted Buntings (SGCN High) to the local Hispanic community. Photo provided by Alix Pedraza Larrotta, SCDNR

Developing partnerships and educating the public about opportunities to integrate habitat management and enhancement strategies into land management activities is an important way to increase bird conservation efforts. Events and strategies to educate the public about how to help conserve birds include workshops, presentations at clubs and organizations, tabling at festivals, bird walks, and social media. Formal partnerships, such as Migratory Bird Joint Ventures and working groups, facilitate sharing conservation techniques and plans that can benefit birds across the landscape.

For most bird species, we do not know if populations are limited during the breeding season, wintering period, or migratory periods (Berlanga et al. 2010). Thus, surveys, research, partnership building, and conservation actions can be taken throughout the species' annual cycle to help identify factors which may assist in restoration and improved conservation of these species and habitats. Southern Wings and the Neotropical Migratory Bird Conservation Act are two programs that help enable habitat conservation for birds and their habitats, research and monitoring, law enforcement, and outreach and education in the United States, Canada, Mexico, Central and South America, and the Caribbean. (See Chapter 11 on international conservation.)

An additional complication is that migratory bird species, especially long-distance migrants, are negatively impacted by climate change. While plant and food resources are tending to become available earlier within the calendar year, birds use photoperiods to determine when they migrate. The result is an increasing level of mismatched timing for migration and available food resources. More detailed information about food availability, foraging, and demographic impacts is needed to further clarify implications of these phenological mismatches (Robertson et al. 2024).

In the past thousands of years, South Carolina's salt marshes adapted to sea level rise by migrating inland. Climate change is causing sea level rise, but lands adjacent to salt-marsh edges are often developed and/or armored, limiting the natural process of salt marshes migrating inland. Rising seas are causing salt marshes to drown, thus reducing the size of this valuable

wildlife habitat (Tibbetts 2007). Facilitated marsh migration and nontidal (inland) wetland creation in South Carolina can offset some of this loss of saltmarsh habitat.

Window collisions can be reduced by being conscientious about tree and shrub placement, installing screens on the outside of the window, or by using decals, film, paint, or other markers (FLAP and Mosco 2024) to break up the reflection and make the glass more visible to birds. The proximity of bird feeders and bird baths to windows can also reduce collision severity (Barges and Morris 2023; FLAP and Mosco 2024). Artificial light can be reduced by using down-shielded light fixtures with bulbs less than 3000 Kelvin, using motion activated lights, setting light timers, closing blinds or curtains, and only lighting areas that need to be lit (ABC 2024). Collisions with communication towers can be reduced by using the Recommended Best Practices for Communication Towers (USFWS 2021). Through education and regulatory actions, bird-friendly building requirements should be considered by states and/or municipalities. Resources for bird-friendly ordinance and statues can be found online: Dark Sky International's Principles for Responsible Outdoor Lighting can assist with lighting choices and American Bird Conservancy's (ABC) glass collision information can provide building code design ideas, especially for mid-rise buildings where most songbirds fly and forage (Barges and Morris 2023).

Imprint of a Mourning Dove that collided with a window. Photo by Anna Smith

There are a few ways to decrease the impacts of chemical contamination and diseases to birds. Using native plants in landscaping and establishing seed banks provides food resources, directly through production of seeds and berries, and indirectly by creating habitat for insects. Minimizing the use of neonicotinoids and rodenticides can be challenging since they are commonly used. However, efforts to preserve and improve water quality can reduce contamination of aquatic insect food resources—the base of the food chain—by neonicotinoids and other contaminants. The need for rodenticides can be minimized by rodent-proofing buildings. Some diseases affecting birds can be reduced by thoroughly, and regularly, cleaning bird feeders and other locations where birds tend to congregate.

A Carolina Chickadee feeds at a black oil sunflower feeder. Regular disinfection of feeders and waterers can limit the spread of infectious diseases in wild birds. Photo by Anna Smith, SCDNR.

Mammals

According to the American Society of Mammalogists, South Carolina is home to approximately 101 native species of mammals with a higher diversity found in the Coastal Plain and the Mountains. The largest group of mammals in the Southeast is the rodents at around 36 members. However, back in colonial times, South Carolina was also home to several additional species including the American Bison, Eastern Elk, Red Wolf, Gray Wolf, and Eastern Cougar. Overhunting, persecution, and habitat changes eventually led to their extinction in the region. Declines in other species such as White-tailed Deer in sections of the State prompted the creation of restocking programs beginning in 1951 and ending in 1989 which were extremely successful. Because all 642 deer were not brought in from other states to accomplish this, the genetic integrity of the species was retained (C. Ruth, SCDNR, pers. comm.). Beavers, which had been extirpated in the 1800s, were reintroduced to the Pee Dee region in the 1940s by the USFWS. Fox squirrels have also been translocated from healthy populations in the State to depauperate areas in the Coastal Plain by SCDNR, the University of Georgia, and other private entities (B. Dukes, pers. comm.). South Carolina is experiencing changes in its mammalian assemblage once again as new species colonize the landscape. Some have been introduced by humans, as in the case of Coyotes and feral pigs, while others have made it here on their own such as the Nine-banded Armadillo.

Six Southeastern Myotis pack into a weep hole in Jasper County, SC. Photo by Jennifer Kindel, SCDNR

The following mammal species are legally classified as furbearers and may be taken by hunting or trapping during the open season by those with a valid license: Bobcat, Coyote, Red Fox, Gray Fox, Virginia Opossum, Raccoon, North American River Otter, American Mink, Long-tailed Weasel, Striped Skunk, Spotted Skunk, Muskrat and North American Beaver. All these species, except for the Coyote, are also classified as small game. Although the Spotted Skunk, American Mink, Appalachian Cottontail, Swamp Rabbit, and Southern Fox Squirrel are considered priority species for the purposes of the SWAP, they are still game animals capable of being harvested. Their populations are currently stable, and hunting has not been found to be a threat to their continued existence in the State. They are monitored here due to concerns about potential population fluctuations as regulated species.

Challenges

One of the major challenges to mammals in South Carolina is loss, fragmentation, and/or alteration of habitat. Disease, exposure to pollutants, and wind turbines also have a significant negative impact on mammal species in the State.

Terrestrial Mammals

As urban development expands, changes to forests and grasslands often lead to outright loss or degradation of foraging, roosting (bats), and denning/nesting habitat. Additionally, habitats are

fragmented by development. Roads can limit movement of many species and often result in mortality to individuals.

Destruction of habitat can also come in the form of wind turbines. Turbines can also cause mortality directly through collision, and unfortunately bats may be attracted to wind turbine towers, increasing their chance of mortality (Cryan and Barclay 2009). Wind energy around the world is growing by 10%–20% per year (IRENA 2022), and an estimated 500,000 bats are killed every year by wind turbines in the United States (Voigt et al 2024).

Pollutants from a variety of sources can impact mammals. The American Mink occupies a niche at or near the top of the food chain; therefore, this species is especially vulnerable to environmental contamination, particularly from mercury and PCBs. Trash and litter pose challenges to both terrestrial and aquatic mammals. Small mammals can become trapped in bottles and other litter while foraging.

A Northern Short-tailed Shrew's (*Blarina brevicauda*) skeletal remains were found after being trapped in a discarded beer bottle. P

Two diseases, raccoon roundworm and Sudden Oak Death (SOD), can adversely affect mammals in South Carolina. Raccoon roundworm can cross species boundaries to infect other mammals, resulting in death. It has been suspected in the decline of the Eastern

An Eastern Woodrat in a live trap. Photo by Anna Smith, SCDNR.

Woodrat in some states. The disease is undergoing a range expansion and may impact counties outside of the Appalachians. SOD attacks and destroys oak trees which are vital mast producers used as food sources by several mammals on South Carolina's Priority Species List including the Eastern Woodrat. In addition, Hemlock Wooly Adelgid has defoliated and killed hemlocks in South Carolina, altering hemlock coves which are important to some small mammals such as Masked and Pygmy Shrews.

Another disease, White-nose Syndrome (WNS) affects bats. WNS is a disease caused by a white fungus species, *Pseudogymnoascus destructans*, that forms on the nose, wing membranes, and ears of affected hibernating bats. Mortality rates attributed to WNS have reached up to 90-100% at hibernacula (Kunz and Tuttle 2009) causing the death of between 5.7 to 6.7 million bats in North America since it was first documented in New York during the winter of 2006/2007 (USFWS 2012). In less than 10 years, WNS has killed over 90% of Northern Long-eared, Little Brown, and Tri-colored Bat populations (Cheng et al. 2021). On February 21, 2013, a Tricolored Bat was found dead at Table Rock State Park. Testing by the Southeastern Cooperative Wildlife Disease Study in Athens, GA confirmed that the bat had WNS, the first case in South Carolina. In April 2013, an Eastern Small-footed Myotis infected with the fungus was found in a more southerly portion of the same state park. After WNS was confirmed in the State, Tricolored Bat populations in major Upstate hibernacula declined at an alarming rate, up to 97%. A total decline of 91% at a single major site occurred after only a period of three years. Though recent hibernacula surveys show those populations leveling out or beginning to rebuild, despite the continued presence of the fungus, Tricolored Bats only have 2 pups per year so it will take many years to return to pre-WNS populations.

The estimated annual value of bats in pest suppression services to South Carolina's agricultural industry is nearly $115 million, with the US agricultural industry estimate at $22.9 billion (Boyles et al. 2011). The beneficial ecological effects of bats can extend past insect consumption as they indirectly suppress pest-associated fungi and the toxic compounds they produce in corn (Maine and Boyles 2015), as well as reduce the need for pesticides which have substantial impacts on many other wildlife species (Pimentel 2009).

Introduced and non-native species can adversely affect South Carolina's mammals. Predation by domestic or feral cats and dogs can reduce population numbers. One study estimated that free-ranging domestic cats kill approximately 6.9-20.7 billion mammals each year in the United States (Loss et al. 2013). Feral hogs can destroy habitat for many species, particularly those found in wetland habitats. Spongy Moths (formerly known as Gypsy Moths), like SOD, can eliminate food sources for mammals by destroying important tree species. Thankfully, no Spongy Moth outbreaks have been recorded in South Carolina to date, although the species has been in the State since 1998.

Several species of mammals are regarded by humans as "pests;" this view can lead to persecution of these species. Examples include Raccoons, and species of moles, mice, squirrels, skunks, and bats.

Finally, global warming could shift suitable high elevation habitat farther north and into higher elevations not found in South Carolina (W. Mark Ford, pers. comm.). This would affect the

Woodland Jumping Mouse and both species of moles on South Carolina's priority list. A study from 2023 shows that North American small mammals have been decreasing in body size in response to the warming of terrestrial ecosystems, likely impacting the structure and function of these mammal communities (Searing et al 2023).

Marine Mammals

Human interactions in the marine environment (e.g. vessel strikes, entanglement, coastal development, pollution, anthropogenic noise, climate change) pose significant challenges to marine mammals in South Carolina waters. Marine transportation corridors often exist in the same areas used by marine mammals including the coastal and estuarine stocks of Bottlenose Dolphin and migrating Atlantic Right Whales. Collisions with vessels (boat strikes) can injure or kill marine mammals and are especially challenging to Florida Manatees occupying shallow water areas, and to the Bottlenose Dolphin stocks utilizing estuarine and coastal waters. Marine mammal stranding data for South Carolina show fishery interactions, primarily crab pot buoy line entanglements, to be the leading cause of anthropogenic mortality in Bottlenose Dolphins (McFee et al. 2007; McFee et al. 2009; Krzewinski et al. 2024). Incidental entanglement in derelict fishing gear may also impede an animal's ability to properly forage, navigate, or avoid collisions with vessels. The presence of warm water industrial discharge in areas of coastal development encourage Florida Manatees to prolong their visits to areas far beyond their wintering grounds and can lead to cold shock and death when cold weather arrives. Also, navigational locks on riverine systems can inadvertently crush Manatees not visible in the dark waters.

Bottlenose Dolphin. Photo by SCDNR.

Pollutants and contaminants from a variety of sources (e.g. urban and industrial development, manufacturing, wastewater discharge, stormwater runoff) can impact marine mammals. Species in coastal areas with more urban and industrial development are at risk of accumulating higher concentrations of contaminants (Houde et al. 2009; Fair et al. 2010; Battaglia et al. 2020). As pollutants and contaminants enter the aquatic environment, they bioaccumulate in fish and other organisms and are transferred to marine mammals primarily through the ingestion of prey (Fair et al. 2010, Battaglia et al 2020). Exposure to contaminants can cause adverse health conditions in marine mammals including increased susceptibility to infectious diseases and reproductive dysfunction (Fair et al. 2010). Specific emerging diseases include brucellosis (McFee et al. 2020), erysipelas, coronovirus, lobomycosis (lacaziosis), and paracoccidiosis (W. McFee, personal communication, November 11, 2024). Trash and other marine debris that enter the marine environment can be mistaken for food items and ingested resulting in morbidity and/or mortality.

Anthropogenic noise pollution from commercial and recreational vessels, dredging operations, bridge construction, land development, and other marine activities may affect marine mammal abundance, distribution, and behavior. Noise pollution can disrupt communication, foraging,

social activities, reproductive success, and cause displacement from home ranges and preferred habitats. In Charleston Harbor, the Charleston Estuarine System Stock of Tamanend's Bottlenose Dolphin increased their vocalizations in the presence of vessel noise, suggesting they may be modifying their vocal behavior in response to increased anthropogenic noise (Transue et al. 2023, Tribble et al. 2023).

Warming sea temperatures due to climate change can affect marine mammal prey availability, habitat availability, spatial and temporal distribution, behavior, physiological stress, and their overall health. A shift in the availability of prey could result in the lack of available food resources causing emaciation and starvation. Additionally, species may exhibit changes in their spatial or temporal distributions from historic norms. Trends in South Carolina strandings data suggest there may have been a shift in the migration patterns of the Southern Migratory Coastal Stock of Bottlenose Dolphin due to increasing ocean temperatures, with the southern migration beginning later in the year and the northern migration beginning earlier in the year (Krzewinski et al. 2024).

Conservation Opportunities

Terrestrial Mammals

As with other wildlife, the protection and restoration of habitat while utilizing already disturbed land and minimizing fragmentation is an opportunity for conservation. Identification of high priority habitat for rare and sensitive SWAP mammals in differing ecoregions and seasons should be conducted, and prioritizing those habitats based on connectivity and other key factors such as river corridors, streams, and marsh habitat for differing mammal species should be maintained. With that information, a focus should be placed on those high priority habitats for protection through future land acquisition and/or enhancement of current protected lands.

State of South Carolina

Governor's Proclamation

WHEREAS, bats provide important ecological services that contribute substantially to the economy of the United States by protecting American forests and agriculture from crop-damaging insect pests and by providing the fundamental benefit of pollination; and

WHEREAS, South Carolina is home to fifteen bat species that save our state's agricultural industry over $115 million each year in pest suppression services and help reduce the spread of dangerous mosquito-borne viruses; and

WHEREAS, recent bat population losses from white-nose syndrome and other factors require attention to ensure the sustainability of our food production systems and protect environmental and human health; and

WHEREAS, it is critically important to continue federal and state efforts, including developing new public-private partnerships and increasing citizen engagement, to promote the health of bat populations; increase the quality and quantity of bat roosting and foraging habitat; and help restore bat populations to healthy levels.

NOW, THEREFORE, I, Henry Dargan McMaster, Governor of the great State of South Carolina, do hereby proclaim October 24 - 31, 2024, as

SOUTH CAROLINA BAT WEEK

throughout the state and encourage all South Carolinians to learn more about the vital significance of protecting the health of bat populations and celebrate their contributions to healthy ecosystems, our food supply, and human health.

HENRY DARGAN MCMASTER
GOVERNOR
STATE OF SOUTH CAROLINA

Public outreach and partnerships with others across the State about the challenges faced by terrestrial mammals is key to their conservation, especially for privately owned high priority habitats. Regional partnerships for habitat protection, and working groups and cooperative study groups for outreach and research connections are beneficial opportunities for

conservation. For example, the goals of the Eastern Spotted Skunk Cooperative Study Group are to promote the conservation of the Eastern Spotted Skunk across their distribution through (1) enhancing communication about the species, (2) identifying management and resource priorities, and (3) facilitating collaborative planning, funding, outreach, monitoring and research opportunities. The mission of the South Carolina Bat Working Group is to conserve South Carolina bats through communication, collaboration, education and research. Other regional conservation focused organizations include the Southeastern Bat Diversity Network and the Colloquium on the Conservation of Mammals in the Eastern United States.

Research should continue to investigate the impacts of environmental contaminants on terrestrial mammals. It should also focus on estimating the amount of habitat necessary to sustain viable populations, and the effects of prescribed fire on differing mammal populations, ecoregions and seasons. Additional data needs to be collected to further determine population genetics, density, and viability, as well as to delineate regional and seasonal distribution and maintain long-term demographic data to better monitor, identify, and manage their declining populations.

Marine Mammals

In South Carolina waters, there are five Tamanend's Bottlenose Dolphin (*Tursiops erebennus*; Costa et al. 2022) stocks as well as the North Atlantic Right Whale (*Eubalaena glacialis*) and other migrating Right Whales that are protected under the Marine Mammal Protection Act of 1972 and Amendments. Further, Florida Manatees are protected in South Carolina waters and administered by the United States Fish and Wildlife Service (USFWS).

The National Marine Fisheries Service has created marine mammal stranding networks nationwide under the Marine Mammal Health and Stranding Response Act of 1992, and South Carolina has had an active SC Marine Mammal Stranding Network since 1992 led by the SCDNR (1992-2005), National Ocean Service (2006-2008), Coastal Carolina University (2008-2020), and the Lowcountry Marine Mammal Network (2021- present). The objectives of the US Marine Mammal Stranding Response Network are to: "1) monitor, track, and investigate causes of marine mammal illness, injury, death, health trends and effects of climate change, 2) collect data for scientific investigations, management decisions, and law enforcement investigations, 3) minimize the risk to public health and safety of stranded marine mammals, 4) provide for the welfare of live stranded or otherwise distressed marine mammals, 5) advance public education and engagement in ocean conservation, and 6) enhance the conservation and management of wild marine mammal populations and the wider marine ecosystem (https://fisheries.noaa.gov/national/marine-life-distress)."

In addition, conservation aims to mitigate human interactions by reducing bycatch in commercial fisheries and reduce collisions with vessels. Take Reduction Plans and teams are in place for multiple species to provide information for agency regulations related to vessel strikes, mortality and serious injury reports, investigations into effects from harmful algal blooms, monitoring of climate change effects, and investigations into Unusual Mortality Events. Individual private organizations regularly assist with outreach and education to the public, as well as investigate strandings through a competitive Prescott Grant Funding program (https://fisheries.noaa.gov/grant/john-h-prescott-marine-mammal-rescue-assistance-grant-program).

Research should continue to investigate the impacts of environmental contaminants on marine mammals (Houde et al. 2009, Fair et al. 2010), as well as microplastics (Battaglia et al. 2020), and emerging diseases and pathogens (McFee et al. 2020). It should also focus on continuing dolphin photo-identification (Speakman et al. 2010; Bouchillon et al. 2019), acoustic studies (Transue et al. 2023, Tribble et al. 2023), and human interaction studies (McFee et al. 2006, 2007, 2009). Additional data needs to be collected to further determine population genetics, density, habitat shifts due to climate change, as well as to delineate regional and seasonal distribution and maintain long-term demographic data (Krzewinski et al. 2024) to better monitor, identify, and manage populations.

Freshwater Fishes

South Carolina has an abundant and diverse aquatic community. There are 146 fish species that are known to inhabit the freshwaters of South Carolina or are seasonally dependent on freshwater habitats to complete their life cycle, such as shad and sturgeons. Several other fish taxa have not been scientifically described but may warrant species status review and would increase the number of species native to South Carolina. South Carolina's diverse fish fauna is largely due to the myriad of aquatic habitats that can be found throughout the State. Small, high-gradient Blue Ridge streams; large, fertile Piedmont rivers; and the "blackwater" streams and bays of the Coastal Plain are just a few of the aquatic habitats that contain numerous and diverse fish communities. South Carolina's freshwater fish fauna also boasts a relatively high degree of endemism with distributions of approximately 32 species, including the Carolina Darter and the Sandhills Chub, that are restricted predominantly to South Carolina or to a few drainages that South Carolina shares with one or more of its neighboring states.

Despite the Southeast's aquatic faunal diversity, some species are increasingly at risk of extinction. More than four decades ago, a fish assessment of the Southeastern US identified 85 fishes in peril (Deacon et al. 1979). A decade later, Williams et al. (1989) recognized 109 Southeastern fishes as in jeopardy. A published assessment focusing exclusively on southeastern fishes (Warren et al. 2000) identified 187 taxa as extinct, endangered, threatened, or vulnerable, which represents a 125% increase in imperiled fish taxa in only 21 years. Eighteen fish species that inhabit South Carolina were identified as endangered, threatened, or vulnerable to imperilment by Warren et al. (2000). An additional 38 fish species were determined to be of conservation concern in South Carolina in the first version of the SWAP (formerly the CWCS) (Kohlsaat et al. 2005). The third and latest published assessment of North American freshwater fishes reported that approximately 39% of described fish species on the continent are imperiled (Jelks et al. 2008). Compared to the 1989 assessment of Williams et al. (1989), Jelks et al. (2008) found that most taxa were the same or worse in conservation status; only 11% of those imperiled in 1989 had improved or been delisted. Our assessment currently places 53 freshwater fishes on South Carolina's list of Species of Greatest Conservation Need. Although many of these species may not be in jeopardy globally, they warrant conservation concern if the goal is to maintain South Carolina's rich and diverse fish fauna. Future extinction rates of freshwater fish species in North America may approach 53 to 86 additional species by 2050; 57 taxa have already been lost since 1898 (Burkhead 2012).

Challenges

One of the major challenges to freshwater fishes in South Carolina is degradation and loss of habitat. As urbanization through development occurs, waterbodies are altered in ways that change both the topography and hydrology of streams, rivers, wetlands, lakes and ponds. Removing riparian vegetation can result in siltation, increases in nutrient and pollutant loading, increases in velocity of flow both into and within the waterbody, and temperature increases. Erosion from agriculture and silviculture (logging) can significantly lower water quality and cause drastic adverse reactions in aquatic life (Butler 1968). Runoff carries silt, chemicals and nutrients into wetlands that, acting alone or in combination, can be lethal to aquatic life, and particularly to larval forms (Matthews et al. 1980, Aust et al. 1997). Runoff can cause sedimentation while nutrients can encourage algal blooms, both leading to eutrophication and possible dissolved oxygen (DO) depletion (Matthews et al. 1980, Lockaby et al. 1997). Siltation can also cause an increase in water temperature (Aust and Lea 1991, Perison et al. 1993). Forestry Best Management Practices (BMPs) for bottomland forests are recommendations to landowners in order to conserve site productivity—primarily for silviculture—and are voluntary (SCFC 1998). When BMPs are not used, braided streams may be obstructed by plant material and disturbed soils; excessive ruts may channel eroded sediments into streams. Additionally, partially stagnated waters may become nutrient-rich and promote algal growth that can die under extended periods of cloud-cover (J.W. McCord, SCDNR, pers. obs.). These factors contribute to increased water temperature and reduced DO.

Rapid development in some parts of South Carolina also contributes to siltation in many ways. Impervious surfaces such as roads, buildings and parking lots increase erosion in adjacent areas and contribute to flooding. Clearing riparian vegetation also destabilizes stream and riverbanks allowing excessive siltation. Clear cutting in a substantial part of a watershed can also contribute to siltation even if a riparian buffer is maintained. In a study of several watersheds in the Georgia piedmont, streams in urban and agricultural watersheds had much higher nutrient and suspended sediment concentrations than watersheds that remained mostly forested. Suburban watersheds had intermediate levels of nutrients and suspended sediments when compared with watersheds dominated by forested or urban and agricultural land use (Meyer and Couch 2000).

When streamside management zones are not maintained and cattle are allowed into the creek, bank sloughing and sedimentation occurs, smothering aquatic life. Photo by Ericah Beason, SCDNR.

The use of motor vehicles in streams and along banks can also degrade the stability of banks, stir up benthic sediments, and increase siltation. Factors that contribute to siltation can also change the topography of

the stream or river by changing the slope of the bank and eliminating heterogeneity in the channel.

Siltation from agricultural, silvicultural and other land use practices can also reduce spawning success by causing mortality of eggs or by coating substrates needed for attachment of adhesive eggs (NMFS 1998). Pollution, runoff and siltation input contaminants and pollutants into sturgeon habitat that can cause lowered pH or lowered DO. This, in turn, can reduce survival of eggs, larvae or juveniles (Rogers and Weber 1995, NMFS 1998). Bioaccumulation of contaminants may reduce productivity or increase susceptibility to diseases or stress (Cooper 1989; Sindermann 1994; Varanasi 1992; NMFS 1998).

The SC Statewide Aquatic Research Program team electrofishing. Photo by Charles Dymock, SCETV.

Hydrologic alterations to waterbodies can be detrimental to freshwater fishes. Dams prevent upstream migration of fish (ASMFC 1990; NMFS 1998; USFWS et al. 2001). Dams can block spawning migrations and severely restrict the availability of spawning and nursery habitat. In the event of a catastrophic event along a stream section, such as the diesel spill on a portion of the Reedy River in 1996, dams can make it very difficult for fishes and other aquatic animals to recolonize areas devastated by the catastrophe. Dewatering streams and rivers for anthropogenic purposes can result in reduced flows, elimination of critical habitats, and reduced water quality by concentrating non-point source pollution and increasing water temperature.

Nonnative fish species, particularly the nonnative Flathead Catfish (*Pylodictis olivaris*) and the Blue Catfish (*Ictalurus furcatus*), can severely impact native fish populations through competition for resources and predation. Flathead Catfish are voracious predators that have decimated ictalurid and other fish populations throughout the Southeastern United States (Guire et al. 1984; Jenkins and Burkhead 1994; Bart et al. 1994).

Climate is a primary force driving ecosystem dynamics, and aquatic systems are particularly susceptible to alterations in the hydrologic cycle. Our ability to predict the consequences of climate change is limited by uncertainty in climate predictions compounded by complexity in ecological system behavior. Climate will interact with a host of other ongoing system alterations—such as land use change—with which organisms must cope. Changes in precipitation timing and amount will affect water quantity and quality and timing of flows.

Conservation Opportunities

Some of the unique characteristics of aquatic ecosystems in South Carolina that must be considered when planning for climate change impacts include: (1) a high level of aquatic organism diversity and endemism; (2) if migration of fishes is limited to within drainage networks, preventing natural migration across watershed boundaries; and (3) if barriers to connectivity within drainages are widespread, limiting natural migration upstream and downstream. Data collected during the South Carolina Stream Assessment are being used to model potential consequences of climate change for streams in the State. Other opportunities include continuing to work with federal, state, and NGO partners to remove barriers to dispersal, genetic and life history studies to inform management, and stream restorations.

Diadromous Fishes

Diadromous fishes are species with complicated life histories, including partial growth and development in fresh and brackish and/or marine waters. These species are dependent on access to a wide diversity of habitats, particularly relative to water salinity or salt content, to most successfully complete their life cycle (McDowall 1988). There are several basic life history patterns within this group.

Anadromous fishes spawn in freshwater but typically spend much of their developmental life in marine waters (McDowall 1988). In the Southeast, the classic anadromous life history is exemplified in the three alosine herrings or alosines (all members of the genus *Alosa* and the family Alosidae): American Shad, Hickory Shad, and Blueback Herring. The alosines are highly migratory species that occur along much of the Atlantic coast of North America and spawn in freshwater during late winter and spring. Genetically distinct populations occur in most coastal, freshwater drainage basins throughout the range of these species, including those in South Carolina (ASMFC 1985; ASMFC 1999; ASMFC 2020; ASMFC 2024). Because of similarities in life history, the alosines face similar threats and are often included in single, comprehensive management plans just as they are addressed in the Supplemental Volume of this SWAP.

Atlantic Sturgeon is the largest species of fish found in freshwaters of Eastern North America (Robins and Ray 1986). The Atlantic Sturgeon is a Federally Endangered anadromous species in South Carolina, and both juveniles and non-sexually mature adults may move between fresh, brackish, and marine habitats during much of their lifespan (ASMFC 1990; McCord 2003; Post et al. 2014). Atlantic Sturgeon are genetically distinct by Atlantic coastal ecoregions or distinct population segments (dps) (Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic) (Wirgin 2000; White et al. 2021). The current extent of genetic mixing between drainage basin-specific populations or stocks is unknown. Atlantic Sturgeon occur in most major river systems along the east coast and exhibit a periodic life history strategy that increases their vulnerability to exploitation and habitat change, thus complicating conservation and recovery efforts (Winemiller 2005).

The Shortnose Sturgeon, also Federally Endangered, displays a variant anadromous life cycle in southern populations (Dudley et al. 1977; Kynard 1997; McDowall 1988; NMFS 1998). Shortnose Sturgeons can move into Atlantic Ocean coastal waters, though with much less frequency than do Atlantic sturgeons (NMFS 1998). Both species generally move between waters over a broad salinity range within particular drainage basins, and occasionally move into

high salinity estuarine or nearshore marine waters (McDowall 1988, NMFS 1998). This semi-anadromous life cycle has been termed “freshwater amphidromous” (Kynard 1977, NMFS 1998). Such species typically occur in relatively unique genetic populations or population segments since there is limited opportunity for mixing between riverine populations (NMFS 1998). Genetic mixing between populations is likely rather limited. A potentially dam-locked population of Shortnose Sturgeon occurs in the Santee-Cooper lakes (Collins et al. 2003, Post et al. 2014). Evidence to date indicates that this population is stressed, possibly because of lack of access to habitats with more appropriate food resources (Collins et al. 2003).

The Striped Bass is anadromous in basins along the North Atlantic and most of the Mid-Atlantic Coast, but is marginally anadromous, or freshwater amphidromous, in much of the Southeast (Dudley et al. 1977). However, some anadromous stocks exist in the Edisto, Combahee, and Savannah Rivers.

Catadromous fishes have a life history opposite that of anadromous fishes (McDowall 1988). This unusual life history strategy occurs in American Eel (McDowall 1988, ASMFC 2000). The American Eel is distributed along much of the Atlantic Coast from Canada to South America in a single population (ASMFC 2000). Adults spawn in the Sargasso Sea, a region of the central North Atlantic, south of Bermuda and east of the Bahamas. Adults die after spawning; juveniles migrate across the Atlantic continental shelf and populate many estuarine and freshwater habitats where they remain until sexually mature (ASMFC 2000).

Ultimately, all seven diadromous fish species described here are included on South Carolina’s SGCN list. However, the Striped Bass is included on the list of freshwater fishes because the populations for which there is concern are located inland.

Since most diadromous species are highly migratory and use, or even require, a vast diversity of habitats, management of such species is much more problematic than for more habitat-specific species. Management is particularly complicated for species such as alosines and sturgeons that occur as individual populations (genetic races) by river basin, or even by major tributary within a basin (as has been indicated for American Shad). Most diadromous species are potentially impacted by threats both within and outside of a particular state’s jurisdiction; for example, American Shad from South Carolina rivers occur in coastal bays of Canada during part of each year (Neves and Depres 1979). Likewise, Atlantic Sturgeon also undergo migrations north during certain times (Post et al. 2014) All portions of the life cycle are equally important for long-term sustainability of stocks. Accordingly, diadromous species generally require management through interstate or interjurisdictional plans.

The six diadromous species (American Shad, Hickory Shad, Blueback Herring, Atlantic Sturgeon, Shortnose Sturgeon, and American Eel) are considered to be highest priority species. All perform integral roles in the diverse habitats and ecosystems in which they reside during all portions of their complicated life cycles, and all have faced impacts that have caused stock declines, sometimes dramatic, in at least some river basins, both in South Carolina and across their broader ranges (ASMFC 1985; ASMFC 1990; NMFS 1998; ASMFC 1999; ASMFC 2000; ASMFC 2024). The ecological functions of these species are described in detail within the species profiles. These species are all currently covered by dynamic management plans

developed through the Atlantic States Marine Fisheries Commission (ASMFC) or the National Marine Fisheries Service (NMFS). Such management plans are primarily guidance documents that require action and cooperation by individual states. Several plans include mandates to the states that require specific monitoring or management actions. Unfortunately, funding associated with such plans and mandates has been insufficient to support actions necessary to collect information essential to assess and protect most basin-specific populations.

The Shortnose Sturgeon is a Federally Endangered species under the Endangered Species Act (ESA). However, individual basin-specific stocks of other anadromous species may be more imperiled than are many Shortnose Sturgeon stocks. All of the State's priority diadromous species are currently, or have been, targeted by commercial and/or recreational fisheries. Management of these species has generally been limited to control of fisheries. This is oftentimes based on limited data, perceived population levels, and regulatory actions presumed to produce desired positive effects. Currently, all take of Shortnose Sturgeon is prohibited because of its Endangered status.

The Atlantic Sturgeon is also a Federally Endangered species under the Endangered Species Act. State law has closed commercial gear fisheries for alosines in several rivers and has limited such fisheries within the past decade. In past years, the Blueback Herring and American Eel were petitioned for listing under the Endangered Species Act by the NMFS and the USFWS but found to be unwarranted. However, stocks will continue to be monitored. Prudent, effective, and responsive management of all of these species is dependent upon surveys and monitoring that can establish current distribution and stock status for all six priority diadromous species.

Challenges

There is a paucity of information on all diadromous species, particularly in regard to current population trends or distribution. For most of the priority diadromous species, information concerning presence or absence of these fishes is available for major rivers but is lacking for many state river basins. Also, the known or perceived status of individual populations for which there is data is variable, ranging from "secure" to "apparently depleted".

Dams that block or limit access of migratory fishes to historical habitats and prevent free movement both up- and downstream, have been indicated as major contributors to stock declines for all diadromous species (ASMFC 1985; ASMFC 1990; NMFS 1998; ASMFC 1999; ASMFC 2000; ASMFC 2024). Information on current distribution and stock status of all six high priority species is highly applicable to Federal Energy Regulatory Commission (FERC) relicensing considerations for dams and other water diversion facilities. Many dams on drainage basins within South Carolina are currently, or soon will be, undergoing the FERC-relicensing process. Both the National Marine Fisheries Service (NMFS) and the USFWS have primary authority over fish passage and diadromous fish restoration issues related to FERC-relicensing (ASMFC 1985; ASMFC 1990; NMFS 1998; ASMFC 1999; ASMFC 2000). However, state natural resource agencies generally participate in such activities as well.

Because of the broad diversity of life history characteristics and habitat utilization displayed by diadromous species, and because of their complicated life cycles, survey and monitoring techniques must be diverse and performed for a decade or more to establish meaningful trends

indicative of stock status. Most survey and monitoring to gather information on stock status of diadromous species in South Carolina over the past two decades or more has been funded by various federal grants and takes place only on major rivers. These studies have been primarily performed in response to mandates in ASMFC management plans. Funds have not been sufficient to allow for either comprehensive studies of all populations in South Carolina, or for the accumulation of sufficient long-term data to provide for conclusive indications of stock status for even any single population.

Furthermore, mandated data collection is most extensive for American Shad, and such data collection is not required for all populations since participants in the ASMFC management plan development process understood (and currently understand) funding limitations. Generally, small rivers are not covered by mandates within the ASMFC plan for alosines (ASMFC 1999; ASMFC 2002; ASMFC 2020). ASMFC management plans for the Atlantic Sturgeon and the American Eel include few mandates, but like all ASMFC plans, the National Marine Fisheries Services' recovery plan for Shortnose Sturgeon (NMFS 1998) and other management plans, make numerous recommendations for data collection needs. These studies will help to establish population status and conservation actions needed to restore or enhance individual populations or population segments.

In many South Carolina river basins, basic surveys must be conducted to determine either presence or absence of these species. Population surveys in some rivers may be useful as indicators of probable stock trends in similar basins. Perhaps among the highest priorities should be the continuation or expansion of existing surveys (i.e. a survey of sturgeons in the Waccamaw River initiated in 2018) for sufficient duration to follow multiple year classes and allow for characterization of stock status.

Modification of existing habitat poses a threat to all diadromous fishes. Changing the river's profile by deepening of the river channel or closing off existing corridors, can lead to lost habitat, differences in hydrologic features, and changes in water quality (i.e. salinity, dissolved oxygen, temperature, and pH). In addition, deforestation without proper buffers can lead to sedimentation and shoaling. These modifications to spawning habitat not only make once deep river reaches shallow, but affect areas upriver, causing siltation which makes it impossible for eggs to survive.

Climate change also has the potential to affect all diadromous fishes in one way or another. Long-term observations confirm that the climate is changing at a rapid rate. Some of the major impacts to diadromous fishes will include loss of nursery habitat, loss of spawning habitat, and reduced flows. Expected consequences would be a decrease in the amount of dissolved oxygen in surface waters and an increase in the concentration of nutrients and toxic chemicals due to reduced flushing rate (Murdoch et al. 2000). Increasing temperatures over time is already beginning to result in earlier spawning migrations of many alosine species (Nack et al. 2019).

Because many rivers are already under a great deal of stress due to excessive water withdrawal or land development—and this stress may be exacerbated by changes in climate—anticipating and planning adaptive strategies may be critical (Hulme 2005). A warmer-wetter climate could ameliorate poor water quality conditions in places where human-caused concentrations of nutrients and pollutants currently degrade water quality (Murdoch et al. 2000). A global analysis

of the potential effects of climate change on river basins indicates that due to changes in discharge and water stress, the area of large river basins in need of reactive or proactive management interventions in response to climate change will be much higher for basins impacted by dams than for basins with free-flowing rivers (Palmer et al. 2008). Consistently low stream flow can limit available spawning, thermal refugia, and foraging habitat.

Sea-level rise (SLR) is one of the more certain consequences of climate change; it has already had significant impacts on coastal areas, and these impacts are likely to increase. Since 1852 when the first topographic maps of the southeast region were prepared, high tidal flood elevations have increased approximately 30 cm (12 in.). During the 20th century, global sea level has increased between 15 and 20 cm (6 and 8 in.) (NAST 2000). Analyses attribute the coastal forest decline in the Southeast to saltwater intrusion associated with sea level rise. Coastal forest losses will be even more severe if sea-level rise accelerates as is expected as a result of global warming. It is difficult to ascertain which impacts will occur and over what time period, but there is little doubt these impacts will affect diadromous fishes.

Other important issues in diadromous fish management include the determination of the extent of genetic isolation of populations or population segments using tributaries within larger drainage basins. For example, detailed and expensive genetics studies may be required to determine the relationships of alosines spawning within various tributaries of the greater Waccamaw-Pee Dee Basin. Similar relationships may exist for alosines in the ACE Basin rivers. Genetic relationships and the extent of genetic isolation of Atlantic Sturgeon in riverine spawning populations are also poorly understood. In addition, genetic implications are very important with regard to the development of some fish passage and fish restoration programs when the integrity of genetically distinct populations may be negatively affected. For effective management of the Atlantic Coast American Eel population, it is of utmost importance to better understand the contribution of various riverine or regional sub-populations or population segments to the current and long-term productivity of the entire continental population.

Lastly, piscivorous birds such as the Double Crested Cormorant and White Pelican, and non-native, invasive species can impact populations of diadromous species. Blue Catfish and Flathead Catfish are both presumed to act as both competitors and predators to sturgeon, for example (NMFS 1998).

Conservation Opportunities

Many dams in South Carolina are currently, or are soon to be, required to go through the Federal Energy Regulatory Commission (FERC) re-licensing process, which includes considerations for improved access for passage and migration of diadromous species. Therefore, increasing opportunities for passage, habitat enhancement, and monitoring studies are possible in the future. For example, after almost 30 years, Santee Cooper received their long-awaited license in 2023. Requirements in the 40-year license include

American Eel ladder at St. Stephen Dam on the Rediversion Canal, Santee River. Photo by SCDNR staff.

monitoring studies and construction of passage facilities at both the Pinopolis and Santee Dams for the American Eel. Requirements also include monitoring and passage studies for American Shad and Blueback Herring in the Santee and Cooper Rivers. Additionally, the Biological Opinion for Shortnose and Atlantic Sturgeon concurrently issued by NMFS as part of the license, requires up to 40 years of monitoring studies and increased minimum flows (NMFS 2020). Duke Energy also received their license for the Yadkin Pee Dee in 2015. As part of the requirements in this license, an eel ladder was installed at Blewett Falls Dam and began passing fish in 2022. In addition, the utility began required American Shad monitoring and is constructing a fish passage facility. Lastly, Duke Energy received a license for the Catawba Wateree System in 2015. Requirements in this license continued monitoring of an already constructed eel ladder and American Shad monitoring at and below the Wateree Dam in Lugoff, SC.

Although these opportunities are mandated through the FERC process, they are ever so important due to the long-term monitoring commitment for diadromous species. These partnerships between utilities and State and Federal agencies are crucial in maintaining annual catch data for sustainability of diadromous species resources. Because federal funding continues to decrease annually, reducing the ability to fund long-term monitoring/research projects, conservation opportunities such as those mentioned are vital.

Freshwater Mussels

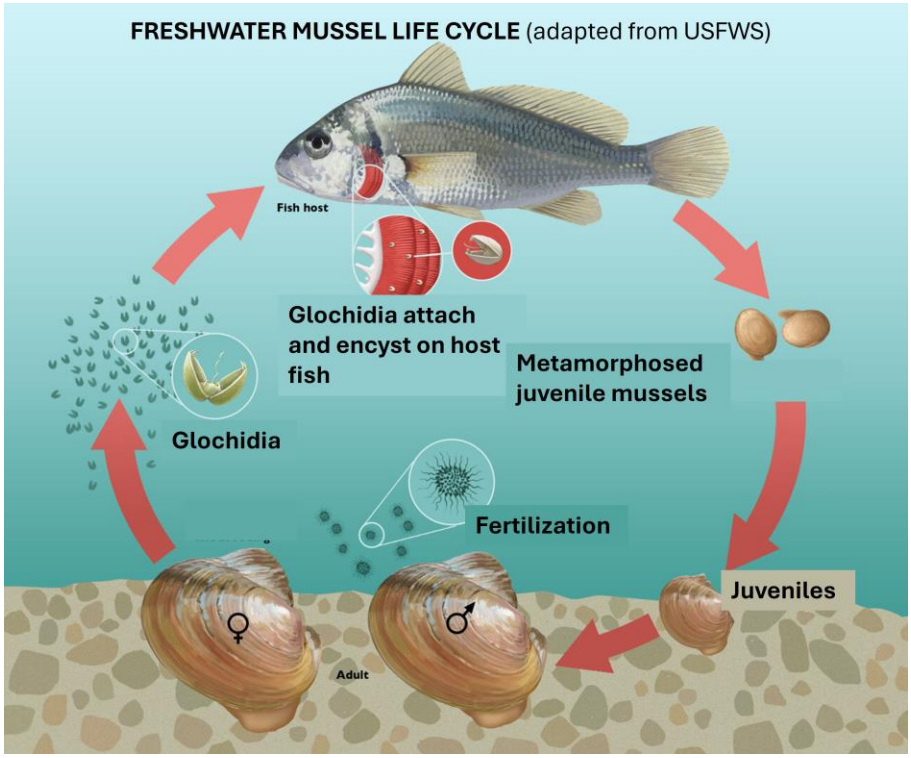
Freshwater mussels native to the United States are bivalve mollusks belonging to the order Unionoida and superfamily Unionoidea. There are two families within Unionoidea, Unionidae and Margaritiferidae; all of South Carolina's species belong to the family Uniondiae. North America has the highest diversity of freshwater mussels in the world with roughly 300 species recognized; however, they are one of the most imperiled groups of organisms with approximately 70% of species in North America considered either threatened, endangered, or extinct (Bogan 1993, Williams et al. 1993; Haag and Williams 2014; Lopes-Lima et al. 2018). In 1993, the American Fisheries Society evaluated the conservation status of freshwater mussels in the United States and Canada (Williams et al. 1993) and they determined that 7.1% of mussel species were endangered and possibly extinct, 20.6% were endangered and extant, 14.5% were threatened, 24.2% were of special concern, and 4.7% had an undetermined status. Only 23.6% of mussel species were determined to be stable. In recent years, unionid mussel populations in North America, including both rare and common species, have faced

Native freshwater mussel being used in a chub mound. Photograph taken by Ericah Beason, SCDNR.

dramatic declines (Bogan 1993, Vaughan and Taylor 1999) resulting in loss of benthic, filter feeding biomass, and ecosystem services provided by such animals.

The conservation of North American freshwater mussels has many broad implications beyond the survival of individual mussel species. As filter feeders, unionid mussels, even in low densities, remove algae, diatoms, bacteria, and particulate organic matter from the water column and then convert that material into dissolved nutrients that can be taken up directly by the algae (Vaughn et al. 2004). These effects are far greater when unionid biomass is high, water volume is reduced, and flows are low (Vaughn et al. 2004). Freshwater unionid mussels also affect stream nutrients by burrowing into the substrate which enhances the rate at which nutrients release from the sediment (Matisoff et al. 1985). Not only does burrowing allow for the release of nutrients, but it also aids in the structural integrity of the substrate, aiding in the creation or improvement of habitat that can be utilized by other invertebrates (Vaughn et al. 2008). Mussel shells left in the system after an animal dies are also important for creating and enhancing habitat. Sometimes mussels themselves are used by other species and in South Carolina, some have been observed being used in chub mounds.

Additionally, macroinvertebrate assemblages are influenced by unionid mussels, and densities of macroinvertebrates were positively correlated with unionid density (Vaughn and Spooner 2006). Macroinvertebrates provide many ecosystem services such as breaking down organic matter and acting as a staple food source for higher trophic levels (Covich et al. 1990, Nery and Schmera 2016). Unionid mussels are also an important food resource for fish, crayfish, flatworms, waterfowl, turtles, muskrats, raccoons, and river otters. Not only are freshwater mussels a food source, but their biodeposits (feces and pseudofeces) also act as a food source. For example, the Western Pearlshell's (*Margaritifera falcata)* biodeposits act as a food source for larval lampreys in oligotrophic streams; it was found that over 80 days, the lamprey grew twice as fast when caged with mussels in western California (Limm and Powers 2011). Since mussels are sometimes found at densities as high as 200 to 400 per m^2 (19 to 37 per $ft.^2$), removing them from our rivers and streams can have drastic consequences for these ecosystems, particularly in terms of nutrient processing (Bogan 2001).



Freshwater unionid mussels have a unique life cycle and larvae require

attachment on a species-specific host fish to complete metamorphosis into juvenile mussels. Most freshwater mussels are dioecious (separate sexes), although a few species are hermaphroditic (Van der Shalie 1970; Kat 1983; Johnston et al. 1998). During spawning, male unionid mussels release sperm or spermatozeugmata, a hollow, spherical aggregate of sperm, into the water column. If filtered by the appropriate female, the sperm fertilizes eggs which are inside of the female mussels' gills. Female mussels deposit eggs in primary water tubes of gills, called marsupia or brooding chambers, and the location of where eggs are deposited varies among species (Williams et al. 2008). Once fertilized, embryos develop until they become glochidia (larvae), and the duration of embryo and glochidia retention in the marsupium varies among phylogenetic groups (Williams et al. 2008). Species generally fall within two groups, the short- (tachytictic) and long- (bradytictic) term brooders (Ortman 1911), though a handful of mussel species differ from these patterns. Short-term brooders, as the name suggests, brood embryos until they become mature glochidia (generally less than 2 months) before immediately releasing them, which typically occurs in the spring and summer (Weaver et al. 1991, Garner et al. 1999). Long-term brooders' eggs are usually fertilized in late summer or fall and glochidia, like glochidia of short-term brooders, develop within about two months. However, glochidia are not released immediately after maturing, rather, they are brooded over winter until the following spring or summer (Zale and Neves 1982). Upon release, glochidia must attach to the fins, skin, or gills of species-specific host fish, or in a few cases, a salamander, to transform into juvenile mussels. If glochidia attach to an appropriate host fish, they become encysted on the host, which occurs as fish cells encapsulate the glochidia; if they attach to a non-suitable host, they will be rejected by the fish's immune system and be sloughed off the fish (Haag 2012).

Glochidia can survive in the water column from a few hours to a couple of weeks before attaching to a host, but this time frame depends on mussel species, water chemistry, and temperature (Fisher and Dimock 2000, Zimmerman and Neves 2002). If glochidia do not successfully find a host during that period, they die. To increase chances of survival, unionid mussels have developed unique methods of dispersing glochidia which aim to increase their odds of attaching to an appropriate host. Common, known host infection strategies include broadcasting, conglutinate production, and luring. Broadcasting is a strategy utilized by many opportunistic mussel species and involves free releasing glochidia into the water column in hopes they encounter a suitable fish, or releasing glochidia in mucus threads or webbing which allow glochidia to get "trapped" onto host fishes (O'Brien and Williams 2002, Aldridge and McIvor 2003). Mussel species that utilize the broadcasting strategy are often host generalists and glochidia can successfully transform on different species of fish, although the percentage of success still differs among species (Haag 2012). Conglutinates are specialized packages of glochidia that range in complexity from "loose conglutinates" that contain little structure, to highly specialized conglutinates such as those seen from the kidneyshell (*Ptychobranchus fasciolaris*) which encapsulate glochidia in a pigmented, membranous capsule that mimics larval insects or fish fry—prey items for darters—and can attach to rocks or vegetation (Watters 1999). Different conglutinate types seem to target different fishes. Pelagic conglutinates are simple structures composed of undeveloped eggs and mature glochidia. They are small, lance or oval shaped, and usually uniform in color; they usually target drift-feeding minnows (Haag 2012). Demersal conglutinates vary widely in shape, size, and color but they are complex structures that remain at or near the streambed and target benthic invertivores such as darters (Haag 2012). Mucoid conglutinates are loose conglomerates of glochidia in large, unpigmented, packages that

mimic caterpillars or worms and are also associated with the bottom of a system; these conglutinates typically target catfishes (Haag 2012). Lastly, some mussel species produce a lure from modified mantle tissue which usually mimics prey for specific fish species. Lures range in size and complexity, but all lures aim to attract host fishes within proximity to the female mussel for release of glochidia. For instance, the Yellow Lampsmussel (*Lampsilis cariosa*), which is found in South Carolina, produces a lure that mimics a small minnow that attracts piscivorous fish species such as the White Perch, a known host fish species (Kneeland and Rhymer 2008).

As a group, freshwater mussels are found in a variety of environments throughout South Carolina, though the majority of targeted sampling efforts have occurred in wadeable streams. Many of South Carolina's species can be found throughout the Atlantic slope, but there are several species that are endemic to one or a few river drainages, see species profiles for more information. Furthermore, some species are endemic to only North and South Carolina or only to South Carolina and Georgia (Bogan and Alderman 2004, 2008).

Since the conservation plan for freshwater mussels of South Carolina was drafted nearly 20 years ago, substantial efforts have been made to survey mussels in the State by a variety of organizations including The Nature Conservancy, the USFWS, the South Carolina Department of Natural Resources, and private consulting groups. Many significant distribution records across the State have been accumulated because of these surveys, but comprehensive ranges of some species are still unknown (e.g., *Utterbackiana implicata*). During the "South Carolina Stream Assessment" from 2006–2013 (funded by a State Wildlife Grant (SWG)), freshwater mussels were recorded at 77 of 397 random stream sites in 17 ecobasins across the state. Although these records do not reflect the actual presence and abundances accurately because no standardized surveys were completed, they do provide useful distribution information and museum specimens that will be used by mussel specialists to reassess the taxonomy and conservation status of various species. In 2018, SCDNR began its Freshwater Mussel Program and employed a dedicated freshwater mussel biologist, with the primary focus being on the conservation and monitoring of the Federally Endangered Carolina Heelsplitter (*Lasmigona decorata*). Since 2018, the program has grown and, while it still focuses on the Carolina Heelsplitter, it also prioritizes species distribution data collection, life history research, and conservation and monitoring of all freshwater mussels within the state. From 2021-2024, the Freshwater Mussel Program completed a SWG grant "Occupancy and Distribution of SWAP Listed Freshwater Mussel Species" that prioritized conducting standardized freshwater mussel surveys across the State. A total of 45 sites were surveyed and collected occupancy data was used to update the Natural Heritage Database. Though these efforts aided in updating species occupancy within the State, more work is needed to fill distribution data gaps, unknown life history strategies, habitat preferences, and environmental and toxicological tolerances of freshwater mussel species in South Carolina.

Freshwater mussels are ecosystem engineers and have important roles and interactions with other freshwater species in numerous freshwater systems. Unfortunately, species throughout North America have historically faced many large declines due to commercial harvesting. Within the last 50 years, declines are largely associated with anthropogenic sources of pollution and habitat degradation, agriculture, habitat loss, invasive species, and climate change.

Challenges

There are many challenges regarding freshwater mussels in South Carolina, and additional challenges may be discovered as associated habitat, population range and trends, and species-specific threats are determined for unionid mussel species in the State. Some of the known challenges regarding freshwater unionid mussels in South Carolina include uncertain taxonomy and species' distributions, limited life history research, systemic exploitation and habitat destruction, invasive species, and climate change.

South Carolina is home to 30 recognized freshwater mussel species; however, the taxonomic identification of mussels to species can be difficult, and ongoing genetic research informs changes to species designations regularly. Like many taxa, freshwater mussel species were originally designated due to shell morphology and/or internal anatomy. Because of this, many species have been described as distinct or synonymized based on geographic variation and/or phenotypic plasticity of a single species. Phenotypic plasticity, in this document, refers to non-heritable variation of size, shape, and coloration of individuals due to environmental parameters such as, but not limited to, substrate, shear stress, stream size, water chemistry, etc., that the individuals interact with during life. Recent molecular data continues to reveal that speciation cannot be determined simply based on shell morphology but must consider shell morphology, internal anatomy, location, and genetic analysis before synonymy or species designations can be made (Zanatta and Murphy 2006; Raley et al. 2007; Kuehnl 2009; Smith et al. 2018; Whelan et al. 2023). Many of South Carolina's species' designations currently in use may change as more comprehensive, range-wide genetic analysis is completed, and this is likely to alter the presumed distributions of species which may lead to changes in conservation priorities.

Historical occupancy data in South Carolina is minimal and standardized surveys did not begin until 2019 which make determining short- and long-term population trends difficult, and the difficulty in identifying mussels has only added to the challenges of quantifying species' decline (e.g. *Elliptio producta*). Historic species identifications are often questioned, and the extent of a species' historic range is usually uncertain. Museum specimens are especially lacking in South Carolina because there is no state natural history museum, and collections are not in a centralized location or remain uncatalogued; however, there are several natural history museums in the eastern United States that contain mussel specimens from South Carolina. Mussel specimens collected during the South Carolina Stream Assessment and subsequent Mussel Program assessments (2006–2011, 2019-present) were deposited in the North Carolina Museum of Natural Sciences for long-term storage and for use by mussel specialists, but temporal gaps in data exist because surveys have not been conducted at regular intervals prior to 2019. Unresolved taxonomy of mussel species contributes further to the difficulty in making identifications. Taxonomic and systematic studies continue to be done on mussels in South Carolina, and over the next decade or two, additional species diversity will likely be known from the State because of these efforts.

Additionally, most freshwater mussel sampling by SCDNR has occurred in wadeable streams, and while this has aided in the collection of many occurrence data points, it does not provide comprehensive, range-wide distribution data for freshwater mussel species in South Carolina, especially for species that seem to prefer large river habitats. Effort is needed to target large, non-wadeable streams across South Carolina, particularly areas with historical occupancy of

highest conservation priority species outlined in the 2025 SWAP. Consequently, research is needed to determine the effects of impoundments on mussel species in large rivers, although pre-impoundment data may be minimal or nonexistent.

Another challenge regarding freshwater mussels in South Carolina is the lack of life history data. While the identity of the host fishes for more than half of South Carolina's mussels is now known (Bogan and Alderman 2004, 2008), most studies are laboratory trials and have not verified host usage in the wild, although some have (e.g. Kneeland and Rhymer 2008) and others have been attempted (e.g. Poelmann et al. 2023). Spawning and brooding cycles are also understudied for many species in South Carolina which would make propagation efforts, if needed, difficult. Oftentimes, spawning cycles are temperature-dependent, and without known temperature thresholds, management techniques cannot be suggested or implemented. Habitat preference data is also lacking for species within South Carolina, and unfortunately, streams continue to be degraded from anthropogenic sources making it difficult to determine pre-impact habitat preferences.

Historically, mussels have been used for a variety of commercial purposes including food resources for human consumption, pearl collection, and even button creation. In the mid- to late-1800s, harvesting mussels for pearls was common across North America and was initially sparked by the 1857 sale of a pearl collected from New Jersey for 12,500 francs, approximately $98,000, in 2024 US dollars (Dakin 1913). This led to harvesting of mussels almost to complete elimination in the north which forced pearl hunters south and west to continue collecting mussels (Kunz 1898). After the "first great pearl excitement," periodic accidental pearls collected from mussels resulted in "pearl rushes" that would last until the mussel beds in nearby streams were depleted (Kunz 1898; Dakin 1913; Sparks et al. 1990). Freshwater mussels were collected to near extirpation in some areas and harvesting mussels for pearls began to subside in the early 1900s due to low returns and increasing competition from the button industry which, unfortunately, did not slow mussel harvests (Kunz 1898, Haag 2012).

The modern shell button industry began in the 1890s and is largely credited to Johann Boepple, a German immigrant; however, shell buttons have been in literature as early as 1802 (Haag 2012). Shell camps were established along banks, and collected mussels were brought to camp, steamed open, had their shells removed, and then tissues were sifted through to find pearls which were still of value (Kunz 1898, Coker 1919). In 1902, it was estimated that 20,000 people were harvesting mussels from just the Mississippi River (Knott 1980), and in 1920 there were more than 2,600 boats used for mussel collection in Illinois (Danglade 1914). The industry peaked in 1916 with at least 196 factories in 20 states assisting with the manufacturing of buttons (Coker 1919, Claassen 1994). As was seen in the harvesting of pearls, mussels were once again exploited and nearly depleted around shelling camps and factories which forced harvesters to new areas. The shell button industry withered in the mid-1940s when the development and production of plastic buttons became popularized (Claassen 1985).

Today, there is still some demand for mussel shells for use in the pearl industry and large-scale harvests still take place, but not in the same sense as before. Now, mussel shells are harvested and sold to the pearl industry where the shells are ground into beads that are used to form the nucleus of cultured pearls (Williams et al. 1993). Large-scale commercial harvesting currently

does not occur in South Carolina, and it is unlawful to take, possess, transport, import, export, process, sell, offer for sale, ship, or receive native unionid mussels without a permit from SCDNR. Although illegal, some members of the public voluntarily reported using native mussels as fishing bait, human food, and pond maintenance.

In the last 60 years, large-scale harvesting has not been the primary cause of mussel diversity and abundance declines are largely due to an influx of anthropogenic impacts, invasive species, and more recently, climate change. Mussels are an indicator species and are often the first taxa to be affected when pollutants are present in streams. Freshwater mussels and snails represent the most sensitive taxa in the EPA's 2013 criteria for ammonia, which resulted in a reduction of the acute criterion for total ammonia nitrogen being listed (USEPA 2013). Unionid mussels represented the top 7 most sensitive species to ammonia compared to other species tested which included species of freshwater fishes, other freshwater mollusks, freshwater amphibians, and other freshwater invertebrates (USEPA 2013). Although among the most sensitive taxa, tolerances vary across species. As of 2013, only 17 species of freshwater mussels have had ammonia toxicity testing. Ammonia in freshwater systems is naturally occurring; however, it is a common toxicant introduced at elevated concentrations through effluent discharge and agricultural, industrial, and urban runoff.

Copper is another toxicant that is naturally occurring in freshwater systems in trace amounts (0.2-30µg/L; Bowen et al. 1985); however, it becomes toxic to some organisms at elevated levels. Like ammonia, copper is introduced to freshwater systems through anthropogenic and industrial inputs. Copper is found in many herbicides and algaecides and is a byproduct of mining, leather and metal production, and is found in runoff from copper bearings in industrial use (McKnight et al. 1983, Patterson et al. 1998). Copper toxicity testing using glochidia of 9 freshwater mussel species found that most 24-hour median effective concentrations (EC50s) for survival were <45µg Cu/L (Wang et al. 2007). More research is needed to determine acute and chronic lethal concentrations of copper and other pollutants to different species of unionid mussels.

Keller and Zam (1991) found through acute toxicity testing that juvenile paper pondshell mussels (*Utterbackia imbecillis*) were more sensitive than commonly tested fish and aquatic invertebrates to six metals (zinc, copper, chromium, nickel, cadmium, and mercury), with cadmium being the most toxic in both soft and moderately hard water. Mercury was also found to have significant negative effects on mussel growth (Beckvar et al. 2000). Keller and Zam (1991) noted that hardness had a major effect on metal toxicity to mussels (and other organisms), with metals becoming less soluble in hard waters as they form complexes with carbonates. Much of South Carolina has soft waters, lower pH, and low alkalinity which may increase the toxicity of metals in stream. Acidification also appears to have drastic effects on the survival and

Erosion and shell damage of an *Elliptio complanata* mussel that is still alive. Photograph taken by Ericah Beason, SCDNR.

shell structure of mussels (Fuller 1974). Many mussels in South Carolina that are collected are found with heavily eroded shells which weaken their protection against predation and environmental disturbances. Wang et al. (2017) found that in compiled databases for all freshwater species, one or more mussel species were among the four most sensitive species for alachlor, ammonia, chloride, potassium, sulfate, copper, nickel, and zinc. Unionid mussels have demonstrated a high degree of sensitivity to many inorganic toxicants; but unionid mussels, at least those on which toxicology tests were performed, were not among the most sensitive organisms to organic chemicals in acute exposures; however, chronic toxicity tests are needed (Wang et al. 2017). Although it is undeniable that freshwater unionid mussels are sensitive to common pollutants, toxicity testing is still needed to determine species-specific acute and chronic endpoints and behavioral and physiological effects from toxicant exposures.

Most pollutants enter freshwater systems due to anthropogenic and agricultural sources and this is exacerbated by increased runoff due to impervious surfaces (roads, buildings, parking lots, etc.), clearcutting of land that reduces contact time of runoff with vegetation, and disjunct or missing riparian buffers. A riparian buffer is the section of trees, woody plants, bushes, shrubs, grasses, and even downed vegetation adjacent to a waterbody that partially protects it from impacts from surrounding land use. Clearing riparian vegetation also destabilizes stream and riverbanks allowing excessive siltation and destruction of instream mussel habitat.

Siltation is the accumulation of fine particles in water bodies and historically results from clearing land for agriculture and development, mining operations, and dam construction. In South Carolina, observational data suggests that siltation is largely attributed to clearcutting land for pasture, housing developments, and mining operations. Like pollutants, the effects of siltation are exacerbated when impervious surfaces increase, cattle are allowed to enter streams, and sufficient riparian buffers are not maintained. Clearcutting in a substantial part of a watershed can also contribute to siltation due to exposed sediment and increased runoff even if a riparian buffer is maintained. The use of motor vehicles and allowing livestock in streams and along banks can also degrade the stability of banks, stir up benthic sediments, and increase siltation. Factors that contribute to siltation can also change the topography of the stream or river by changing the slope of the bank and eliminating heterogeneity in the channel. Eliminating structural heterogeneity may also slow the flow of water and reduce its oxygen content, thereby harming species that require highly oxygenated water.

Most studies that discuss the impacts of sedimentation on unionid mussels are related to sudden sediment deposits like that seen in the creation of dams, dredging, and channelization. No studies have determined the direct effects on unionid mussels of slow deposition of silt, like that usually seen in free-flowing waters. In (1980) Marking and Bills found that mussels' ability to emerge from burial under sediment declined with increasing sediment depth from 5-25cm and mussels that did not emerge died. Responses varied across species. Ellis (1931) found >90% unionid mortality in the bottom of hatchery raceways which reportedly had slowly deposited silt, but the rate of siltation, water chemistry parameters, and "control" animal (mussels held above the bottom in wooden frames) mortality was not reported. Another study by Imlay (1972) found that mussels held in jars buried under 8-18cm of sediment did not reemerge from burial and many died; however, no controls were used. Although the sudden onset of several centimeters of silt is unlikely in free-flowing rivers, observation data (e.g. Stewart and Swinford 1995, Nicklin and

Balas 2007) suggest that over time, siltation in flowing waters can lead to increase embeddedness and changes in habitat which may lead to the decline of certain mussel species. In South Carolina, observational data show that many streams in urban areas are dominated by unstable sand which is not suitable habitat for most species of mussels as they become dislodged during high flows (Allan 1995, Gordon et al. 2004). Habitat alteration is not only seen in response to sedimentation but also direct habitat destruction from small (off-road vehicles in streams) to large scale (impoundments and channelization), and these have undeniable negative effects on unionid mussels.

The construction of impoundments directly and drastically alter sthe physical characteristics of a stream and shift the lotic (flowing) system into a lentic (still) one. When this occurs, riverine habitat is directly lost, species richness and abundance decline, and host fish assemblage and distribution is affected. Dam construction across the United States skyrocketed from the 1910s-1940s and river impoundments were constructed for water storage, hydroelectricity, navigation, and transportation. By the mid-1940s, thousands of dams were constructed, the Ohio River was canalized by 1929, and the upper Mississippi River and Tennessee River were completely impounded by 1940 and 1944, respectively (Haag 2012). The construction of impoundments causes the direct loss of riverine habitat and at least 12 unionid mussel species were directly eliminated by the construction of impoundments and an estimated 8% of all North American mussel fauna were lost because of habitat destruction (Haag 2012). After construction, impoundments that create deep reservoirs show shifts in mussel assemblages from lotic to lentic species and may lead to localized extirpation of riverine mussel species (Garner and McGregor 2001; Vaughn and Taylor 1999; Haag and Warren 2007). Lentic unionid mussel species display opportunistic life history strategies which allows them to quickly colonize lentic environments. Opportunistic mussel species typically have short life spans, fast growth rates, and high population growth rates; they are usually host generalists or use an impoundment-tolerant host fish species, may tolerate lower dissolved oxygen, and are adapt to finer sediments, all traits that are needed in unstable environments (Haag 2012). Haag and Warren (2007) found that across four habitats that represented a gradient from lotic to lentic habitats, mussel abundance and density were highest at lotic sites, and lentic sites were mostly inhabited by opportunistic mussel species. The shift in mussel species assemblage and abundance may not only be attributed to changes in habitat for mussels but also changes in habitat that affect the distribution of fish species, which can affect recruitment and distribution of unionid mussels. Impoundments do not only change the habitat which may affect fish species' presence, but they can directly impede fish migration which affects mussel distribution and range (Watters 1996, Eads et al. 2015).

Non-native, invasive *Corbicula* clams in Lake Marion, Orangeburg County, SC. Photo by Anna Smith, SCDNR.

There are several non-native species in South Carolina that can have negative impacts on unionid mussels, although their impacts and interactions have not been

directly studied in South Carolina. The Asian Clam (*Corbicula fluminea*) is an invasive freshwater bivalve that has spread throughout the United States (Benson et al. 2024b). *Corbicula* are small (< 50mm) bivalves that have distinct, concentric sulcations (ridges), and vary in color from pale yellow to almost black. *Corbicula* often co-occurs in large numbers with native mussels and may compete for food and habitat, but research suggests that *Corbicula* do not reach high densities in established, dense, adult unionid mussel patches (Vaughn and Spooner 2006b). Although small, *Corbicula* have much higher mass-specific filtration rates than unionid mussels and this could limit the available food for adult mussels, but the high metabolic demand for *Corbicula* could be why it cannot reach high densities in dense, adult native mussel patches (Vaughn and Spooner 2006b). *Corbicula* seems to have more negative effects on juvenile mussels through food competition, displacement of juveniles, siphoning juveniles and glochidia, and increasing ammonia above acute tolerance levels of juvenile mussels (Vaughn and Spooner 2006b). During the South Carolina Stream Assessment (2006–2011), *Corbicula fluminea* was recorded at 68 of 397 random stream sites in 21 ecobasins, and as of 2024, it remains widely distributed in all river basins in South Carolina. Research on the direct interactions and effects of *Corbicula* on mussel species in South Carolina is needed. Unfortunately, there seems to be no pre-invasion data to assess impacts on native populations in systems such as Lake Marion where *Corbicula* overwhelmingly dominates the benthos (B. Taylor, pers. comm.).

The Zebra Mussel (*Dreissena polymorpha*) was introduced into the United States and has become well established throughout the Great Lakes, Ohio, Upper and Lower Mississippi, and Texas Gulf drainages (Benson et al. 2024). Zebra Mussels are small (<50mm) and typically have a striped pattern on their shell. They differ from *Corbicula* by producing byssal threads which are used to attach to hard surfaces such as rocks, pipes, and even unionid mussel shells. Zebra Mussels are a much more problematic bivalve than *Corbicula*. Establishment of Zebra Mussels can cause the rapid decline of native mussels by competing for food and fouling unionid mussels which impedes locomotion, valve closure, and energy stores (Ricciardi et al 1998, Strayer 1999). Zebra Mussels have invaded nearby parts of Tennessee and may eventually spread into South Carolina, although the risk of them becoming established has been assessed as low due to unsuitable water chemistry, specifically low calcium concentrations, and lower pH (Cohen and Weinstein 2001, de Kozlowski et al. 2002). In 2021 and 2024, Zebra Mussels were found attached to Marimo Moss Balls (*Aegagropila linnaei*) in the aquarium trade and efforts were made to collect and dispose of all potentially contaminated moss balls. As of 2024, there are no known populations of Zebra Mussels in South Carolina.

In addition to invasive mollusks, the introduction of Red Swamp Crayfish (*Procambarus clarkii*) could also have negative effects on unionid mussels. Red Swamp Crayfish are native to the Mississippi drainage and were first observed in South Carolina in 1988 (Hobbs et al. 1989). While their effects on native mussels in South Carolina are unknown, a study by Covich et al. (1981) found that Red Swamp Crayfish preyed on juvenile *Corbicula* that were less than 6mm in length. Observational data also show crayfish feeding on the mantle tissues of exposed mussels in South Carolina, but this has not been formally documented. Additionally, non-native fishes such as Black Bullhead, Flathead Catfish, Blue Catfish, and Channel Catfish are known to feed on mussels (Forbes 1888; Edds et al. 2002; Grist 2002; Haag 2012), but the extent of their effects on mussel populations in South Carolina is unknown. Targeted effort is needed to determine the

interactions between native unionid mussels and non-native species in South Carolina and what potential threats they pose to the organisms themselves, or the habitat in which they exist.

Collectively, environmental instability and habitat alterations are two primary driving forces behind the continued decline of native freshwater mussels in South Carolina. Changes in the climate, such as increasing air and water temperatures and altered precipitation patterns, are likely to exacerbate such conditions. Climate change is the shift in climate patterns mostly caused by greenhouse emissions which cause heat to be trapped by the Earth's atmosphere. Both natural (e.g. forest fires, earthquakes, etc.) and human activities (e.g. energy production, industrial activities, etc.) are primary sources for greenhouse gas emissions (Yue and Gau 2018, Endenhofer et al 2014). Global warming is not expected to be uniform across space and time, rather warming will be substantially greater in many land regions and less in most ocean regions; regional seasons may be substantially warmer or cooler than global averages (Collins et al. 2013; IPCC 2018). Impacts of climate change are not limited to changes in temperature; other impacts include rising atmospheric CO_2, shifting rainfall patterns, rising sea levels, increased ocean acidification, and extreme floods, droughts, and heat waves (Lee et al. 2018, IPCC 2018). Climate change impacts that are most likely to impact freshwater mussel diversity, abundance, and distribution are increasing stream temperatures, extreme precipitation events (e.g. flood, drought, etc.), and sea level rise.

Freshwater unionid mussels are mostly sessile and are unable to escape detrimental habitat changes such as rising water temperatures and dewatering events. Rising water temperatures are associated with global climate change, altered precipitation and hydrology, land-clearing, and urbanization (Bates et al. 2008; Burlakova et al. 2011; Hester and Doyle 2011). Drought conditions exacerbate in-stream temperatures, and South Carolina regularly experiences drought conditions (Figure 1, https://www.drought.gov/) from abnormally dry (D0) to exceptional (D4), the most intense category.

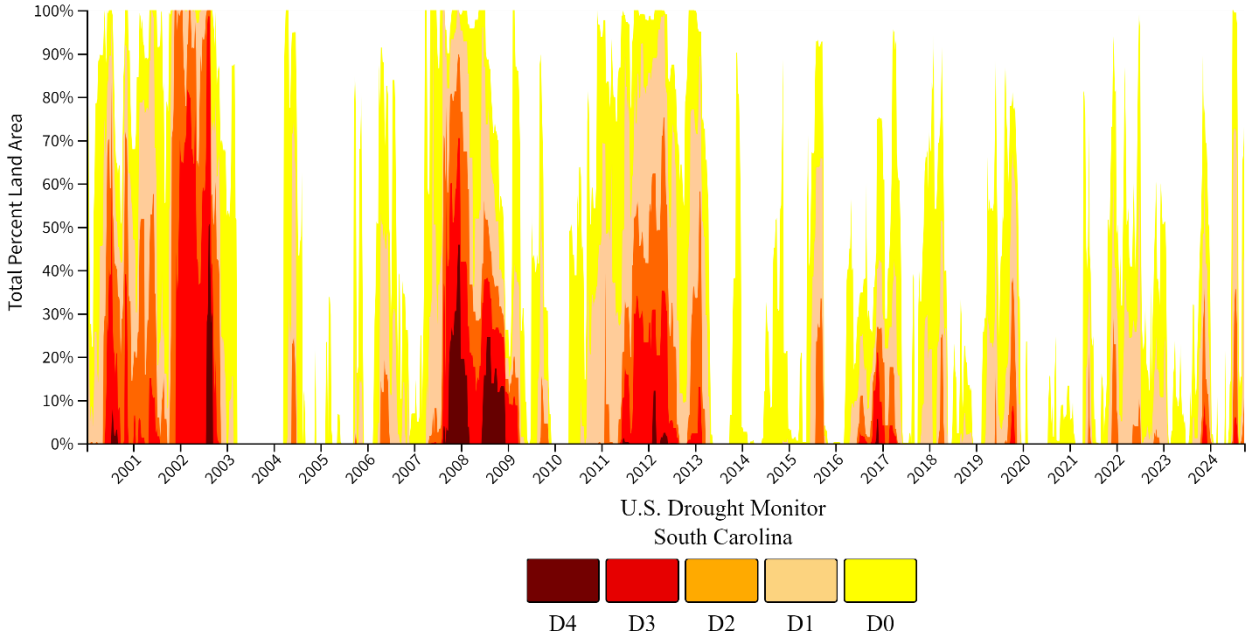
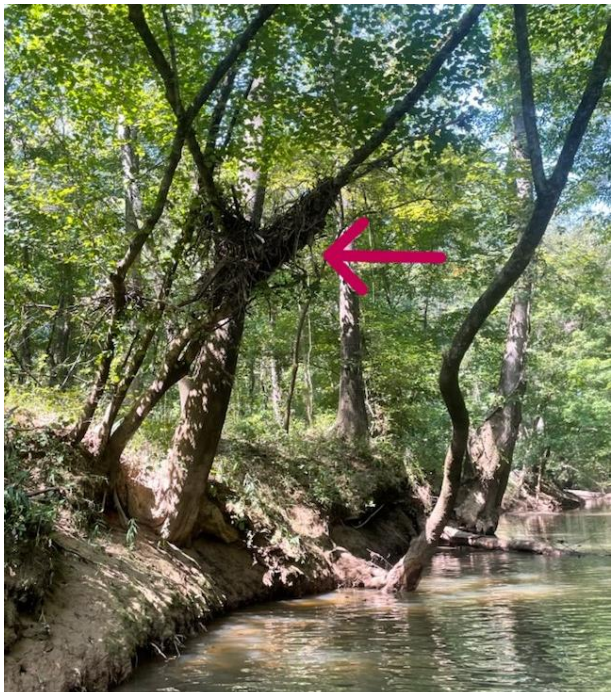


FIGURE 1: Graph of intensity of drought from U.S. Drought Monitor which is updated every Thursday by authors from NOAA, USDA, and the National Drought Mitigation Center, see Drought.gov for more details.

Freshwater mussel stranded during drought. Photo by Ericah Beason, SCDNR.

The effects of rising temperatures and drought conditions on native freshwater mussels are numerous and may be direct (e.g. mortality) or indirect (e.g. habitat loss). As of 2023, lethal thermal tolerance estimates have only been determined for ~10% of mussel species in the order Unionida; mean acute median lethal temperatures were 32.8°C/91.0°F for glochidia (19 species), 35.0°C/95°F for juveniles (13 species), and 36.3°C/97.3°F for adults (4 species) (Fogelman et al. 2023). Unfortunately, most studies do not determine the physiological responses and thermal tolerance of a species across its geographic range which vary across longitudinal gradients (Malish and Woolnough 2018, Fogelman et al. 2023). Water temperatures in South Carolina regularly exceed 30°C/86°F (USGS), and only 2 priority species in South Carolina have temperature studies completed on glochidia and juveniles. See Pandolfo et. al 2010 for *Alasmidonta varicosa* and Archambault et al. 2014 for *Lampsilis cariosa*, one priority species has a temperature study on adults (no glochidia or juveniles). See Galbraith et al. 2020 for *Strophitus undulatus*. Additionally, increased water temperatures exacerbate adverse effects of most pollutants (Cushway et al. 2024). Research on the effects and tolerances of temperature for mussel species in South Carolina is needed, especially studies that look at compounding effects due to other stressors and temperature (Fogelman et al. 2023, Cushway et al. 2024).



Debris caught in trees during high flow event in Sixmile Creek. Photograph taken by Ericah Beason, SCDNR.

The adverse effects of drought on native mussels are comprehensive, with effects ranging from individual mussels (e.g. mortality, behavior, physiology, etc.) to population responses and ecosystem services provided by mussels (Cushway et al. 2024). During standardized mussel surveys in South Carolina during periods of drought,

native mussels are regularly encountered dead from emersion due to reduced, or even non-existent flow. Drought conditions may also lead to concentrated pollutants, low dissolved oxygen, and altered habitat which have varying effects on native mussels (Cushway et al. 2024). Climate change impacts are not only likely to affect drought periods in South Carolina. The intensity and frequency of precipitation events are likely to result in more intense flooding, and like most threats to freshwater mussels, the effects of flooding are exacerbated by urbanization, inadequate riparian buffers, and excessive clearcutting of land. Due to their mostly sedentary lifestyle, native mussels can be buried, dislodged, or stranded during periods of flood, and some species may be more susceptible to stranding than others (Tucker 1996; Tarter et al. 2023). Small streams, like many of those found in South Carolina, are especially vulnerable to intense flooding and drought. During periods of drought or floods, mussels have been observed stranded in the floodplain and on sandbars. During sampling, debris stranded in trees from high flow periods in small streams is regularly seen 8-15ft above base flow. Stable habitat provides refugia from scour during floods and (Strayer 1999b, Hastie 2001), and burrowing behavior may aid in the stability of mussels during high flows (Schwalb and Pusch 2007). A singular flood event can have catastrophic impacts on mussels. For instance, in 1998, a historic flood in Scotland resulted in the conservative estimate of 50,000 mussels killed (Hastie et al. 2001). There have been no estimates of the amount of direct loss or displacement of mussels due to extreme drought or flooding in South Carolina.

Lastly, sea level rise and saltwater intrusion is another climate change concern in South Carolina as all freshwater unionid mussels, except for *Glebula rotundata*, are found strictly in freshwater. Salinity tolerance studies for unionid mussel species are minimal, and even less than that of thermal tolerance studies, with only ~5% of unionid species being evaluated (Johnson et al. 2018). Sea level rise has been largely attributed to thermal expansion, glacier melt, and ice sheet melt (Bindoff et al. 2007; Cazenave and Llovel 2010). As sea levels rise, saltwater will intrude upon freshwater systems which is likely to have adverse effects on freshwater mussels in South Carolina.

Conservation Opportunities

Thanks to genetic studies over the years, the 2025 SWAP includes 7 taxonomic name changes which are outlined in Table 1. Additionally, *Elliptio waccamawensis* was synonymized with *Elliptio congaraea* and *Elliptio hopetonensis* was added to the list of recognized species in South Carolina.

TABLE 1: Freshwater mussel scientific name changes since the 2015 SWAP.

Name as seen in 2015 SWAP	Name as it appears in 2025 SWAP
Anodonta couperiana	*Utterbackiana couperiana*
Anodonta implicata	*Utterbackiana implicata*
Leptodea ochracea	*Atlantichonca ochracea*
Ligumia nasuta	*Sagittunio nasutus*
Villosa constricta	*Venustachonca constricta*
Villosa modioliformis	*Villosa vibex*
Villosa vaughaniana	*Sagittunio vaughanianus*

There will continue to be changes in the knowledge of the freshwater bivalve fauna of South Carolina, including new records of both native species and non-native species, along with information on their life histories, habitat preferences, distributions, and threats and stressors which will collectively result in substantial changes to the list of SGCN.

Freshwater Snails

Freshwater snails are a diverse group of animals within the class Gastropoda (phylum Mollusca) and are broadly distributed worldwide. North America is of global importance, having one of the highest numbers of freshwater snail species recognized. In 2013, Johnson et al. completed a conservation assessment of 703 species of native freshwater snails from Canada and the United States, representing 16 families and 93 genera. Here they described that freshwater gastropods have 67 species (10%) considered likely extinct, 278 (40%) endangered, 102 (15%), threatened, 73 (10%) vulnerable, and 26 (4%) have uncertain taxonomic status. This makes 74% of the entire fauna imperiled, exceeding levels of fishes (39%), crayfishes (48%), and even bivalves (72%) by a small margin. The remaining 157 of North American species, only 26%, are considered stable.

Freshwater gastropods are an important component in their aquatic ecosystems; most feed on periphytic and epiphytic algae and biofilms (Covich et al. 1999). In some habitats, freshwater gastropods may be the principal grazers and are capable of significantly influencing algal primary production; others are suspension or deposit feeders, capturing and resuspending nutrients in the water column (Brown and Lydeard 2010). Furthermore, snails historically were and presently are important food sources for fishes, turtles, birds, and muskrats (Johnson et al. 2013).

Campeloma decisum in the Waccamaw River in Horry County, SC. Photo by Keith Bradley, SCDNR.

In South Carolina, as of the 2023 Freshwater Mollusk Conservation Society (FMCS) gastropod names list, a total of 45 species are recognized to potentially occur in the State; however, 8 are non-native to South Carolina and 2 need to be genetically confirmed. The bulk of observations which lead to species recognition in South Carolina came from Burch and Tottenham (1980), placing the species in South Carolina, or Dillon et al. (2019) reporting observations from 1952-2019. In recent years, efforts have been made to survey and identify snails in the state by Dr. Robert T. Dillon, Jr. and colleagues, private consulting groups, and the South Carolina Department of Natural Resources. During the South Carolina Stream Assessment (2006–2011), freshwater gastropods were recorded at 50 of 397 stream sites across the State. In addition, more collections were made as part of other research projects. Identifications were made possible with the kind assistance of

Robert Dillon. *Campeloma decisum* was the initial identification given to the snail specimens collected most often and in greatest abundance, but that species is not recognized by FMCS (2023) to occur in the southern Atlantic slope. *Campeloma limum* is the species recognized to occur in South Carolina, and collected specimens were likely this species but verification is needed. Although these records do not reflect the actual presence and abundances accurately because no targeted surveys for gastropods were conducted, they do provide useful distribution information and museum specimens that can be used for taxonomic or biological studies.

All SCDNR snail records were provided to Robert Dillon for inclusion in the web-based Freshwater Gastropods of North America. Gastropod specimens from the South Carolina Stream Assessment were deposited in the North Carolina State Museum of Natural Sciences for long-term documentation and so that the specimens can be used for morphological and genetic research that will contribute a better understanding of the diversity of gastropods in South Carolina. In 2023, the Freshwater Mussel Program at SCDNR began collecting voucher snail specimens at freshwater mussel stream survey sites and vouchers will be deposited at the North Carolina State Museum as well.

Recently, the taxonomy of freshwater snails in South Carolina has received some attention, resulting in the description of a new species, *Physa carolinae*, which occurs in Georgia, South Carolina, North Carolina, and Virginia (Wethington et al. 2009), but substantial genetic work is still needed, see data deficient snail guild for more.

Challenges

To date, there have been no known standardized surveys for freshwater snails in South Carolina, and most surveys have been completed by one group of individuals. The lack of knowledge and information about life histories, habitat requirements, and current distributions for freshwater snails represents the most significant challenge. There are also challenges that lie solely in creating a standardized survey for snails as species are found in a variety of habitat types from swift riffles to moist leaf litter on land but near freshwater. Additionally, many species have patchy distribution and very specific microhabitat requirements that can be overlooked when sampling at a large scale. Other sampling concerns in South Carolina lie in the unfavorable survey conditions of some species' preferred habitat. Some species are often found in swamps which are difficult to navigate and pose additional challenges due to mosquitos, alligators, and deep, soft mud that is can be dangerous to traverse. The lack of sampling and collection of vouchers in South Carolina makes determining species' distributions and short- and long-term population trends difficult.

Like freshwater mussels, nomenclature and uncertain taxonomy pose a specific challenge when placing observation records in South Carolina. The South Carolina SWAP aims to provide a framework for the conservation of species with the greatest need for conservation in the State; however, it proves difficult to place a conservation ranking on species with minimal data. Because of this, 9 species representing 6 families are given a data deficient conservation ranking, highlighting the need to prioritize collection of baseline data.

Like other aquatic organisms, freshwater gastropods are largely threatened by rapid habitat changes due to anthropogenic development, inputs, degradation, or modifications. Johnson et al.

(2013) point to habitat destruction in medium and large rivers as the primary cause for most extinctions of highly endemic species (those occurring in a single lake, stream, or spring), citing damming and channelization (45 species, 67% of total), drainage or diversions of lakes (8 species, 12%), alteration of springs (4 species, 6%), and potential effects of exotic fish introduction (2 species, 3%).

Siltation of streams and rivers through agricultural runoff and erosion of unstable streambanks appears to be another main threat to freshwater snails (Dillon and Keferl 2000). Siltation is the accumulation of fine particles in water bodies and historically results from clearing land for agriculture and development, mining operations, and dam construction. In South Carolina, observational data suggests that siltation is largely attributed to clearcutting land for pasture, housing developments, and mining operations. The effects of siltation are exacerbated when impervious surfaces increase, cattle are allowed to enter streams, and sufficient riparian buffers are not maintained. A riparian buffer is the section of trees, woody plants, bushes, shrubs, grasses, and even downed vegetation adjacent to a waterbody that partially protects it from impacts from surrounding land use. Clearcutting in a substantial part of a watershed can also contribute to siltation, even if a riparian buffer is maintained due to exposed sediment and increased runoff. The use of motor vehicles and allowing livestock (e.g. cows) in streams and along banks can also degrade the stability of banks, stir up benthic sediments, and increase siltation. Factors that contribute to siltation can also change the topography of the stream or river by changing the slope of the bank and eliminating heterogeneity in the channel. Eliminating structural heterogeneity may also slow the flow of water and reduce its oxygen content, thereby harming species that require highly oxygenated water.

Collectively, environmental instability and habitat alterations are two primary driving forces behind the continued decline of freshwater snails in North America, and changes in the climate such as increasing air and water temperatures and altered precipitation patterns are likely to exacerbate such conditions. Climate change is the shift in climate patterns mostly cause by greenhouse emissions which cause heat to be trapped by the Earth's atmosphere. Both natural (e.g. forest fires, earthquakes, etc.) and human activities (e.g. energy production, industrial activities, etc.) are primary sources for greenhouse gas emissions (Yue and Gau 2018, Endenhofer et al 2014). Global warming is not expected to be uniform across space and time, rather warming will be substantially greater in many land regions and less in most ocean regions; regional seasons may be substantially warmer or cooler than global averages (Collins et al. 2013, IPCC 2018). Impacts of climate change are not limited to changes in temperature; other impacts include rising atmospheric CO_2, shifting rainfall patterns, rising sea levels, increased ocean acidification, and extreme floods, droughts, and heat waves (Lee et al. 2018, IPCC 2018). Climate change impacts that are most likely to impact freshwater snail diversity, abundance, and distribution are increasing stream temperatures, extreme precipitation events (e.g. flood, drought, etc.), and sea level rise.

Conservation Opportunities

There will continue to be changes in the knowledge of the gastropod fauna of South Carolina, including new records of both native species and non-native species, along with information on their life histories, habitat preferences, distributions, and threats and stressors which will collectively result in substantial changes to the species of greatest conservation need.

Crayfishes and Freshwater Shrimps

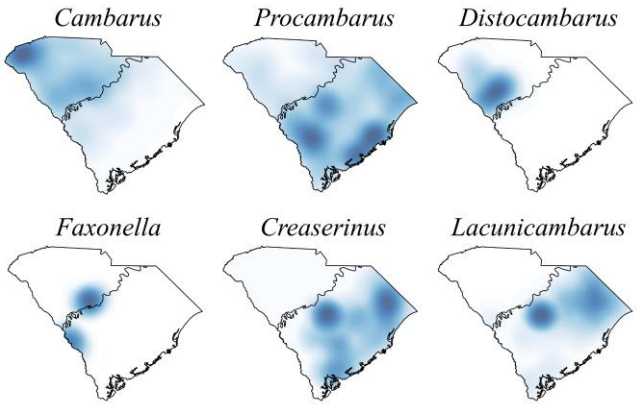


FIGURE 2: Heat maps showing dominant collection areas for the six crayfish genera known from SC.

Decapod crustaceans, including crabs, lobsters, crayfishes, and shrimps, are found across the State of South Carolina from coastal waters to upland habitats. As compared to marine-oriented crustaceans like crabs, lobsters, and penaeid shrimps, other major groups of decapod crustaceans such as crayfishes, river shrimps, and grass shrimp are often associated with freshwater environments but can also be found from estuarine waters near the coast to underground burrows in the mountains. These inland species represent an important component of South Carolina's biodiversity and are critical to the State's various ecosystems. For example, the southeastern United States is a global hotspot of crayfish diversity with >350 native species (Richman et al. 2015) with South Carolina home to at least 39 native species across 6 genera (Figure 2) and at least two non-native crayfishes. Many crayfish have limited ranges, leading to high rates of endemism for this group. Additional decapod crustaceans in South Carolina include caridean shrimp in the family Palaemonidae (e.g. *Palaemon* and *Macrobrachium*). The eastern grass shrimp *Palaemon paludosus* occurs throughout the Coastal Plain of South Carolina. Six river shrimps in the genus *Macrobrachium* occur in estuarine and freshwater rivers of the United States (Bowles et al. 2000) with two native species found in South Carolina. River shrimps spend most of their life cycle in freshwater rivers and streams, but adult females migrate to estuaries to spawn their eggs since larval development requires more saline conditions (Rome et al. 2009).

Decapods play several important ecological roles in inland aquatic habitats. They make up a large portion of the invertebrate biomass and represent a critical nexus of aquatic food webs as they feed on algae, detritus, or small animals while also serving as prey for higher trophic levels including several game fish species, migratory and wading birds, and mammals (Probst et al. 1984; Rabeni 1992; Roell and Orth 1993). Some South Carolina snakes, such as Crayfish Snakes and Queen Snakes, for example, rely heavily on crayfish as food. Crayfish also have a drastic effect upon the biomass and species composition of aquatic macrophytes and snails (Lodge et al. 1994). Despite their abundance and importance in many North American freshwater habitats, both the taxonomy and natural history of many species of crustaceans are poorly understood. New species are frequently being discovered and existing species are often reclassified. In fact, multiple species on South Carolina's SGCN list warrant, or are currently undergoing, taxonomic work (Kendrick and Williams, *In Review*). Much less is known about the abundance, distribution, and taxonomy of river shrimps and grass shrimp, so additional concerted efforts are needed to better understand their conversation status (Cooper 2011).

Historically, the conservation of crustaceans has received little attention by regulatory agencies; however, there has been some progress over the past decade. In 1996, the American Fisheries Society considered 65 species (19.2%) of North American crayfish as endangered, 45 (13.3%) as

threatened, and 50 (14.8%) as special concern (Taylor et al. 1996). In 2007, updates to the previous assessment resulted in nearly the same composition with 66 species (18.2%) of North American crayfish as endangered, 52 (14.3%) as threatened, and 54 (14.9%) as special concern (Taylor et al. 2007). Listing with the American Fisheries Society does not give species any protection. The USFWS website currently lists the following six species known from South Carolina as 'USFWS Focus' species: *Distocambarus carlsoni, Distocambarus youngineri, Cambarus spicatus*, *Procambarus echinatus*, *Cambarus strigosus*, and *Procambarus lepidodactylus*.

Commonly thought to inhabit strictly aquatic environments, crayfish can utilize a variety of habitats. All species rely on water for reproduction, but many burrowing species either access the water table by digging deep enough or by constructing the burrow with compact soil around the walls, allowing it to retain moisture from rainfall and runoff. Some crayfish are obligate burrowers and rely on habitat such as farm fields, prairies and forests, while others inhabit streams, small lakes, or temporary ponds, occasionally digging terrestrial burrows during dry periods. Hobbs (1981) distinguished crayfish as primary, secondary, or tertiary burrowers. Primary burrowers spend almost their entire lives in the burrow. Secondary burrowers spend much of their lives in a burrow but may move to open waters during rainy periods. Tertiary burrowers live primarily in open water but may move into a burrow to escape frost or drought and when brooding eggs. The habitat requirements of many species, particularly primary burrowers, are not well understood, but research has been underway in South Carolina to better understand requirements.

Challenges

There are a number of potential challenges to both crayfishes and river shrimps. It is, however, difficult to assess the degree to which each species is vulnerable to particular threats until the habitat associations, population trends, and distributions are better understood for all of these species. However, complex life histories (e.g. Macrobrachium moving between fresh and salt water to spawn), small endemic ranges, and a variety of habits and habitats (e.g. crayfish burrowing habits) make studying these underrepresented species difficult. Genetic and taxonomic work is particularly important where there are questions regarding classification because misidentification can obscure the presence of rare species in need of conservation. The case of the Keeowee Crayfish (*Cambarus* sp. nov. "B" cf. *longirostris*), which was mistaken for an introduced species, is an excellent example. It has previously been treated as an introduced population of *C. longirostris* in South Carolina (McLaughlin et al. 2005, Taylor et al. 2007), and as of October 2023 this species remains undescribed. Formal description of this species is sorely needed to ensure its conservation status.

The arrival of introduced species is probably the greatest challenge to these crustaceans (Lodge et al. 2000a,b). The ranges and abundances of many native crayfish may have been reduced by invasive crayfish, both in the United States and in Europe (Lodge et al. 2000a; Hobbs et al. 1989). In Europe, crayfish introduced from the Southeastern US are responsible for the spread of crayfish plague to native European species (Lodge et al. 2000a). Other potential mechanisms for the deleterious effects of invasive crayfish include predation upon natives, competition, and genetic hybridization with native species (Lodge et al. 2000a).

The Red Swamp Crawfish, *Procambarus clarkii*, has been introduced from waters draining into the Gulf of Mexico into waterways throughout South Carolina, with concurrent declines in native crayfishes (Kendrick et al. 2024). Potential negative effects of its introduction include the spread of fungal diseases, helminth parasites for which this species is an intermediate host (Hobbs et al. 1989, Rothman et al. 2024), and viruses that can broadly infect many decapod crustaceans (Sasson et al. 2024). In South Carolina, *P. clarkii* has been collected at sites at which native crayfishes were present in some cases and absent in others (Poly 2007, Kendrick et al. 2024). Several sites in North Carolina that once had native species of crayfishes now have only *P. clarkii* (Cooper and Armstrong 2007), suggesting that *P. clarkii* has also possibly displaced native taxa in that state.

The Bristled River Shrimp, *Macrobrachium olfersii*, is native to Central and South America (Holthuis and Provenzano,1970), but has been introduced to South Carolina with unknown impacts on native species (Cooper 2011). The Virile Crayfish *Faxonius virilis* and the Rusty Crayfish *Faxonius rusticus* have been widely introduced outside of their native Midwestern US states (Hobbs et al. 1989). The Virile Crayfish is now known to occur in the Catawba River of South Carolina, with potential deleterious impacts on native fauna as well as unknown impacts on the iconic Spider Lily, *Hymenocallis coronaria*, that grows expansively on shoal outcrops in this river system. The Rusty Crayfish has been reported from the upper Broad River drainage in North Carolina (Cooper and Armstrong 2007) and possibly could spread downstream into South Carolina. Several shipments of crayfishes to South Carolina schools for educational use have contained Rusty Crayfish (W. Poly, pers. obs.).

Prevention of future introductions is most likely the only effective way to deal with the challenges caused by non-native crayfish. No methods for eliminating invasive species without also harming native species are currently available. Even if effective biological control methods are developed, preventing introductions will still be much easier than eradicating an established species. Other non-native crayfishes and shrimps have also been introduced into South Carolina. *Cherax quadricarinatus*, *Macrobrachium rosenbergii*, *Macrobrachium nipponense* were introduced to South Carolina for aquaculture (Smith et al. 1978; Brummett and Alon 1994; Procopio and Daniel 2024). While these species do not appear to have become established in the wild, additional sampling is needed, especially for *M. nipponense*.

Some species, such as *Cambarus* sp. nov. “B” cf. *longirostris*, have been eliminated from parts of their range because of damming activities associated with reservoir construction of upstate systems, while damning of large Coastal Plain rivers has likely had negative impacts on river shrimps that make catadromous migrations from large rivers to estuaries for spawning. Channelization and dredging can also be very detrimental to aquatic crayfish that require rocks, crevices, or tree roots along undercut banks as hiding places (Hobbs and Hall 1974).
The most serious known challenge to terrestrial burrowing crayfish is the alteration of soil hydrology. These species occur in association with some agricultural fields, timber harvest practices, and roadside ditches, but it is unclear how soil manipulations may have impacted some populations. In some areas, fire suppression—or the lack of fire management—may be a threat, since some species appear to prefer Piedmont prairies, savannahs, and other open canopy habitats to densely wooded areas.

These crustaceans are harmed by a variety of insecticides, herbicides, and industrial chemicals (Eversole et al. 1996). Juvenile crayfish are generally about four times more sensitive to water-borne pollution than adults; early instars are about three times more sensitive as juveniles (Eversole and Sellers 1996). There is little knowledge of the differences in sensitivity to toxins among species. Nutrient enrichment is less likely to harm crayfish than other aquatic life because they are omnivorous and can act as scavengers as well as primary and secondary consumers. Hobbs and Hall (1974) noted several casual observations in which crayfish were more abundant downstream of areas with large amounts of garbage or animal remains. Enrichment may be harmful to crayfish, however, when it results in oxygen depletion (Hobbs and Hall 1974). Pollution of groundwater may impact terrestrial burrowers, because they inhabit water trapped in their burrows. Additional work is needed to understand pollution tolerances of river shrimps.

Conservation Opportunities

Crayfishes are in need of additional assessments to determine their distribution, abundance, and life histories so that effective conservation strategies can be applied in a way that will have the most direct impact on these species.

Freshwater Sponges

Freshwater sponges are found in diverse environments including fast flowing and deep rivers, shallow (<3 cm deep) streams, or slow flowing ponds and ephemeral wetlands. Species grow on both natural (rock, vegetation roots and stems, live and dead wood) and artificial (plastic and wooden docks and pilings) substrates. Sponges are found near the surface and down to a depth of approximately 10 cm. Species are generally found in clear water but have also been found in turbid waters, though rarely. They have been identified at sites both distant from and near human development and pollution. Members of this group are widespread within both the Coastal Plain and Coastal Zone Ecobasins.

A freshwater sponge clings to the underside of a rock in Turkey Creek, Edgefield, SC. Photo by Keith Bradley, SCDNR

Challenges

Sponges as a group are not threatened globally, but freshwater sponges may be at increased risk due to pollution and temperature fluctuations, as well as habitat destruction. Observations suggest that adult sponges die off at some sites in South Carolina during high temperatures in the summer. Following these mortality events, sponge gemmules (asexual

buds) are left behind on the substrate to "hatch" into sponges again once environmental conditions are favorable. In many cases, these gemmules are embedded in a tough, resin-like structure underneath the adult sponges. Although little is known about these die-offs in South Carolina, it is possible that they may become more frequent under future climate change and that sponges will rely on gemmules more frequently to overcome these environmental challenges. [Chris Freeman, pers. comm.]

Conservation Opportunities

There are no known conservation accomplishments pertaining to freshwater sponges, but any initiatives that protect wetlands and maintain water quality are likely to protect habitat for these organisms. Several recommendations would improve our understanding of this group. For example, determining the role of freshwater sponges in nutrient and organic matter cycling in freshwater systems in South Carolina would be beneficial. Establishing baseline growth rates for dominant species is also needed. The use of freshwater sponges by aquatic insects (particularly the use of sponges by insect larvae) needs to be assessed. Reproductive cycles and seasonality of freshwater sponges and their use of gemmules to survive high or low temperatures or other disturbances should be examined. Wetlands should be protected from human development or other anthropogenic impacts that might destroy sponge habitat or contribute to pollution.

Leeches

Leeches (Phylum Annelida; Order Hirudinida) occur in a diversity of freshwater, marine, and terrestrial habitats. They are key components of ecosystems in which they reside, serving as detritivores, predators, or ectoparasites. Leeches are indicators of water quality and wetland health but may also play a role in the transmission of pathogens among hosts. Much of our understanding of leech diversity in South Carolina is rooted in work done over 40 years ago (e.g. Sawyer 1972; Sawyer and Pass 1972; Sawyer et al. 1975; Sawyer and Shelley 1976; Sawyer 1979). The 2015 SC State Wildlife Action Plan reported 25 leech species known to occur in South Carolina and, while that number remains approximately the same, recent surveys (Moser et al. 2017, 2022; B.W. Williams unpublished) integrating molecular, morphological, and ecological data, have begun to substantially revise our understanding of leeches in the Southeastern US.

Challenges

Among the largest challenges to the conservation of leeches is a lack of basic understanding of the taxonomy and distribution of species. Despite how common they are in aquatic habitats, leeches are difficult to encounter in targeted surveys and are most frequently found opportunistically. Furthermore, they are often overlooked by field biologists focused on other taxa, including hosts. As such, most leech species in South Carolina are known from only a handful of localities at best. This dearth of sampling presents a challenge to understanding the basic ecology of leech species, including host preference (for ectoparasites) and in turn, the potential for host health. Many leech species are taxonomically challenging; this is particularly true for the genera *Erpobdella* and *Helobdella*. In addition, ontological variation occurs among and within species such that misidentification is common. These taxonomic difficulties are compounded by the admittedly onerous and slow manner by which leeches should be fixed for

ideal identification purposes; leeches placed directly into fixative tend to curl tightly, making morphological identification very tricky, if not impossible.

Conservation Opportunities

The conservation of leeches is inextricably linked to the conservation of their habitats and, for the ectoparasitic species, their hosts. This means that furthering our understanding of leech diversity, distribution, and ecology serves as a critical umbrella that covers numerous other taxa. To do so will entail a highly collaborative effort among herpetologists, aquatic biologists (both freshwater and marine), and other folks who may encounter leeches in their work, either free-swimming or on host taxa. Collection of leech specimens with sufficient locality information is foundational to every other aspect of the conservation of these worms.

Marine Fishes and Invertebrates

Atlantic Ribbed Mussels at Cape Romain NWR. Photo by WDPM field trip participant.

Most marine fishes and invertebrate species have rather broad geographical distributions that extend outside of South Carolina's jurisdictional boundaries to the north or south and/or offshore, outside of the 3-mile (4.8 km) state territorial limit and in some cases outside the United States EEZ (200 miles) off the coast. Many species—particularly marine and diadromous fishes—are highly migratory, and some occur in state marine waters or federal waters off South Carolina only during portions of the calendar year or during portions of their life cycle. Efficient and effective management of migratory species and species with complicated life cycles is dependent upon management plans that have coverage outside of any individual state's jurisdiction.

American Horseshoe Crabs congregate to spawn along South Carolina Beaches.
Photo by SCDNR-MRD/MRRI staff

Many marine fish species and some invertebrate species—particularly those of recreational and commercial fishery importance—are currently addressed by state and/or federal or regional plans, laws and/or regulations; however, the population status of most species remains poorly understood. Further, the genetic relationships of stocks or sub-populations throughout their distribution are also poorly understood. Understanding such relationships is of utmost importance in the identification of individual management units. In general, existing management does not identify individual management units, but attempts to establish a framework for managing commercial and recreational harvest as a surrogate to population management to prevent excessive directed fishing mortality over a broad geographic range. Many management plans identify potential threats and conservation actions to mitigate such threats, but plans do not include sufficient links to funding needed to provide comprehensive population-based management by specific stocks or management units.–

Challenges

There are a number of challenges to marine fishes and invertebrates; however, it is difficult to assess the degree to which each species is vulnerable until habitat associations, population trends, and distributions are better understood. In some cases, regional management organizations (South Atlantic Fisheries Management Council, Atlantic States Marine Fisheries Commission) are currently conducting stock assessments to determine the health of the populations.

One of the major challenges to marine organisms in South Carolina is the degradation and loss of habitat. As rapid human population growth, coastal development, and urbanization occur along the coast, marshes, beaches and water bodies are altered in ways that change both the topography and hydrology of coastal systems. Removing riparian vegetation can result in siltation and increases in nutrient and pollutant loading.

Habitat loss can affect all life stages of marine organisms. Salt marsh is an extremely productive habitat and is often used by juvenile stages of both fishes and invertebrates. Degradation of this habitat would be especially detrimental to marine organisms. Coastal development continues to encroach upon salt marshes in South Carolina. Habitat alterations in marine waters also include damage resulting from trawling, dredging, and the disposal of dredged material. These types of habitat alterations are particularly detrimental to benthic fishes and invertebrates.

All marine organisms are affected to some degree by water quality. Industrial and municipal sewage discharge along with runoff from agriculture, golf courses, and suburban developments negatively affect Tarpon (*Megalops atlanticus*) and other estuarine fishes. Stormwater runoff from developed areas contains sediment, nutrients, and contaminants. These substances can substantially degrade water quality. Sedimentation can impair the ability of many marine organisms to feed. Eutrophication can result in harmful algal blooms (HABs) that substantially reduce dissolved oxygen in the water. Chemical pollution (PCBs, mercury, etc.) can be detrimental to all species; but can be particularly detrimental to benthic species, even in small amounts. Some species, such as fiddler crabs, have been shown to bioaccumulate contaminants; bioaccumulation can result in contamination being passed up the food chain. Another species also affected by benthic contaminants is the Southern Flounder (*Paralichthys lethostigma*), a bottom-dweller.

Several marine fishes may be adversely affected by fishing pressure. Many marine fishes are not managed as either commercial or recreational species but are targeted by recreational fishermen. If left unchecked, such fishing pressure can reduce population abundances. Many species of finfish and invertebrates are harvested as by-catch in commercial fishing operations. Even if alive when discovered and released, many animals can die due to stress or physical damage sustained during harvest. Some of South Carolina's priority species, such as Sheepshead (*Archosargus probatocephalus*), are often caught as by-catch.

SCDNR's Marisa ValeCruz tags Atlantic Blue Crabs for a SC Sea Grant Consortium-funded project that will help researchers learn more about the species' movement patterns within the Charleston estuary. Photo on left by Hailey Murphy, SC Sea Grant Consortium; photo of crab on right by SCDNR-MRD/MRRI staff.

Unregulated harvest threatens some marine species. For example, South Carolina does not currently regulate a commercial Cannonball Jellyfish fishery. This species is a major component of endangered sea turtles' diets; however, this fishery does exist in other portions of the cannonball's range. Asian countries are developing fisheries management plans to conserve jellyfish because populations are unstable or declining due to pollution, overfishing, or climate

change. Consequently, dealers are looking for new sources of jellyfish (Hsieh et al. 2001). Interest in Cannonball Jellyfish from the United States increased recently because of high consumer demand in Asia (Hsieh et al. 2001). Rising demand in Japan and Southeast Asia may create an international market for Cannonball Jellyfish from South Carolina coastal waters. Likewise, some marine species are collected for the aquarium trade; many of these collections are also unregulated.

Non-native invasive species also have the potential to negatively affect native populations of marine finfish and invertebrates either directly (through predation or the transmission of disease), or indirectly (through competition for resources, such as food and space). On an ecosystem level, the introduction of non-native species is one of the major causes of decreased biodiversity (*e.g.* Molnar et al. 2008). Examples of introduced marine organisms include the Indo-Pacific Lionfish (*Pterois volitans/miles*) and the Asian Tiger Shrimp (*Penaeus monodon*).

Non-native, invasive Lionfish in a South Carolina reef.
Photo by SERFS survey personnel.

As the climate changes and becomes warmer, oceans are warming and becoming more acidic. Stressed by these environmental conditions, marine fish and invertebrates may experience decreases in reproductive success. Further, outside the long-term warming trend, incidences of marine heatwaves may have an outsized effect on stock productivity if it leads to increases in natural mortality and/or declines in productivity. Additionally, parasite loads on fish may increase. It is also expected that with climate change and increased temperatures, some species will increase their geographic range northwards in a phenomenon known as 'Caribbean creep' with such range expansions and/or contractions now becoming common. The outcome of the interactions between these new invaders and native communities are difficult to predict but based on precedents have the potential to be negative.

Conservation Opportunities

The numbers of marine species—both fishes and invertebrates—that can be found within the boundaries and/or jurisdiction of South Carolina is vast. Prior to beginning the process of preparing South Carolina's conservation strategy, lists for these taxonomic groups did not exist. Development of completed species lists for these taxa represent a major accomplishment for the SCDNR. Opportunities exist for further study of life histories, genetics, habitat usage, threats and stressors for these species.

Conservation opportunities for marine fishes and invertebrates varies depending on the aquatic system(s) used by individual species. This is in respect to both the types of marine water used (estuarine, coastal, open ocean) as well as the portion (e.g. benthic, mid-water, surface) of water column used. As such, the techniques used to conserve species of greatest conservation need

must be able to adapt to the different challenges imposed and the opportunities afforded in specific systems and habitats.

Often the most readily apparent conservation opportunity are techniques designed to mitigate habitat loss and degradation in estuarine and coastal ocean environments. This is particularly important to species reliant on benthic or highly structured habitats often associated with salt marshes and/or intertidal oyster reefs. These habitats are often those most immediately impacted by local development and shoreline hardening. While it is unlikely coastal development will significantly slow or stop in the near-term, techniques such as the promotion of the use of living shorelines *in lieu* of bulkheads and sea walls to control coastal erosion and the enforcement and use of riparian buffers along coastal properties are of great benefit. Further, the direct acquisition and/or placement of conservation easements on adjacent upland areas restricting development should be promoted. This is particularly important when considering the impacts of sea level rise and its potential impacts to coastal South Carolina salt marsh habitats. Historically, South Carolina's salt marshes adapted to sea level rise by migrating inland or through sediment accretion that increased their elevation in step with rising sea levels. These processes are reliant on having the upland space to be able to migrate naturally or sufficient sediment supplies to the localized area to support accretion rates sufficient to offset sea level rise.

Opportunities also exist to promote the development and rebuilding of intertidal oyster reefs throughout coastal South Carolina. Oyster reef habitats are used by many marine fish and invertebrates identified as species of greatest conservation need during at least portions of their life stage. Further, fringing oyster reefs act as a natural buffer to coastal South Carolina salt marshes, reducing erosion rates due to wave action and coastal storms. Research suggests that appropriate substrate, not oyster spat recruitment, is often the limiting factor controlling the placement, size, and rate of expansion/contraction of oyster reefs in appropriate habitats along coastal South Carolina. As such, programs promoting the responsible harvest of oysters along the coast, the recovery and placement of harvested shell back into estuarine waters, and construction of alternative substrates for oyster spat recruitment should be a high priority. This should be coupled with ongoing research on techniques and materials most suitable for the creation and expansion of oyster reefs in different estuarine environments.

Beyond habitat loss and habitat degradation, an additional major concern facing marine finfish and invertebrates are declines in water quality. While there are local drivers impacting water quality, such as nutrient runoff leading to eutrophication of estuarine waters, tackling this driver is much more nebulous than direct habitat loss owing to the impacts of local development coupled with the upstream impacts affecting freshwaters throughout the State. This implies a concerted effort must be made to work with both local and upstream watershed municipalities to implement sound management plans with respect to waste water treatment including both sewer and septic systems, ground water and surface water withdrawals, proper application of riparian buffers in both agricultural and urban areas, and upstream impoundment flow regimes. Each of these can lead to declines in estuarine and coastal ocean water quality, whether it be the effects of saltwater intrusion, due to altered riverine flows, groundwater/surface withdrawals, changing riverine flow regimes, or the effects of eutrophication leading to lower dissolved oxygen and harmful algal blooms due to nutrient inputs both locally and upstream through agricultural and development practices.

Related to degradation in water quality, all marine systems are currently threatened because of the impacts of contaminants of emerging concern. Such contaminants of emerging concerns include per- and polyfluroalkyl substances (PFAS), micro- and nanoplastics, marine debris, estrogen-like compounds, and water soluble pharmaceuticals. While some of these, like PFAS, are likely to impact more benthic-dominated food webs, evidence suggests many can affect a wide range of marine habitats ranging from estuarine benthic habitats to offshore pelagic habitats. As in many cases, these are emerging threats so research is needed to investigate the potential impacts on marine fish and invertebrates and to assess the fate of these compounds in aquatic ecosystems. Such information is critical for conducting ecological risk assessments and ultimately understanding potential human health impacts. At the same time, it is imperative we work with local and regional municipalities, governments, and agencies to mitigate the impacts and sources of these contaminants to marine environments through sound policy and enforcement of such policies.

Climate change, and its resultant impacts on the productivity and spatial distribution of marine finfish and invertebrates is another conservation opportunity to highlight. One aspect of the impacts of climate change was discussed previously concerning habitat degradation and loss due to sea level rise. Beyond that, climate change is set to pose a more insidious threat to marine environments through long-term changes in temperature and salinity patterns, the more acute effects of marine heatwaves, and predicted increases in climate variability along coastal South Carolina. While long-term changes in temperature and salinity patterns may be overcome for some non-sessile organisms by their ability to move, this inevitably will lead to species range expansions and hence conflicts with native species, the consequences of which are hard to predict. Such range expansions are already occurring, with several sub-tropical species (e.g. Common Snook, Atlantic Tripletail, Tarpon) typically rare in South Carolina becoming more abundant and competing with native species. At the same time, increasing ocean temperatures and changing salinity patterns are leading to phenological shifts in the timing of ecological events (e.g. spring phytoplankton blooms) likely to affect the productivity of higher trophic levels. More insidious is the effects of marine heatwaves and increased intensity of storms and their long-term effects on marine ecosystems and productivity of SGCN. In both cases, the impacts of relatively short—but highly abnormal—thermal and precipitation patterns may have a more direct effect on marine systems through higher natural mortality, altered spawning behaviors, or decreases in natural ecosystem productivity. Such effects are becoming more evident, with one example being the effect of intense precipitation events during and after the Red Drum spawning season can have on recruitment. While it will not be possible to halt the effects of climate change, studies are needed to better understand and predict its effects on coastal South Carolina marine finfish and invertebrates of greatest conservation need.

A unique conservation opportunity for marine finfish and invertebrates relative to many of the other species identified in this document is our ability to address the direct removals of these organisms from the environment through human harvest. Unlike many of the other organisms identified, many marine species still support commercial, recreational, and subsistence fisheries with commercial and subsistence fisheries (either fish or invertebrates) being one of the last large-scale wild sources of meat protein to feed the human population. In contrast, most wild populations of terrestrial and freshwater organisms no longer support the bulk of the protein need

for humans with the primary terrestrial and freshwater sources being derived from farming activities (e.g. poultry farms, cattle farms, freshwater aquaculture). While it is unlikely interactions of these organisms via fisheries will disappear, there is the opportunity to work at the local, state, regional, and national level to address overfishing of these resources and to adapt these fisheries due to changes in ecosystem productivity. To this end, we need research to evaluate the impact fisheries have had on these resources and ecosystems historically, the socio-economic impacts of the current fisheries, the historical and future effects of traditional (e.g. harvest controls) and non-traditional (e.g. effort controls, ecosystem-based controls) management strategies, and management in the face of changing ecosystem productivity.

Finally, building upon the long history of stock enhancement research conducted by SCDNR, the role of population augmentation as both a conservation tool and research tool for marine finfish and invertebrates and needs continued evaluation. As a conservation tool, such population augmentation can be used to offset the effects of some of the other challenges facing marine finfish and invertebrates, whether it be to offset the impact a marine heatwave or intense storm has on the productivity of an individual species or ecosystem in a given year or as a long-term restoration tool for a distinct population segment. Such historic examples include stock enhancement programs for Cobia and Spotted Seatrout, the latter to assist rebuilding a severely over-exploited distinct population segment and the former to offset the effects of high mortality during winter marine cold spells where water temperatures drop below lethal temperatures. Care must be taken to undertake any such stock enhancement using a responsible approach, and the overall goals and risks involved should be considered prior to any action to ensure the desired outcomes. As a research tool, stock enhancement and population augmentation can be used to investigate the effect climate change, marine heat waves, changing weather intensity and precipitation patterns, and water quality are likely to have on wild populations so that we can better predict their future impacts. For over 20 years, we have been using such approach to investigate the recruitment of Red Drum throughout coastal South Carolina, although many more questions both within and external to this species still need to be addressed.

Some of South Carolina's most iconic species are in the SWAP, including whelks and other shelled species beachgoers find along the shore. Photo by Anna Smith, SCDNR.

Insects and Allies

Insects, along with other terrestrial invertebrates, are the planet's most species-rich group of organisms. They exist in almost every terrestrial ecosystem conceivable, absent only from the extreme heat of volcanic vents and permanently frozen polar icecaps. Despite their prevalence, they are relatively poorly known compared to other taxonomic groups. Their small size often

renders them inconspicuous and generally unremarkable to the casual observer, yet their presence on this planet has a profound influence on all other life forms. Their complex life cycles and seemingly endless diversity make basic identification and taxonomy challenging, even for skilled entomologists. The task of developing conservation strategies for this group of animals is further complicated by their understudied life histories and habitat needs.

The actual number of insect species is unknown. Of the estimated 2 million named species, approximately 1 million are insects (Roskov et al. 2024). Erwin (1983), through work conducted in tropical forests, estimated that at any one time there are approximately 10 quadrillion (10,000,000,000,000,000) individual insects alive, representing as many as 30 million species (Erwin 1997). More recent analysis of taxonomic data has further refined the estimate to approximately 5.5 million species of insects, not including another possible 1.5 million species of non-insect arthropods (Mora et al. 2011, Stork 2017). There are debates about what estimates are correct, but even at the lowest estimates, as much as 80% of the world's entomofauna remain unknown to science. Despite the lack of resolution about the number of total species on Earth, data consistently show that insects are the single largest component of world biodiversity and a major component of animal biomass.

Insects and their allies (related arthropods) are an extremely important taxa group for their roles in pollination, natural pest control, and decomposition (deMaynadier et al. 2024). In South Carolina, invertebrates such as mussels are considered "wildlife" in state statute; therefore, by extension of that definition, insects and their allies are also animals falling into the "wildlife" category. For this edition of the SWAP, even though most of the insects are data deficient, there was at least a knowledge base in place for 42 distinct groups to be considered eligible SGCN with at least one member in each. Having insects and related species included in the South Carolina SWAP provides visibility and encourages research and management efforts (deMaynadier 2024) for this huge base of the food web and both terrestrial and aquatic ecosystems.

Challenges

Some challenges for insect conservation are similar to those faced by plants and other animals. Degradation of habitat through land use changes, exotic and invasive species introductions, urban sprawl, and hydrologic modification such as dredging and dam construction alter insect communities, often resulting in reduced species richness. A factor that will have unpredictable effects on insect ecology is a changing climate. While some studies indicate increasing biomass and species richness of insects across an increasing temperature gradient (Welti et al. 2022), changes in plant communities, soil conditions, and associated natural forages will ultimately alter insect assemblages at local scales (Outhwaite et al. 2022). Insects also suffer from introductions of novel pathogens (Vilcinskas 2019), but our extremely poor understanding of pathology in native insect populations makes it impossible to determine the degree to which novel diseases will affect insect conservation (Flaminio et al. 2022).

Insect conservation differs from conservation of vertebrates and some marine animals in two very distinct ways. One is that direct "take" by humans generally has no measurable effect on populations. While there are rare exceptions, such as tropical butterflies where commercial harvest may be profitable, insects are not generally harvested from the wild for consumption or

profit in South Carolina. On the contrary, most insect species are under-collected and underrepresented in museum collections. Collecting and cataloguing insects for monitoring and scientific purposes will almost certainly benefit the conservation of this diverse but understudied group of animals.

The second distinct threat that insects face is widespread and expanding use of pesticides, which generally has a much lower acute effect on vertebrate populations. While pesticide related impacts are reported in vertebrates—especially among amphibians and fishes—the general effects of pesticide exposure to these larger organisms tend to be sublethal in nature and affect populations in inconspicuous ways. Exposure of insects to these compounds has immediate and measurable negative affects, which is understandable because many commonly used active ingredients specifically target arthropods (insecticides and miticides). Still other widely used compounds that do not target arthropods specifically—such as herbicides, fungicides, and adjuvants—have indirect impacts to insect populations by eliminating host plants, natural forages and nesting sites as well as impeding insect development, altering behavior, and reducing immunity to natural stressors (Bartling et al. 2024).

A variety of insects are displayed in museum drawer. Photo by Clemson University Entomology Department.

While insects face numerous perils, one of the greatest challenges to invertebrate conservation is the relative scarcity of entomologists dedicated to studying this diverse group of animals. Robert May (2010) noted that while invertebrates comprise at least 90% of named species, only one-third of professional taxonomists specialize in invertebrates. Thus, the fundamental task of describing and naming insect species, or simply the ability to identify them accurately, is lacking and probably will be for the foreseeable future until greater emphasis is placed on training skilled entomologists. The SWAP should incentivize academic institutions and funding agencies to prioritize describing and naming insects, determining their evolutionary relationships, and studying their life histories, empowering conservationists to infer the unknown from that which is known.

There have been some positive trends that allow for a better understanding of insect diversity. Molecular analysis is improving our understanding of the evolutionary relationships among insects, their functions, and their habits. These genetic analytical tools are already helping to refine and rearrange even higher taxa within the arthropods. The advancement of computer technology and digitizing arthropod collections now enables the cataloguing and sharing of data with greater speed and efficiency. Confocal imagery is improving photographic detail and records of diagnostic characters, and geospatial tools such as mapping and global information systems (GIS) that are accessible online have revolutionized the tracking and recording of where species occur. Computing technology has become so advanced that mobile devices now have applications, such as iNaturalist, that are capable of recording images, geospatial data, and—through artificial intelligence—assisting with identification of organisms. This opens the collection and sharing of insect occurrence data to conservationists and citizen scientists that are not specifically trained entomologists, which greatly expands the data set for understanding where insects are observed and their phenologies.

Conservation Opportunities

Because the insects contain such a vast number of species, conservation of this group is daunting. Each species has unique habitat needs and phenologies. Many insects, as in the case of some dragonflies or cicadas, may require years to complete development, whereas others, such as aphids or midges, can complete their entire life cycle in a matter of days. Some insects are generalists, thriving in several ecosystems or on numerous hosts, while others are specialists, requiring very specific nesting sites or hosts to reproduce and finish development. A comprehensive statewide conservation strategy for native insects would require developing an action plan for each species, which is not feasible for the reasons already discussed. For this reason, the South Carolina SWAP must focus on certain taxa or life habits that, through their conservation, will benefit the widest swath of species.

An Eastern Tiger Swallowtail, State butterfly of South Carolina, visits a native Buttonbush. Photo by Anna Smith, SCDNR

Aquatic macroinvertebrates have long been used as indicators of water quality. Their sensitivity to hydrological changes, sediments, and pollution among the numerous species of aquatic invertebrates provides a method for monitoring the health of freshwater ecosystems and watersheds. Sensitive taxa such as the stoneflies (Plecoptera), mayflies (Ephemeroptera), and caddisflies (Trichoptera), among others, deserve conservation attention. Their presence in the environment is a principal measure of the suitability of water resources to other organisms, so conservation of these insects and the streams and bodies of water where they live has a profound influence on the conservation of organisms throughout the watershed.

In a similar manner, pollinating insects serve as biological monitors of terrestrial environments. Approximately ¾ of the plant species in South Carolina are Angiosperms (flowering plants), most of

which rely on insect pollination for sexual reproduction. This coevolutionary relationship is over 100 million years in the making, to the extent that the long-term survival of most plant species in the State is directly dependent on the insects that visit their flowers. Pollinators are worthy of attention also because they forage over relatively large areas compared to other insects. While some invertebrates, such as springtails (Collembola) who spend their entire life in a single meter of leaf litter, or scale insects (Coccomorpha) which may spend their entire life on a single plant, pollinators traverse the landscape moving through different environments and ecosystems seeking food and nesting sites. In so doing, they expose themselves to pollutants and to changes in those environments. Their occurrences provide an indirect measure of the effects of changing land uses, invasive species, chemical pollutants, and alterations in local climates. Removal of either their forage plants or their nesting sites or exposure to chemical toxins or harsh climatic conditions results in their removal from the ecosystem which ultimately affects the plants they pollinate and the animals that rely on them for food. In particular, the bees, which include hundreds of native species in six families collectively called the "Anthophila" (a.k.a. pollen lovers), are the most efficient pollinators of most groups of native plants. Because bees rely specifically on pollen as their primary source of protein, they are particularly sensitive to the distribution and condition of their host plants in the landscape. Conservation of the bees through expanding suitable habitat and natural forages as well as reducing pesticide exposure ultimately benefits a wider array of pollinator species and the animals and plants that rely on them and their ecosystem services.

A few individual insect species and easily recognizable groups of species deserve conservation attention because of their influence on public awareness. The South Carolina state insect is the Carolina Mantid, *Stagmomantis carolina*. This relatively large and charismatic insect is widely considered to be a beneficial predator which exhibits intriguing behaviors. Fireflies (Lampyridae) also garner public attention through ecotourism by their conspicuous behavior of bioluminescence (e.g. Blue Ghost Firefly tours across the Blue Ridge Ecoregion and the annual Synchronous Fireflies Event at Congaree National Park and Audubon's Firefly Nights at Beidler Forest in the Coastal Plain). Once common across the State, these easily recognizable beetles are becoming rare in many areas and drawing attention to the impacts of pesticide use and light pollution. Finally, certain butterflies (*Rhopalocera* within the Lepidoptera) are easily recognized because of their relatively large size, dramatic colors, and flight patterns. The most iconic species in this group is the Monarch Butterfly, a quintessentially North American species that migrates from Canada across the continental US to Mexico. Because of its interesting migratory patterns where the majority of individuals overwinter in very specific locations such as southern California, Mexico's Sierra Madre Oriental Mountains, and more recently observed in the Lowcountry of South Carolina, this species allows for annual monitoring of the entire population of the species. For several decades, overwintering populations have declined, a trend attributed to the elimination of their host plants

A Snappy Single Sync Firefly (*Photuris frontalis*), a species that can be seen displaying at Congaree National Park in Richland County, SC.
Photo by Xerces Society/Richard Joyce.

(milkweeds, *Asclepias* spp.) across their migratory paths. A hallmark of insect conservation and the power of restoring habitat and raising public awareness, the monarch is rebounding largely through initiatives to replant and protect milkweeds across the continent and the attention it receives through citizen science projects. If conservation initiatives can restore insects such as the Monarch Butterfly, then there is hope that similar attention to other species such as is provided in the South Carolina SWAP will result in more widespread appreciation and conservation of insects in general. Future editions of the SWAP will hopefully see habitat descriptions to accompany the list of SGCN insects and their allies.

Plants

South Carolina boasts about 2,752 native vascular plant species (SCDNR internal data; Weakley et al. 2024). Six of these species occur nowhere else in the world but South Carolina. The State is also rich in bryophytes (mosses, liverworts, and hornworts) and lichens. Precise data are not available, but there are approximately 500-700 bryophytes and over 1,000 lichens in the State. The diversity of plants in the State is much higher than most groups of animals except insects. Over half (56%) of all federally listed species in the United States and its territories (i.e. those listed under the United States Endangered Species Act (ESA) of 1973, as amended) are plants. Diversity of plants is threatened globally. Pimm and Raven (2017) estimate that one fifth of the world's plant species are at risk of becoming extinct in the wild.

The SCDNR recognizes that plants are an important component of the landscape. They provide the foundation for most habitats, are the base of food chains, regulate floods, influence the climate, and many are also of major cultural significance. The conservation status of plants, with so many native species, is also an indicator of statewide environmental problems. In addition, some of South Carolina's SWAP priority species, such as insects, depend upon some of the State's plants of conservation concern for some part of their life cycle. For example, the Ohoopee Dunes Crossidius Beetle's (*Crossidius graham*) host plant is Woody Goldenrod (*Chrysoma pauciflosculosa*), while the Okeefenokee Zale (*Zale perculta*) utilizes Vine Wicky (*Pieris phillyreifolia*). There are many more plant species that are not in peril themselves but should be maintained for the sake of the insects and other animals that rely on them for survival. Monarch Butterflies (*Danaus plexippus*) and other migratory butterflies are highly dependent on Silverling (*Baccharis halimifolia*) as a nectar plant (J.W. McCord, pers. obs. 2003, Urquhart and Urquhart 1976), and Monarchs also depend upon milkweeds (*Asclepias* spp.) as a larval food plant. Maintaining associations such as these are ways to ward off population declines and the need for listing species. The SCDNR therefore is being proactive in the discussion of plant species of concern in this iteration of the SWAP. It has been suggested that the recovery costs for plants may be less than those for vertebrates, so perhaps it is time to start considering their inclusion (Stein and Gravuer 2008). Currently, the federal guidelines for the State Wildlife Grants Program exclude plants from funding. This is because plants are harder to protect on private lands because laws protect plants within South Carolina only if they occur on federal property or if a federal activity on private lands would harm them. There is also the precedent set forth during colonial days that suggests that animals fall under the jurisdiction of the Crown and plants belong to the people (Stein and Gravuer 2008). However, about 31 states have created Acts or state ESA requirements that do cover plants along with animals (Stein and Gravuer 2008, Camacho et al. 2017). South Carolina does not provide legal protection for rare plants.

A 2024 assessment by SCDNR found that of the native vascular plants known to exist in South Carolina, about 48% (1,322 species), are considered as Critically Imperiled, Imperiled, or Rare, and tracked by the agency. This tracking follows guidelines by NatureServe for subnational conservation rankings (S-ranks) (NatureServe 2015) which have been applied to about 82% of the state's native plant species. This indicates the dire state of South Carolina's plant diversity. In fact, 594 species are S1 ("Critically Imperiled"), usually with five or fewer populations and/or small population sizes. An additional 77 species haven't been located in the State in recent years (48 Historical (SH), and 29 Extirpated (SX)).

This SWAP includes 874 species of plants, specifically 843 vascular plants, 16 bryophytes, and 15 lichens, an increase of 163% from the 332 species in the 2015 SWAP. Assignment of plants to the SWAP priorities included a combination of subnational ranks (S-ranks) as delineated by SCDNR, global ranks (G-ranks) as delineated by NatureServe, Federal status under the Endangered Species Act, and presence on the Regional Species List of Greatest Conservation Need (Radcliffe et al. 2023). Neither floristic diversity nor the richness of rare plant species is uniform across the State. Data is not available for all five of the ecoregions defined in the SWAP, but Weakley et al. (2024) and SCDNR internal data show that about 2,276 native species are in the Coastal Plain (which includes the SWAP Coastal Zone and Sandhills), 1,771 are in Piedmont, and 1,439 are in the Blue Ridge. SWAP priority species are richest in the Coastal Plain Ecoregion with 455 species, followed by the Piedmont (303), Blue Ridge (264), Sandhills (250), and Coastal Zone (222). Within the Blue Ridge Ecoregion, Rich Cove Forests have the highest diversity of SWAP plant species (82). Fens and Spray Cliffs (73), Mountain Alluvial Communities (71), and Montane Rock Outcrops and Glades (65) are also rich in rare species, but the habitat with the most "Highest Priority" species is Fens and Spray Cliffs with 11such species. There are also 11 Federally listed/At-Risk species. These Federal species occur in several different habitats, including Southern Appalachian Purple Pitcherplant (*Sarracenia jonesii*), Mountain Sweet Pitcherplant (*Sarracenia purpurea* ssp. *montana*), Swamp Pink (*Helonias bullata*), and White Fringeless Orchid (*Platanthera integrilabia*) in fens, Rock Gnome Lichen (*Cymatoderma caperatum*) on a cliff face, and Persistent Trillium (*Trillium persistens*) in Acidic Cove Forests. Some are fire dependent, such as several of the fen species, and Smooth Purple Coneflower (*Echinacea laevigata*).

Federally Threatened Swamp Pink and a Red Salamander at Ashmore Heritage Preserve in Greenville County, SC. Photo by Mary Bunch, SCDNR, ret.

Within the Piedmont Ecoregion, the communities with the highest diversity of SWAP plant species are Floodplains and Riparian Zones (69) and Basic Mesic Forest (68). There are also nine

Federally listed/At-Risk species. Surprisingly, the next most diverse habitat is Early-Successional Habitats (55) which likely indicates—on one side—the radical disturbance to natural habitats in the Ecoregion, but also to the persistence of sun-loving species that were likely once present in fire-maintained habitats such as Piedmont Prairies and Woodlands. The habitat with the most "Highest Priority" species is Basic Mesic Forest with 10 species.
The Sandhills Ecoregion has the highest diversity of SWAP species within the most common habitat in the zone, Longleaf Pine Sandhill (72), which also has the most "Highest Priority" Species (11). There are also 11 Federally listed/At-Risk species. However, this broad "Longleaf Pine Sandhill" ecosystem classification doesn't capture the variation in the ecosystem, many of the rare species are in habitat subtypes such as "bean dips", edges of wetter habitats, sandstone outcrops, or the deepest xeric sands. Sandhill seeps have the next richest diversity (50) and are also one of the most threatened habitats in the State. They are almost entirely restricted to powerline rights-of-ways, except for small examples on protected lands in Chesterfield and Richland counties.

The Coastal Plain has the highest richness of rare plant species of any ecoregion by far. There are also 16 Federally listed/At-Risk species, the most of any ecoregion. Pine Savannas and Flatwoods have at least 144 SWAP species, followed by Depression Wetlands, and Carolina Bays (109). Early Successional Habitats, with 74 species, are also very diverse, with many of those species found in disturbed habitats along roadsides or other areas such as utility rights-of-ways that are maintained to be free from woody plant encroachment. The habitat with the most "Highest Priority" species is Pine Savannas and Flatwoods with 20 species. In terms of diversity of rare plants, this habitat has more SWAP species and "Highest Priority" SWAP species of any habitat in South Carolina.

A Squirrel Treefrog and Yellow Pitcher Plant demonstrate a mutualist relationship in Lewis Ocean Bay Heritage Preserve, Horry County, SC. Photo by Anna Smith, SCDNR.

The Coastal Zone has the fewest number of SWAP plant species but is also the smallest ecoregion. There are six Federally listed/At-Risk species. The most diverse habitat is Pine Savannas and Flatwoods (54), despite only a fairly small representation, mainly in northern Charleston County. Early Successional Habitats are the next richest with 45, tied with Depression Wetlands. The habitat with the most "Highest Priority" species is Pine Savannas and Flatwoods with 9 species.

Challenges

Threats to plants in South Carolina, both at the species level and ecosystem level, are many. These threats are not unique to the State but shared across the Southeast and the globe. Because plants form the foundation for most of the State's habitats, the threats facing plants mean that those are also threats to the wildlife species that depend on those plant species or habitats. Noss et al. (2020) summarizes these major threat categories and each is discussed below.

Habitat loss, fragmentation, and disruption of functional connectivity. This factor is the biggest challenge to conservation of the State's biodiversity. This has been a long-term problem that started with early European settlement and agricultural activities. Cotton cultivation from ~1820 to 1920 resulted in ecologically devastating changes in the Piedmont Ecoregion because of deforestation and subsequent severe erosion and gullying (Trimble 1974, Galang et al. 2007). This devastated most of the ecoregion's ecosystems, radically altering ecosystem structures and processes. In the Coastal Zone Ecoregion, widespread impoundments of Tidal Freshwater Marsh for rice cultivation in the 18th and early 19th centuries altered most of a once extensive ecosystem along all the State's tidal rivers (Odum 1984). While we have inherited this legacy of landscape changes, the current and future threat is habitat loss due to development. As the State's human population increases, natural areas containing rare species are under constant threat.

Habitat fragmentation isolates species into smaller populations and creates deleterious edge effects. With plants the isolation of species from pollinators and seed dispersers is a major concern (Nayak and Davidar 2010). Disruption of plant-animal interactions will be a challenge that is difficult to overcome. Pollinators and dispersers often have limited travel distances, and they may be absent or have small population sizes in isolated habitat fragments. This results in lower pollination, fruit set, and limited gene flow between populations. Further, populations of pollinating insects between fragments are often limited by pesticide use (Brittain et al. 2010).

Climate change. Alterations of the earth's climates will have a variety of impacts on plant species throughout the State. Wrobleski et al. (2023), in an evaluation of 771 plants listed under the ESA, considered all the species to be threatened by climate change. The increase in temperatures is a major concern, but other factors are also important including sea level rise and changes in precipitation. These could alter physiological responses of plants to their environments, alter ecosystem structures and functions, change flower and fruit phenology, alter plant-animal interactions, and cause cold-sensitive species—including exotic invasive species—to migrate.

Maritime forests and marshes succumb to sea level rise along South Carolina's coast. Photo by SCDNR Marine Resources Staff.

The most urgent threats to South Carolina's rare plants are the impacts of sea level rise. There are 222 SWAP species in the Coastal Zone with four that are listed under the ESA. Schwab (2009) states that "Changes in storm activity that might accompany climate change, coupled with anticipated increases in sea-level rise, are expected to strongly affect low-lying, heavily

developed areas of the coast." Thus, species that occur in sensitive habitats—including Beach Dunes, Maritime Forest, Marsh Hammock, and Tidal Freshwater Marsh—are particularly imperiled. For example, Seabeach Amaranth (*Amaranthus pumilus*) grows only on the foredunes of Ocean Beach habitats and has declined dramatically in the State due to coastal erosion.

As the climate continues to warm while the amount of atmospheric carbon dioxide ($CO_{2)}$ increases, forests will expand and trees will grow more in a given year due to an extended growing season (SCFC 2010). The increased atmospheric CO_2 will benefit some plant species but not others due to the way it is absorbed (C3 versus C4 plants). Palatability and nutritional content of crops and native plants will decline as a result of the increased CO_2 uptake (SCFC 2010). Looking further into the future, drought and increased heat will take its toll, possibly turning forests into open savannahs or grasslands under extreme climate scenarios. With increases in temperature (and therefore milder winters) come the threat of invasion of more non-native exotic plants, timber and crop pests, and emerging diseases (SCFC 2010). Together with increased drought, these stresses are likely to accelerate tree death. As dead and dying trees contribute to the buildup of the litter layer, this material will act as mulch to help retain ground moisture but also serve as potential fuel and thus increase the risk of wildfire. One Southern pine species that is being called the "wonder tree" due to its ability to take the heat is Longleaf Pine (*Pinus palustris*). Not only is it a prime candidate in the Southeast for carbon sequestration efforts, but it is more tolerant to fire, drought, overly wet conditions, beetle infestations, forest pathogens, and hurricane-force winds.

Altered disturbance regimes. Periodic natural disturbances are critical to the formation and maintenance of many habitats. Fire is usually the most important factor in many ecosystems across the State, from all pine-dominated habitats across the State to Piedmont Prairies and Woodlands and even Blue Ridge Ecoregion habitats such as some fens and heaths. Other disturbances can also be important including floods, herbivory, windstorms, and drought. In absence of regular fires, habitats can change quickly causing succession to a woody plant dominated habitat and loss of biodiversity.

Invasive species. "Invasive species" are defined here as plants that have been accidentally or intentionally introduced from parts of the world outside of South Carolina that are reproducing on their own within the State (exotic species) but are also invading natural habitats (invasive species). These invasive species occur throughout all of South Carolina's ecoregions and threaten to disrupt the community composition, structure, and function of a variety of habitats. Exotic plant species, even if not invading natural habitats, may also have adverse impacts on succession of disturbed habitats or on agriculture. Invasive plants are characterized by a combination of traits that make them preadapted to their invaded habitats including their ability to establish, increase quickly, and spread, resulting in outcompeting native species (Gioria et al. 2023).

A total of 130 exotic pest plant species have been identified as posing potential (54) to severe (76) threats to South Carolina's habitats (South Carolina Invasive Pest Council 2024). Serious infestations generally result in a significant loss of biodiversity in impacted areas. According to the South Carolina Exotic Pest Plant Council (2004), approximately 100 million acres in the United States already bear some environmental degradation due to invasive plant species. Recognizing potential threats and generating public awareness and support is the first

step in preventing further spread of invasive plants. Management to recapture sites already affected presents an enormous on-going effort. Aquatic habitats are also affected by noxious weeds, with tremendous removal and control efforts provided by SCDNR, Clemson University, and others. In a combined effort, through the South Carolina Aquatic Invasive Species Task Force (2008), a list of noxious weeds for aquatic and wetland habitats has been developed. Invasive plants, and illegal aquatic plants, are listed in Appendices 3A and 3B, respectively. An example of a common exotic species is Johnson Grass (*Sorghum halepense*) from Eurasia. It is not invasive in South Carolina's natural habitats (i.e. not an invasive species), but is an economic threat to agriculture, has become herbicide resistant, is toxic to grazing animals, and invades early successional habitats (Travlos et al. 2019). An example of one of South Carolina's most problematic invasive species is Chinese Privet (*Ligustrum sinense*) from China. This shrub/small tree was introduced for landscaping in 1852 but by 2008 occupied over 1 million acres in the Southeastern United States. It invades a wide range of forests and other habitats (especially moist), especially alluvial communities. Where it occurs, it changes light regimes, shading out native species while also affecting soil nutrient cycles and soil microbial and fungal communities, altering native plant-animal interactions, and sometimes changing fire regimes, making it very costly to manage (Cash et al. 2020). Human activities, including ornamental uses and human-induced climate change, have caused some species that are native to parts of South Carolina to become invasive outside of their former ranges. For example, the iconic Southern Magnolia (*Magnolia grandiflora*) is now common in natural areas far away from its former narrow range right along the coast.

A patch of Ginseng at Chestnut Ridge Heritage Preserve in Greenville County, SC. Photo by Mary Bunch, SCDNR, ret.

While this discussion so far has dealt only with invasive plants, other exotic or invasive organisms are also threats to the State's habitats and plant species. Feral Pigs (*Sus domesticus*) rooting in natural area are threats to many rare plant species, especially those in wetter soils. Exotic insects have long altered South Carolina ecosystems. Chestnut Blight (*Cryphonectria parasitica*) dramatically changed Appalachian forests including those in the Blue Ridge Ecoregion, eliminating a dominant canopy species by the 1930s. This kind of threat continues; a threat to forest structures in the Coastal Plain is the Redbay Ambrosia Beetle (*Xyleborus glabratus*) from Asia that spreads fungal symbionts in the genus *Raffaelea* that kill bay trees (*Tamala borbonia*, *T. palustris*, *=Persea borbonia*, *P. palustris*) and can harm other members of the Laurel family *(Lauraceae*).

Other factors are also a threat to the State's flora but are not discussed by Noss et al. (2020). These include:

Poaching. Intentional removal of some plant species from the wild is a threat to some plant species including rare ones. Some have been referred to as "game species" in the botanical world—those wild specimens harvested for human use (Stein & Gravuer 2008). Many plants are desired by collectors and harvesters because they are aesthetically pleasing with their foliage colors, patterns, growth habits, and floral components; are novelties for niche collectors, such as carnivorous plants or orchids; are medicinal species such as American Ginseng (*Panax quinquefolius*), or for food, medicine, or natural materials. Unfortunately, it is some of these highly sought-after properties that have put certain plant species at risk from overharvesting and poaching (Stein and Gravuer 2008). Such poaching has been documented on SCDNR properties, such as illegal harvest of Venus Flytrap (*Dionaea muscipula*) (Luken 2005).

Land Management Constraints. Given the suite of challenges detailed above, management of the State's habitats face exhaustive hurdles. There are always financial limitations on what land managers can accomplish, be they government, NGO, or private landowners. Difficulties include staffing limitations, plant species identification (rare and also invasive), and the demands of protecting highly localized populations of rare species that can be dependent on specific soils and microclimates (Stein and Gravuer 2008). With most of the State in private ownership, long-term land protection is lacking.

The most important land management activities to protect the State's habitats and rare plant species are prescribed burning to restore historic fire regimes in fire-dependent ecosystems and the control of invasive plant species. For instance, dormant versus growing season burns in pine forests have markedly different outcomes in regard to understory composition (Roth and Franklin 2009). There is a long list of other land management needs that are often site-specific including restoration of hydrology, revegetation, erosion control, and control of human impacts like foot traffic and poaching.

Federally At-Risk Venus Flytraps are an example of a rare endemic plant species. Photo taken by Anna Smith at Lewis Ocean Bay Heritage Preserve, Horry County, SC.

Legal Protection. There is limited regulatory protection for plants in South Carolina. Only one state law addresses plant protection explicitly. This is SECTION 16-11-590 that makes it unlawful to "cut, collect, break or otherwise destroy the rare Venus Flytrap (*Dionaea muscipula*), or the common, but sensitive, Sea Oats (*Uniola paniculata*)". Attempts have also been made to control harvest of Ginseng (*Panax quinquefolius*), but no bills have made it through the State Legislature. The ESA therefore affords the only other legal protection to the State's plants, but it is limited to those species listed under the Act (22), and only on Federal lands, or otherwise where some Federal action is involved.

Conservation Opportunities

Like most of the animal groups discussed in this SWAP and written in each, the foundation for protecting the State's plant diversity is identification of places with important habitats and their subsequent protection. This protection can take many forms such as acquisition by a government agency or a land trust to a conservation easement on private land. However, this is only the first step in protecting biodiversity. This is for several reasons: 1) all of the habitats in South Carolina have been altered to some degree, and those alterations need to be mitigated; 2) external threats are still faced on protected lands; and 3) regular management always needs to occur such as prescribed burning. There are many conservation opportunities to protect South Carolina's plant life in the long term.

Isolation of habitat fragments from pollinators and seed dispersers can be mitigated to some extent by actions to and outside of the fragment. The most directly controlled by land managers is restoration of and applications of appropriate management techniques. Effective restoration and management can be effective in creating healthy and resilient pollinator populations (Kaiser-Bunbury et al. 2017). More difficult is maintaining health of pollinators and dispersers between fragments. This can be accomplished by reducing pesticide use, maintaining early successional habitats that provide nectar and food resources, and in planting native plant species in landscapes that are also beneficial to the same species guilds.

Rights-of-ways are important sites for plant diversity and the support of pollinator populations and can be important as stepping stones between habitat fragments. They are well known in the Southeast as refugia for many rare plants (Sheridan et al. 1997). Areas such as utility easements or road edges are maintained by utility companies and road managers as sunny, early-successional habitats either with herbicides or by mechanical control. Usually sunny, herbaceous species often thrive in such habitats and can include diverse communities of native plants, some of which are rare. This management can be improved to promote plant and wildlife diversity by carefully restricting woody plant control to times of year that promote, rather than hinder, plant populations so they have time to grow, flower, and set seed. This is best accomplished by limiting management to the dormant season but can be modified depending on which species are present and if they are spring, summer, or fall flowering.

Evans' Reindeer Moss (*Cladonia evansii*) is a rare lichen. Photo taken in Marion County, SC by Anna Smith, SCDNR.

A variety of land management techniques are essential to maintaining diversity of habitats that support diverse plant and rare plant populations. Proper management is essential to not only maintaining habitats and biodiversity, but in making ecosystems and species more resilient to stochastic events and influences of climate change (Saha et al. 2011). Among the most necessary is the use of prescribed fire which is essential to prevent encroachment of woody plant species, but fires also have other effects such as stimulating flowering and promoting seed germination. Management of nuisance plant species,

especially exotic invasive species, is also critical. Control of these species can be accomplished with prescribed fire, mechanical control, and herbicides, or a combination of those techniques. Training is also needed for land managers to identify these plant species and how to control them.

In habitats that have been restored and are being managed, there are opportunities throughout the State for restoration of rare plant populations where populations are either small or have been extirpated. These efforts usually involve a combination of ex-situ conservation collections followed by augmentation or reintroduction. These should follow protocols guided by genetics, ecology, and plant biology and followed by proper site management (Maschinski and Albrecht 2017).

Legal protection would afford additional protective measures to be put in place, but there are challenges to passing laws that are effective. However, efforts should be made to give plants some of the same protection as our rarest wildlife species. Poachable species such as Ginseng (*Panax quinquefolius*), orchids, or carnivorous plants would be better protected by increasing fines for unauthorized collection on both private and public lands. Other legal protections could be approached to give "endangered" and "threatened" status to plants on the state level.

Literature Cited

Aldridge, D. C., & McIvor, A. L. 2003. Gill evacuation and release of glochidia by Unio pictorum and Unio tumidus (Bivalvia: Unionidae) under thermal and hypoxic stress. *Journal of Molluscan Studies*, *69*(1), 55-59.

Allan, J.D. 1995. *Stream ecology: Structure and function of running waters.* Chapman and Hall, London, UK. Bates, B., Kundzewicz, Z., & Wu, S. (2008). *Climate change and water*. Intergovernmental Panel on Climate Change Secretariat.

American Bird Conservancy (ABC). 2013. http://www.abcbirds.org.

American Bird Conservancy (ABC). 2021. How Many Birds Are Killed by Wind Turbines? https://abcbirds.org/blog21/wind-turbine-mortality/. Accessed on <September 10, 2024>.

American Bird Conservancy (ABC). Glass Collisions: Preventing Bird Collisions at Home.https://abcbirds.org/solutions/prevent-home-collisions/. Accessed on <August 29, 2024>.

Askins, R.A. 2001. Sustaining biological diversity in early succession communities: the challenge of managing unpopular habitats. Wildlife Society Bulletin. 29:407-412.

Atlantic States Marine Fisheries Commission (ASMFC). 1985. Fishery management plan for American shad and river herring. Atlantic States Marine Fisheries Commission Fisheries Management Rep. No. 6. 369 pp.

Atlantic States Marine Fisheries Commission (ASMFC). 1990. Fishery management plan for Atlantic sturgeon. Atlantic States Fisheries Commission Marine Fisheries Management Rep. No. 17. 73 pp.

Atlantic States Marine Fisheries Commission (ASMFC). 1999. Amendment 1 to the fishery management plan for shad and river herring. Atlantic States Marine Fisheries Commission Fisheries Management Rep. No. 35. 76 pp.

Atlantic States Marine Fisheries Commission (ASMFC). 2000. Atlantic States Marine Fisheries Commission Interstate Fishery Management Plan for American eel. Fishery Management Report 36. 79 pp.

Atlantic States Marine Fisheries Commission (ASMFC).2002. Addendum I to Amendment 1 and technical addendum #1 to the interstate fishery management plan for shad and river herring. Atlantic States Marine Fisheries Commission. 10 pp.

Atlantic States Marine Fisheries Commission (ASMFC). 2020. American Shad 2020 Stock Assessment Peer Review Report. Arlington, VA USA

Atlantic States Marine Fisheries Commission (ASMFC). 2024. River Herring 2024 Stock Assessment Peer Review Report. Arlington, VA USA

Aust, W.M. and R. Lea. 1991. Soil temperature and organic matter in a disturbed forested wetland. Soil Sci. Soc. Am. J. 55:1741-1746.

Aust, W.M., S.H. Schoenholtz, T.W. Zaebst and B.A. Szabo. 1997. Recovery status of a tupelo cypress wetland seven years after disturbance: silvicultural implications. Forest Ecol. And Man. 90:161-169.

Barges, M. and V. Morris. 2023. "Building Safer Cities for Birds – How Cities Are Leading the Way on Bird-Friendly Building Policy," Yale Bird-Friendly Building Initiative.

Barry, J. 1980. Natural vegetation of South Carolina. University of South Carolina Press. Columbia, South Carolina. 214 pp.

Bart, H.L., M.S. Taylor, J.T. Harbaugh, J.W. Evans, S.L. Schleiger and W. Clark. 1994. New distribution records of Gulf Slope drainage fishes in the Ocmulgee River system, Georgia. Southeastern Fishes Council Proceedings. 30:4-9.

Battaglia, F. M., Beckingham, B. A. and W. E. McFee. 2020. First report from North America of microplastics in the gastrointestinal tract of stranded bottlenose dolphins (*Tursiops truncatus*). Marine Pollution Bulletin 160: 111677. https://doi.org/10.1016/j.marpolbul.2020.111677

Beckvar, N., Salazar, S., Salazar, M., & Finkelstein, K. (2000). An in situ assessment of mercury contamination in the Sudbury River, Massachusetts, using transplanted freshwater mussels (Elliptio complanata). *Canadian Journal of Fisheries and Aquatic Sciences*, *57*(5), 1103-1112.

Benson, A.J., Raikow, D., Larson, J., Fusaro, A., Bogdanoff, A.K., and Elgin, A., 2024. *Dreissena polymorpha* (Pallas, 1771): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=5, Revision Date: 12/21/2023, Access Date: 9/30/2024

Benson, A., Fuller, P., Fusaro, A., Bartos, A., Larson, J., Constant, S., Raikow, D., and Foster, A., 2024b. *Corbicula fluminea* (O. F. Müller, 1774): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=92, Revision Date: 8/1/2024, Access Date: 9/30/2024

Berlanga, H., J. A. Kennedy, T. D. Rich, M. C. Arizmendi, C. J. Beardmore, P. J. Blancher, G. S. Butcher, A. R. Couturier, A. A. Dayer, D. W. Demarest, W. E. Easton, M. Gustafson, E. Iñigo-Elias, E. A. Krebs, A. O. Panjabi, V. Rodriguez Contreras, K. V. Rosenberg, J. M. Ruth, E. Santana Castellón, R. Ma. Vidal, and T. Will. 2010. Saving Our Shared Birds: Partners in Flight Tri-National Vision for Landbird Conservation. Cornell Lab of Ornithology: Ithaca, NY.

Bindoff, N. L., Willebrand, J., Artale, V., Cazenave, A., Gregory, J. M., Gulev, S., ... & Woodworth, P. 2007. Observations: oceanic climate change and sea level.

Birdsong, T.W., G.P. Garrett, M.G. Bean, S.G. Curtis, K.B. Mayes, and S.M. Robertson. 2021. Conservation Status

of Texas Freshwater Fishes: Informing State-based Species Protections. Journal of the Southeastern Association of Fish and Wildlife Agencies 8: 40-52. https://seafwa.org/sites/default/files/journal-articles/J8_06_Birdsong%20et%20al%2040-52_0.pdf

Bogan, A. E. 1993. Freshwater bivalve extinctions (Mollusca: Unionoida): a search for causes. *American Zoologist*, *33*(6), 599-609.

Bogan, A.E. 2001. Extinction wave in the making. Pp.138-139. *In*: The Red Book, The Extinction Crisis Face to Face. A. Bräutigam and M.D. Jenkins, Editors. IUCN. Sierra Madre, California. 309 pp.

Bogan, A.E. and J. Alderman. 2004. Workbook and key to the freshwater bivalves of South Carolina. USDA Forest Service. Columbia, South Carolina. 64 pp. Bohall-Wood, P. and M. Collopy. 1986. Abundance and habitat selection of two American kestrel subspecies in north-central Florida. Auk. 103:557-563.

Bogan, A.E. and J.M. Alderman. 2008. Workbook and key to the freshwater bivalves of South Carolina (Revised Second Edition). i–ii + 1–66 pp. + 5 pls.

Bouchillon, H., Levine, N. S. and P. A. Fair. 2019. GIS investigation of the relationship of sex and season on the population distribution of common bottlenose dolphins (*Tursiops truncatus*) in Charleston, South Carolina. International Journal of Geographical Information Science. https://doi.org/10.1080/13658816.2019.1615068

Bowen, H. J. M., Frevert, T., Grant, W. D., Kratz, G., Long, P. E., & Kratz, G. 1985. Modelling the global carbon cycle. *The Natural Environment and the Biogeochemical Cycles*, 29-81.

Bowles, D.E., K. Aziz, and C.L. Knight. 2000. Macrobrachium (Decapoda: Caridea: Palaemonidae) in the contiguous United States: A review of the species and an assessment of threats to their survival. J. Crustac. Biol 20 (1):158–171.

Brittain, C.A., M. Vighi, R. Bommarco, J. Settele, and S.G. Potts, 2010. Impacts of a pesticide on pollinator species richness at different spatial scales, Basic and Applied Ecology, 11(2):106-115.

Brown, K. M., and C. E. Lydeard. 2010. Mollusca: Gastropoda. Pages 277–307 *in* J. H. Thorpe and A. P. Covich, editors. Ecology and classification of freshwater invertebrates of North America. Elsevier.

Brummett, R.E. and N.C. Alon. 1994. Polyculture of Nile tilapia (*Oreochromis niloticus*) and Australian red claw crayfish (*Cherax quadricarinatus*) in earthern ponds. Aquaculture. 122:47–54.

Buhlmann, K.A. and J.W. Gibbons. 2001. Terrestrial habitat use by aquatic turtles from a seasonally fluctuating wetland: implications for wetland conservation boundaries. Chelonian Conservation Biology. 4(1):115-127.

Burch, J.B. & J.L. Tottenham (1980). North American Freshwater Snails: Species list, ranges and illustrations.

Burkhead, N. M. 2012. Extinction Rates in North American Freshwater Fisheries, 1900- 2010. BioScience 62(9): 79-808.

Burlakova, L. E., Karatayev, A. Y., Karatayev, V. A., May, M. E., Bennett, D. L., & Cook, M. J. 2011. Endemic species: contribution to community uniqueness, effect of habitat alteration, and conservation priorities. *Biological Conservation*, *144*(1), 155-165.

Butler, P.A. 1968. Pesticides in the estuary. Pp 120-124. In: Proceedings of the marsh and estuary management symposium, J.D. Newsom (ed.). Louisiana State Univ. Baton Rouge, Louisiana.

Camacho, A.E., M. Robinson-Dorn, A.C. Yildiz, and T. Teegarden, 2017. Assessing state laws and resources for endangered species protection, Envtl. L. Rep. News & Analysis, 47:10837-10844.

Canright, V.R., A.J. Piaggio, S.M. Chinn, R.M. Giglio, J.M. Craine, and J.C. Beasley. 2023. DNA metabarcoding reveals consumption of diverse community of amphibians by invasive wild pigs (*Sus scrofa*) in the southeastern United States. Scientific Reports 13:20889. https://doi.org/10.1038/s41598-023-48139-9

Carolina Bird Club. Official List of the Birds of South Carolina. Birds of South Carolina (carolinabirdclub.org). Accessed on <August 29, 2024>.

Cash J.S., C.J. Anderson, and W.D. Gulsby, 2020. The ecological effects of Chinese privet (Ligustrum sinense) invasion: a synthesis, Invasive Plant Sci. Manag., 13:3-13.

Cazenave, A., & Llovel, W. 2010. Contemporary sea level rise. *Annual review of marine science*, *2*(1), 145-173.

Cazenave, A., Dieng, H. B., Meyssignac, B., Von Schuckmann, K., Decharme, B., & Berthier, E. 2014. The rate of sea-level rise. *Nature Climate Change*, *4*(5), 358-361.

Cely, J. 2003. The South Carolina breeding bird atlas 1988-1995. South Carolina Department of Natural Resources. Columbia, South Carolina. 305 pp.

Cheng, T.L., Reichard, J.D., Coleman, J.T., Weller, T.J., Thogmartin, W.E., Reichert, B.E. et al. 2021. The scope and severity of white-nose syndrome on hibernating bats in North America. *Conservation Biology*, **35**, 1586–1597.

Cilia G, Flaminio S, Zavatta L, Ranalli R, Quaranta M, Bortolotti L, Nanetti A. 2022. Occurrence of Honey Bee (*Apis mellifera* L.) Pathogens in Wild Pollinators in Northern Italy. Front Cell Infect Microbiol. 2022 Jun 30;12:907489. doi: 10.3389/fcimb.2022.907489. PMID: 35846743; PMCID: PMC9280159.

Claassen, C. 1985. The Shell Button Industry in Appalachia. *THE MANY FACES OF APPALACHIA*, 77

Claassen, C. 1994. Washboards, pigtoes, and muckets: Historic musseling in the Mississippi watershed. *Historical Archaeology*, *28*(2), i-145.

Cohen, A. N., & Weinstein, A. 2001. Zebra mussel's calcium threshold and implications for its potential distribution in North America. *San Francisco Estuary Institute*.

Coker, R. E. 1916. The ultization and preservation of fresh-water mussels. *Transactions of the American Fisheries Society*, *46*(1), 39-49.

Coker, R.E. 1919. Fresh-water mussels and mussel industries of the U.S. *Bulletin of the Bureauof Fisheries* 36:13-89 [issued separately as U.S. Bureau of Fisheries Document 865].

Collins, M., Knutti, R., Arblaster, J., Dufresne, J. L., Fichefet, T., Friedlingstein, P., ... & Wehner, M. 2013. Long-term climate change: projections, commitments and irreversibility.

Collins, M.R., D. Cooke, B. Post, J. Crane, J. Bulak, T.I.J. Smith, T.W. Greig and J.M. Quattro. 2003. Shortnose Sturgeon in the Santee-Cooper reservoir system, South Carolina. Trans. Amer. Fish. Soc. 132(6):1244-1250.

Cooper, J. E. 2011. Giant River Shrimps of the Genus *Macrobrachium* (Decapoda: Palaemonidae) in North and South Carolina. Journal of North Carolina Academy of Science, 127(2), 176-178.

Cooper, J.E. and S.A. Armstrong. 2007. Locality records and other data for invasive crayfishes (Decapoda: Cambaridae) in North Carolina. Journal of the North Carolina Academy of Science. 123(1):1–13.

Cooper, K. 1989. Effects of polychlorinated dibenzo-p-dioxins and polychlorinated ibenzofurans on aquatic organisms. Reviews in Aquatic Sciences. 1(2):227-242.

Covich, A. P., Dye, L. L., & Mattice, J. S. 1981. Crayfish predation on Corbicula under laboratory conditions. *American Midland Naturalist*, 181-188.

Covich, A. P., Palmer, M. A., & Crowl, T. A. 1999. The role of benthic invertebrate species in freshwater ecosystems: zoobenthic species influence energy flows and nutrient cycling. *BioScience*, *49*(2), 119-127.

Cryan, P. M., & Barclay, R. M. 2009. Causes of bat fatalities at wind turbines: hypotheses and predictions. Journal of Mammalogy, 90(6), 1330-1340.

Cushway, K. C., Geist, J., & Schwalb, A. N. 2024. Surviving global change: a review of the impacts of drought and dewatering on freshwater mussels. *Biological Reviews*.

Dakin, W. J. 1913. *Pearls* (Vol. 75). University Press.

Danglade, E., & Eldridge, J. A. 1914. The mussel resources of the Illinois River. *[United States] Bureau of Fisheries. Doc, no. 804*.

Deacon, J.E., G. Kobetich, J.D. Williams and S. Contreras. 1979. Fishes of North America endangered, threatened, or of special concern. Fisheries 4(2): 30-44.

de Kozlowski, S., Page, C., & Whetstone, J. 2002. Zebra mussels in South Carolina: the potential risk of infestation. A report by the Zebra Mussel Task Force. 14 pp.

DeMaynadier, P., M.D. Schlesinger, S.P. Hardy, K. P. McFarland, L. A. Saucier, E.L. White, T. A. Zarrillo, and B. E. Young. 2024. Insect pollinators: The time is now for identifying species of greatest conservation need. *Wildlife Society Bulletin* 2024; e1537.

Denison, C. D., M. C. Scott, K. M. Kubach and B. K. Peoples. 2021. Integrating regional frameworks and local variability for riverine bioassessment. Environmental Management 68: 126-145.

Dillon, R.T., Jr. and colleagues (2019). The Freshwater Gastropods of North America. Internet address: http://www.fwgna.org

Dillon Jr, R. T., & Keferl, E. P. (2000). A survey of the pleurocerid gastropods of South Carolina. In *Proceedings of the First Freshwater Mollusk Conservation Society Symposium* (pp. 153-160).

Drought.gov. South Carolina. https://www.drought.gov/states/south-carolina#historicalconditions. Access date: 9/28/2024.

Dudley, R.G., A.W. Mullis and J.W. Terrell. 1977. Movements of striped bass (*Morone saxatilis*) in the Savannah River, Georgia. Trans. Amer. Fish. Soc. 106(4):314-322.

Eads, C. B., Price, J. E., & Levine, J. F. 2015. Fish hosts of four freshwater mussel species in the Broad River, South Carolina. *Southeastern Naturalist*, *14*(1), 85-97.

Edds, D. R., W. J. Mathews, and F. P. Gelwick. 2002. Resource use by large catfishes in a reservoir: is there evidence for interactive segregation and innate differences? Journal of Fish Biology 60:739–750.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Kadner, S., Minx, J. C., Brunner, S., ... & Zwickel, T. 2014. Climate change: mitigation of climate change. Contribution of working group III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Elkins, D., S.C. Sweat, B.R. Kuhajda, A.L. George, K.S. Hill, and S.J. Wenger. 2019. Illuminating hotspots of imperiled aquatic biodiversity in the southeastern US. Global Ecology and Conservation 19: e00654.

https://www.sciencedirect.com/science/article/pii/S2351989418304451

Ellis, M. M. 1931. *Some factors affecting the replacement of the commercial fresh-water mussels*. US Government Printing Office.

Eversole, A.G. and B.C. Sellers. 1996. Comparison of relative crayfish toxicity values. Freshwater Crayfish. 11:274-285.

Eversole, A.G., J.M. Whetstone and B.C. Sellers. 1996. Handbook of relative acute toxicity values for crayfish. SC Sea Grant Consortium, National Oceanic and Atmospheric Administration. 8 pp.

Faber-Langendoen, D., J. Nichols, L. Master, K. Snow, A. Tomaino, R. Bittman, G. Hammerson, B. Heidel, L. Ramsay, A. Teucher, and B. Young. 2012. NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe. Arlington, VA. Pp. 52. https://www.natureserve.org/sites/default/files/natureserveconservationstatusmethodology_jun12.pdf

Fair, P. A., Adams, J., Mitchum, G., Hulsey, T. C. et al. 2010. Contaminant blubber burdens in Atlantic bottlenose dolphins (*Tursiops truncatus*) from two southeastern US estuarine areas: concentrations and patterns of PCBs, pesticides, PBDEs, PFCs, and PAHs. Science of the Total Environment 408: 1577-1597.

Fatal Light Awareness Program (FLAP) Canada and Mosco, R. 2024. Bird-Building Collision Resources Brochure.

Fisher, G. R., & Dimock Jr, R. V. 1998. Viability of glochidia of Utterbackia imbecillis (Bivalvia: Unionidae) following their removal from the parental mussel. In *Proceeding of the first freshwater mollusk conservation society symposium* (pp. 185-188).

Flather, C. H. and C. H. Sieg. 2013. Species rarity: definition, causes and classification. Pp. 40-66 *In* M. G. Raphael and R. Molina, Eds. Conservation of rare or little-known species: biological, social, and economic considerations. Island Press. 389 pp.

Fogelman, K. J., Archambault, J. M., Irwin, E., Walsh, M., Brewer, S., & Stoeckel, J. A. 2023. A review of lethal thermal tolerance among freshwater mussels (Bivalvia: Unionida) within the North American faunal region. *Environmental Reviews*, *31*(2), 278-297.

Forbes, S. A. 1888. Studies of the food of fresh-water fishes. Bulletin of the Illinois State Laboratory of Natural History 2:433–473.

Freitag, S. and A. S. Van Jaarsveld. 1997. Relative occupancy, endemism, taxonomic distinctiveness and vulnerability: prioritizing regional conservation actions. Biodiversity and Conservation 6: 211-232.

Freshwater Mollusk Conservation Society. (2023). Freshwater Gastropods Name List. Freshwater Mollusk Conservation Society [web application]. Available https://molluskconservation.org/. (Accessed July 14, 2024).

Fuller, S.L.H. 1974. Clams and mussels (Mollusca: Bivalvia). Pp. 215-273. *In:* Pollution ecology of freshwater invertebrates, C.W. Hart, Jr. and S.L.H. Fuller, Eds. Academic Press. New York, New York. 389 pp.

Galang, M.A., D. Markewitz, L.A. Morris, and P. Bussell, 2007. Land use change and gully erosion in the Piedmont region of South Carolina, Journal of soil and water conservation, 62(3):122-129.

Garner, J.T., et al. 1999. Reproductive cycle of *Quadrula metanevra* (Bivalvia: Unionidae) in the Pickwick Dam tailwater of the Tennessee River. *American Midland Naturalist* 141:277-283.

Garner, J. T., & McGregor, S. W. 2001. Current status of freshwater mussels (Unionidae, Margaritiferidae) in the Muscle Shoals area of Tennessee River in Alabama (Muscle Shoals revisited again). *American Malacological Bulletin*, *16*(1-2), 155-170.

Gaston, K. 1994. Rarity. Population and community biology series, vol. 13. Springer, Dordrecht.

Gioria, M., P.E. Hulme, D.M. Richardson, and P. Pyšek, 2023. Why are invasive plants successful?, Annual Review of Plant Biology, 74(1):635-670.

Gordon, N.D., et al. 1992. *Stream hydrology: An introduction for ecologists.* John Wiley, Chichester, UK.

Grist, J. D. 2002. Analysis of a blue catfish population in a southeastern reservoir: Lake Norman, North Carolina. Master's thesis. Virginia Polytechnic Institute and State University, Blacksburg.

Guire, C.R., L.E. Nichols and R.T. Rachels. 1984. Biological investigations of flathead catfish in the Cape Fear River. Proceedings of the Southeastern Association of Fish and Wildlife Agencies. 35(1981):607-621.

Haag, W. R., & Warren, M. L. 2007. Freshwater mussel assemblage structure in a regulated river in the Lower Mississippi River Alluvial Basin, USA. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *17*(1), 25-36.

Haag, W. R., & Williams, J. D. 2014. Biodiversity on the brink: an assessment of conservation strategies for North American freshwater mussels. *Hydrobiologia*, *735*, 45-60.

Haag, W. R. 2012. *North American freshwater mussels: natural history, ecology, and conservation*. Cambridge University Press.

Hart, Jr. and S.L.H. Fuller, eds. Academic Press. New York, New York. 389 pp.

Hastie, L. C., Boon, P. J., Young, M. R., & Way, S. 2001. The effects of a major flood on an endangered freshwater mussel population. *Biological Conservation*, *98*(1), 107-115.

Hester, E. T., & Doyle, M. W. 2011. Human impacts to river temperature and their effects on biological processes: A quantitative synthesis 1. *JAWRA Journal of the American Water Resources Association*, *47*(3), 571-587.

Hobbs, H.H. Jr. 1981. The Crayfishes of Georgia. Smithsonian Contributions to Zoology. 318. 549 pp.

Hobbs, H.H. Jr. and E.T. Hall, Jr. 1974. pages 195-214. *In*: Pollution ecology of freshwater invertebrates, C.W.

Hobbs, H.H. III, J.P. Jass and J. V. Huner. 1989. A review of global crayfish introductions with particular emphasis on two North American species (Decapoda, Cambaridae). *Crustaceana*. 56(3): 299-316.

Hocutt, C.H., R.E. Jenkins, and J.R. Stauffer, Jr. 1986. Zoogeography of the fishes of the central Appalachians and central Atlantic Coastal Plain. Chapter 6. Pp. 161-211 In Hocutt, C.H. and E.O. Wiley (eds.). The zoogeography of North American freshwater fishes. Wiley and Sons, New York, NY.

Holthius, L.B. and A.J. Provenzano, Jr. 1970. New distribution records for species of *Macrobrachium* with notes on the distribution of the genus in Florida. *Crustaceana* 21(3):211-213.

Houde, M., Pacepavicius, G., Darling, C., Fair, P. A., et al. 2009. Polybrominated diphenyl ethers (PBDE) and hydroxylated polybrominated dipheyl ethers (OH-OBDE) in plasma of bottlenose dolphins (*Tursiops truncatus*) from the US east coast. Environmental Toxicology and Chemistry 28: 2061-2068.

Huff, L., Delos, C., Gallagher, K., & Beaman, J. 2013. Aquatic life ambient water quality criteria for ammonia-freshwater. *Washington DC: US Environmental Protection Agency*.

Hulme, P. E. 2005. Adapting to climate change: is there scope for ecological management in the face of a global threat? Journal of Applied Ecology 43:617-627.

Imlay, M.J. 1972. Greater adaptability of freshwater mussels to natural rather than to artificial displacement. *Nautilus* 86:7-79.

Intergovernmental Panel on Climate Change (IPCC). 2018. Global warming of 1.5 °C. In: Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T (eds). An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

International Renewable Energy Agency (IRENA). 2022. Renewable Energy Statistics 2022. IRENA. www.irena.org/publications/2022/Jul/Renewable-Energy-Statistics-2022

Jelks, H. L. et al. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33(8): 372-407.

Jenkins, R.E., and N.M. Burkhead. 1994. Freshwater fishes of Virginia. American Fisheries Society. Bethesda, MD. 1080 pp.

Johnston, M. O., Das, B., & Hoeh, W. R. 1998. Negative correlation between male allocation and rate of self-fertilization in a hermaphroditic animal. *Proceedings of the National Academy of Sciences*, *95*(2), 617-620.

Johnson, N. A., Schofield, P. J., Williams, J. D., & Austin, J. D. 2018. Salinity tolerance among three freshwater mussels (Bivalvia: Unionidae) from Gulf Coastal Plain drainages. *Florida Scientist*, *81*(2-3), 61-69.

Johnson, P. D., Bogan, A. E., Brown, K. M., Burkhead, N. M., Cordeiro, J. R., Garner, J. T., ... & Strong, E. E. (2013). Conservation status of freshwater gastropods of Canada and the United States. Fisheries, 38(6), 247-282.

Kaiser-Bunbury, C.N., J. Mougal, A.E. Whittington, T. Valentin, R. Gabriel, J.M. Olesen, and N. Blüthgen, 2017. Ecosystem restoration strengthens pollination network resilience and function, Nature, 542(7640):223-227.

Kat, P. W. 1983. Sexual selection and simultaneous hermaphroditism among the Unionidae (Bivalvia: Mollusca). *Journal of Zoology*, *201*(3), 395-416.

Keller, A. E., & Zam, S. G. 1991. The acute toxicity of selected metals to the freshwater mussel, Anodonta imbecilis. *Environmental Toxicology and Chemistry: an International Journal*, *10*(4), 539-546.

Kendrick, M. R., Walker, M. J., Scott, E. U., Huber, J. H., Roy, M. B., Williams, B. W., ... & Darden, T. L. 2024. Characterising dispersal and potential impacts of non-native red swamp crayfish (*Procambarus clarkii*) populations in the coastal plain region of the pee Dee River basin, USA. Freshwater Biology.

Kendrick, M. R., & Williams, B. W. (In Review). An integrative taxonomic assessment leads to the synonymy of the Waccamaw Crayfish *Procambarus braswelli* Cooper 1998 with the Cedar Creek Crayfish *Procambarus chacei* Hobbs 1958 (Decapoda: Cambaridae).

Kneeland, S. C., & Rhymer, J. M. 2008. Determination of fish host use by wild populations of rare freshwater mussels using a molecular identification key to identify glochidia. *Journal of the North American Benthological Society*, *27*(1), 150-160.

Knott, W. J. 1980. The pearl button industry and its impacts on Mississippi river mussel fauna. In: *Proceedings of the UMRCC Symposium on Upper Mississippi River bivalve mollusks. La Crosse, Wisconsin: Upper Mississippi River Conservation Committee.*

Kohlsaat, T., L. Quattro and J. Rinehart. 2005. South Carolina Comprehensive Wildlife Conservation Strategy 2005–2010. South Carolina Department of Natural Resources. i–viii + 1–287 pp.

Krzewinski, M. M., McFee, W. E. and R. F. Young. 2024. Spatial and temporal trends of Tamanend's bottlenose dolphin (Tursiops erebennus) strandings in South Carolina, USA, 2006-2020. Journal of cetacean Research and Management 25: 31-48.

Kuehnl, K.F. 2009. Exploring levels of genetic variation in the freshwater mussel genus Villosa (Bivalvia: Unionidae) at different spatial and systematic scales: implications for biogeography, taxonomy, and conservation. Unpublished Ph.D. Dissertation, Ohio State University, Columbus.

Kunz, G. F. (1898). *The fresh-water pearls and pearl fisheries of the United States*. US Government Printing Office.

Kunz, T. and M. Tuttle. 2009. White-nose syndrome science strategy meeting II., Austin, TX. http://www.batcon.org/pdfs/whitenose/WNS2FinalReport.pdf.

Kynard, B. 1997. Life history, latitudinal patterns, and status of shortnose sturgeon. Environ. Biol. Fish. 48:319-334.

Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., ... & Wilcox, L. J. 2021. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. *Atmospheric environment*, *244*, 117834.

Limm, M. P., & Power, M. E. 2011. Effect of the western pearlshell mussel Margaritifera falcata on Pacific lamprey Lampetra tridentata and ecosystem processes. *Oikos*, *120*(7), 1076-1082.

Litzgus, J.D. and T.A. Mousseau. 2004. Demography of a Southern Population of the Spotted Turtle (Clemmys guttata). *Southeastern Naturalist,* Vol. 3, No. 3, pp. 391- 400

Lockaby, B.G., R.H. Jones, R.G. Clawson, J.S. Meadows, J.A. Stanturf and F.C. Thornton. 1997. Influences of harvesting on functions of floodplain forests associated with low-order, blackwater streams. Forest Ecol. and Man. 90:217- 224.

Lodge, D.M., M.W. Kershner, J.E. Aloi and A.P. Covich. 1994. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. Ecology. 75(5):1265-1281.

Lodge, D.M., C.A. Taylor, D.M. Holdich and J. Skurdal. 2000a. Nonindigenous crayfishes threaten North American freshwater biodiversity: lessons from Europe. Fisheries. 25(8):7-20.

Lodge, D.M., C.A. Taylor, D.M. Holdich and J. Skurdal. 2000b. Reducing impacts of exotic crayfish introductions: new policies needed. Fisheries. 25(8):21-23.

Lopes-Lima, M., Burlakova, L. E., Karatayev, A. Y., Mehler, K., Seddon, M., & Sousa, R. 2018. Conservation of freshwater bivalves at the global scale: diversity, threats and research needs. *Hydrobiologia*, *810*, 1-14.

Loss, S.R., T. Will and P.P. Marra. 2013. The impact of free-ranging domestic cats on wildlife in the United States. Nature Communications 4, Article number 1396. (www.nature.com/ncomms/journal/v4/n1/full/ncomms2380.html)

Loss, Scott & Will, Tom & Loss, Sara & Marra, Peter. (2014). Bird–building collisions in the United States: Estimates of annual mortality and species vulnerability. The Condor. 116. 8-23. 10.1650/CONDOR-13-090.1.

Luken, J.O., 2005. Characterizing Illegal Harvest of the Venus' Fly Trap (Dionaea muscipula Ellis) at Lewis Ocean Bay Heritage Preserve, South Carolina, USA, Natural Areas Journal, 40(3):204-204.

Mace, G.M., H.P. Possingham, N. Leader-Williams. 2006. Prioritizing choices in conservation. Pp. 17-34 *In* Macdonald, 2006. Key Topics in Conservation Biology.

https://www.cpsg.org/sites/cbsg.org/files/documents/prioritizing%20choices%20in%20conservation1.pdf

Malish, M. C., & Woolnough, D. A. 2019. Varied physiological responses of Amblema plicata and Lampsilis cardium exposed to rising temperatures. *Freshwater Science*, *38*(4), 842-855.

Maschinski, J. and M.A. Albrecht, 2017. Center for Plant Conservation's Best Practice Guidelines for the reintroduction of rare plants, Plant Diversity, 39(6):390-395.

Master, L. L., D. Faber-Langendoen, R. Bittman, G. A. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe. Arlington, VA. Pp. 76. https://www.natureserve.org/sites/default/files/natureserveconservationstatusfactors_apr12.pdf

Mathews, T.D., F.W. Stapor, Jr., C.R. Richter, J.V. Miglarese, M.D. McKenzie and L.A. Barclay, eds. 1980. Ecological characterization of the Sea Island coastal region of South Carolina and Georgia. Vol. 1: Physical features of the characterization area. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-79/40. 212 pp.

Matisoff, G., Fisher, J. B., & Matis, S. 1985. Effects of benthic macroinvertebrates on the exchange of solutes between sediments and freshwater. *Hydrobiologia*, *122*, 19-33.

Marking, L. L., & Bills, T. D. 1977. *Acute effects of silt and sand sedimentation on freshwater mussels*. US Fish and Wildlife Service, Fish Control Laboratory.

McCord, J.W. 2003. Investigation of fisheries parameters for anadromous fishes in South Carolina. Completion Report to NMFS, 1 Mar. 1998 – 28 Feb. 2001, Project No. AFC-53. SCDNR. Charleston, South Carolina. 145 pp.

McDowall, R.M. 1988. Diadromy in fishes: migrations between freshwater and marine environments. Timber Press, Portland, Oregon. 308 pp.

McFee, W. E., Hopkins-Murphy, S. R. and L. H. Schwacke. 2006. Trends in bottlenose dolphin (*Tursiops truncatus*) strandings in South Carolina, USA, 1997-2003: implications for the Southern North Carolina and South Carolina Management Units. Journal of cetacean Research and Management 8(2): 195-201.

McFee, W. E., Pennington, P. L., Burdett, L. G., Powell, J. W. B., Schwacke, J. H. and F. E. Dockery. 2007. Assessing movements of three buoy line types using DSTmilli loggers: implications for entanglements of bottlenose dolphins in the crab pot fishery. NOAA Technical Memorandum NOS NCCOS 67, 58 pp.

McFee, W. E. and T. P. Lipscomb. 2009. Major pathological findings and probable causes of mortality in bottlenose dolphins stranded in South Carolina from 1993 to 2006. Journal of Wildlife Diseases 45(3): 575-593.

McFee, W. E., Wu, D., Colegrove, K., Terio, K., Balthis, L. and R. Young. 2020. Occurrence of *Brucella ceti* in stranded bottlenose dolphins

McLaughlin, P.A., D.K. Camp, M.V. Angel, E.L. Bousfield, P. Brunel, … D.D. Turgeon. 2005. Common and scientific names of aquatic invertebrates from the United States and Canada: crustaceans. American Fisheries Society, Special Publication 31, Bethesda, Maryland. i–xiii + 1–545 pp.

McKnight, D. M., Feder, G. L., Thurman, E. M., Wershaw, R. L., & Westall, J. C. 1983. Complexation of copper by aquatic humic substances from different environments. *Science of the Total Environment*, *28*(1-3), 65-76. *Tursiops truncatus* coincides with calving season. Diseases of Aquatic Organisms 141: 185-193.

Meyer, J.L. and C.A. Couch. 2000. Influence of watershed land use on stream ecosystem structure and function. Environmental Protection Agency and University of Georgia. EPA Grant Number: R824777. http://es.epa.gov/ncerqa/final/grants/95/water/meyer.html

Mineau, P, and C. Palmer. 2013. The Impacts of the Nation's Most Widely Used Insecticides on Birds. American Bird Conservancy. Accessed on <August 29, 2024>.

Moser, W.E., Richardson, D.J., Hammond, C.I., Lazo-Wasem, E.A., & Phillips, A.J. 2017. Redescription and Molecular Characterization of *Placobdella nuchalis* Sawyer and Shelley, 1976 (Hirudinida: Glossiphoniidae). Bulletin of the Peabody Museum of Natural History, 58 (2) 311–316.

Moser, W.E., Richardson, D.J., Hammond, C.I., Rojas, L., Lazo-Wasem, E., & Phillips, A.J. 2022. Resurrection and redescription of *Clepsine pallida* Verrill, 1872 (Hirudinida, Glossiphoniidae) with a phylogeny of the genus *Alboglossiphonia*. ZooKeys, 1127 135–154.

Murdoch, P.S., J.S. Baron and T.L. Miller. 2000. Potential effects of climate change on surface-water quality in North America. Journal of the American Water Resources Association 36: 347-366.

Nack, C.C., D. Swaney, K.E. Limburg. 2019. Historical and Projected Changes in Spawning Phenologies of American Shad and Striped Bass in the Hudson River Estuary. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 11:271–284

National Assessment Synthesis Team (NAST). 2000. Climate Change Impacts on the United States-The Potential Consequences of Climate Variability and Change. Overview by the National Assessment Synthesis Team f or the US Global Change Research Program, Cambridge University Press, Cambridge, UK.

National Marine Fisheries Service (NMFS). 1998. Recovery plan for the shortnose sturgeon (*Acipenser brevirostrum*). Prepared by the Shortnose Sturgeon Recovery Team, National Marine Fisheries Service, Silver Spring, Maryland. 104 pp.

National Marine Fisheries Service, Southeast Regional Office, Protected Resources Division. (2020, January 22). Endangered Species Act - Section 7 Consultation Biological Opinion. *Re-licensing of the South Carolina Public Service Authority (SCPSA) Hydroelectric Project (FERC #199-205)*. St. Petersburg, Florida, United States: National Oceanic and Atmospheric Administration.

NatureServe. 2010. Digital Distribution Maps of the Freshwater Fishes in the Conterminous United States. Version 3.0. Arlington, VA. U.S.A. https://www.natureserve.org/products/digital-distribution-native-us-fishes-watershed

NatureServe. 2015. Protocol for Assignment of NatureServe Conservation Status (National and Subnational) and Distribution Status for Long Distance Migrants (June 2015 edition). Accessed online at https://help.natureserve.org/biotics/content/Methodology/Ranking%20migrants_2015.pdf

Nayak, K.G. and P. Davidar, 2010. Pollinator limitation and the effect of breeding systems on plant reproduction in forest fragments, Acta Oecologica, 36(2):191-196.

Nery, T., & Schmera, D. (2016). The effects of top-down and bottom-up controls on macroinvertebrate assemblages in headwater streams. *Hydrobiologia*, *763*, 173-181.

Nicklin, L., & Balas, M. T. (2007). Correlation between unionid mussel density and EPA habitat- assessment parameters. *Northeastern Naturalist*, *14*(2), 225-234.

Noss, R.F., J.M. Cartwright, D. Estes, T. Witsell, G. Elliott, D. Adams, M. Albrecht, R. Boyles, P. Comer, C. Doffitt, D. Faber-Langendoen, J. Hill, W.C. Hunter, W.M. Knapp, M.E. Marshall, J. Signhurst, C. Tracey, J. Walck, and A. Weakley, 2021. Improving species status assessments under the U.S. Endangered Species Act and implications for multispecies conservation challenges worldwide, Conservation Biology, 35:1715-1724.

O'Brien, C. A., & Williams, J. D. (2002). Reproductive biology of four freshwater mussels (Bivalvia: Unionidae) endemic to eastern Gulf Coastal Plain drainages of Alabama, Florida, and Georgia. *American Malacological Bulletin*, *17*(1), 147-158.

Odum, W.E., 1984. The ecology of tidal freshwater marshes of the United States east coast: a community profile, Fish and Wildlife Service, US Department of the Interior.

Ortmann, A.E. 1911. A monograph of the najades of Pennsylvania. Parts I and II. *Memoirs of the Carnegie Museum* 4:279-347.

Palmer, M.A., C.A. Reidy Liermann, C. Nilsson, M. Florke, J. Alcama, P.S. Lake and N. Bond. 2008. Climate change and the world's river basins: anticipating management options. Frontiers in Ecology and the Environment 6: 81-89.

Pandolfo, T. J., Cope, W. G., Arellano, C., Bringolf, R. B., Barnhart, M. C., & Hammer, E. (2010). Upper thermal tolerances of early life stages of freshwater mussels. *Journal of the North American Benthological Society*, *29*(3), 959-969.

Pashley, D.C. Beardmore, J. Fitzgerald, R. Ford, W. Hunter, M. Morrison and K. Rosenberg. 2000. Partners in Flight: conservation of the land birds of the United States. American Bird Conservancy. The Plains, Virginia. 92 pp.

Patterson, J. W., Minear, R. A., Gasca, E., & Petropoulou, C. (1998). Industrial discharges of metals to water. *Metals in surface waters*, 37-66.

Perison, D., J. Phelps, C. Pavel and R. Kellison. 1997. The effects of timber harvest in a South Carolina blackwater bottomland. Forest Ecol. and Man. 90(1997):171- 185.

Pimm, S.L. and P.H. Raven, 2017. The fate of the world's plants, Trends in ecology & evolution, 32(5):317-320.

Poelmann, O., Jachowski, C. M. B., Darden, T. L., Farrae, D. J., Yong, L., Kern, M., & Peoples, B. K. (2024). Prevalence and Intensity of Mussel Glochidia Infestations on Potential Host Fish Species in a South Carolina Stream. *Southeastern Naturalist*, *23*(1), 84-107.

Post, W.C., T. Darden, D.L. Peterson, J. Hightower, M. Loeffler, and C. Collier. 2014. Research and Management of Endangered and Threatened Species in South Carolina: Riverine Movements of Shortnose and Atlantic sturgeon. South Carolina Department of Natural Resources, Project NAIONMF4720036, Final Report, Charleston.

Pritt, J. J. and E. A. Frimpong. 2010. Quantitative determination of rarity of freshwater fishes and implications for imperiled-species designations. Conservation Biology 24: 1249-1258. https://www.jstor.org/stable/40864025

Procopio, J., and Daniel, W.M., 2024, Macrobrachium nipponense (De Haan, 1849): US Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL, https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=3596, Revision Date: 4/16/2021, Access Date: 10/15/2024.

Probst, W.E., C.F. Rabeni, W.G. Covington and R.E. Marteney. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. Transactions of the American Fisheries Society. 113(3):283-294.

Pyron, R.A. and D.A. Beamer. 2023. Systematic revision of the spotted and northern dusky salamanders (Plethodontidae: *Desmognathus conanti and D. fuscus*), with six new species from the eastern United States. Zootaxa 5311 (4):451-504.

Pyron, R.A. and D.A. Beamer. 2022. Nomenclatural solutions for diagnosing 'cryptic' species using molecular and

morphological data facilitate a taxonomic revision of the Black-bellied Salamanders (Urodela, *Desmognathus 'quadramaculatus'*) from the southern Appalachian Mountains.

Rabeni, C.F. 1992. Trophic linkage between stream centrarchinds and their crayfish prey. Canadian Journal of Fisheries and Aquatic Sciences. 49:1714-1721.

Rabinowitz, D. 1981. Seven forms of rarity. Pp. 205-217 *In* The biological aspects of rare plant conservation. Editor: H. Synge.

Radcliffe, C., S. Norris, J. Ambrose, W. Knapp, T. Rice, A. Treher Eberly, A. Weakley, K. Terwilliger, and E.E.D. Coffey, 2023. Southeastern Plants Regional Species of Greatest Conservation Need, Atlanta, Georgia: Southeastern Plant Conservation Alliance.

Raley, M.E. A.E. Bogan, C.B. Eads and J.F. Levine. (2007). Molecular evidence for a novel placement of the Carolina Creekshell, Villosa vaughaniana (Lea, 1836) [sic]. Directions in Freshwater Mollusk Conservation: Molecules to Ecosystems. 5th Biennial Freshwater Mollusk Conservation Society Symposium and Habitat Restoration Workshop. Meeting Program and Abstracts. 11-16 March2007. Little Rock, Arkansas. Poster Abstract. Page 41

Ricciardi, A., Neves, R. J., & Rasmussen, J. B. (1998). Impending extinctions of North American freshwater mussels (Unionoida) following the zebra mussel (Dreissena polymorpha) invasion. *Journal of Animal Ecology*, *67*(4), 613-619.

Rice, T. M., E. Crisfield, and K. Terwilliger. 2019. Regional Species of Greatest Conservation Need in the Southeastern United States. Report prepared for the Wildlife Diversity Committee of the Southeastern Association of Fish and Wildlife Agencies. Terwilliger Consulting, Inc. Pp. 138. https://secassoutheast.org/pdf/SEAFWA_RSGCN_Final_Report_20190715.pdf

Richman, N. I., Böhm, M., Adams, S. B., Alvarez, F., Bergey, E. A., Bunn, J. J., ... & Collen, B. (2015). Multiple drivers of decline in the global status of freshwater crayfish (Decapoda: Astacidea). *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1662), 20140060.

Rohde, F. C., R. G. Arndt, J. W. Foltz and J. M. Quattro. 2009. Freshwater Fishes of South Carolina. The University of South Carolina Press, Columbia.

Robertson, E. P., F. A. La Sorte, J. D. Mays, P. J. Taillie, O. J. Robinson, R. J. Ansley, T. J. O'Connell, C. A. Davis, and S. R. Loss. 2024. Proceedings of the National Academy of Sciences 121:12. https://doi.org/10.1073/pnas.2308433121

Robins, C.R. and G.C Ray. 1986. A field guide to Atlantic Coast fishes of North America. The Peterson field guide series; 32. Houghton Mifflin Company, Boston, Massachusetts. 354 pp.

Roell, M.J. and D.J. Orth. 1993. Trophic basis of production of stream-dwelling smallmouth bass, rock bass, and flathead catfish in relation to invertebrate bait harvest. Transactions of the American Fisheries Society 122(1):46-62.

Roth, L. and R. Franklin, 2009. Timing of Prescribed Fire in Longleaf Pine Management: Benefits, Risks, and Roles by Season, Clemson Extension Forestry Leaflet 32.

Saha, S., K. Bradley, M.S. Ross, P. Hughes, T. Wilmers, P.L. Ruiz, and C. Bergh, 2011. Hurricane effects on subtropical pine rocklands of the Florida Keys, Climatic change, 107(1):169-184.

Sawyer, R.T. 1972. North American freshwater leeches, exclusive of the Piscicolidae, with a key to all species. Illinois Biological Monographs 46. 1–154 + pp.

Sawyer, R.T. 1979. Leeches of special concern from South Carolina. Pages 100–102 in D.M. Forsythe and W.B. Ezell, Jr., eds., Proceedings of the First South Carolina Endangered Species Symposium. November 11–12, 1976, Charleston, South Carolina. 201 pp.

Sawyer, R.T., Lawler, A.R. & Overstreet, R.M. 1975. Marine leeches of the eastern United States and the Gulf of Mexico with a key to the species. Journal of Natural History. 9: 633.

Sawyer, R.T., & Shelley, R.M. 1976. New records and species of leeches (Annelida: Hirudinea) from North and South Carolina. Journal of Natural History 10(1):65–97.

Schwab, W.C., P.T. Gayes, R.A. Morton, N.W. Driscoll, W.E. Baldwin, W.A. Barnhardt, J.F. Denny, M.S. Harris, M.P. Katuna, T.R. Putney, and G. Voulgaris, 2009. Coastal Change Along the Shore of Northeastern South Carolina-The South Carolina Coastal Erosion Study.

Schwalb, A. N., & Pusch, M. T. (2007). Horizontal and vertical movements of unionid mussels in a lowland river. *Journal of the North American Benthological Society*, *26*(2), 261-272.

Schwoerer, T. and N.G. Dawson. 2022. Small sight-Big might: Economic impact of bird tourism shows opportunities for rural communities and biodiversity conservation. PLoS One. 2022 Jul 6;17(7):e0268594. doi: 10.1371/journal.pone.0268594. PMID: 35793337; PMCID: PMC9258859.

Searing, K. B., Lomolino, M. V., & Rozzi, R. 2023. Melting climates shrink North American small mammals. Proceedings of the National Academy of Sciences of the United States of America, 120(50), e2310855120. https://doi.org/10.1073/pnas.2310855120

Semlitsch, R.D. and J.R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology. 17(5):1219-1228.

Sheridan, P.M., S.L. Orzell, and E.L. Bridges, 1997. Powerline easements as refugia for state rare seepage and pineland plant taxa, Aster, 5:S3.

Sibley, D. 2000. The Sibley Guide to Birds. National Audubon Society. New York, New York. 544 pp.

Smith, C. H., Johnson, N. A., Pfeiffer, J. M., & Gangloff, M. M. (2018). Molecular and morphological data reveal non-monophyly and speciation in imperiled freshwater mussels (Anodontoides and Strophitus). *Molecular Phylogenetics and Evolution*, *119*, 50-62.

Solar Energy Industries Association. 2024. State Overview: South Carolina. Accessed online on September 6, 2024 at https://seia.org/state-solar-policy/south-carolina-solar/.

South Carolina Aquatic Invasive Species Task Force and South Carolina Department of Natural Resources, 2008. South Carolina Aquatic Invasive Species Management Plan.

South Carolina Exotic Pest Plant Council, 2004. Non-native invasive plant species list, Accessed online at http://www.se_eppc.org/states/SC/SCList.pdf.

South Carolina Forestry Commission (SCFC). 1998. South Carolina Forestry Commission Best Management Practices Manual. 65 pp. http://www.state.sc.us/forest/refbmp.htm

South Carolina Forestry Commission (SCFC), 2010 South Carolina's Statewide Forest Resource Assessment and Strategy (June 2010):271.

South Carolina Invasive Pest Council, 2024. Non-native invasive plant species list.

Sparks, R. E., Blodgett, K. D., Durham, L., & Horner, R. (1990). Determination whether the causal agent for mussel die-offs in the Mississippi River is of chemical or biological origin. *ILENR/RE-WR-90/09*.

Speakman, T. R., Lane, S. M., Schwacke, L. H., Fair, P. A. and E. S. Zolman. 2010. Mark-recapture estimates of seasonal abundance and survivorship for bottlenose dolphins *(Tursiops truncatus*) near Charleston, South Carolina, USA. Journal of Cetacean Research and Management 11(2): 153-162.

Stein, B.A. and K. Gravuer, 2008. Hidden in Plain Sight: The Role of Plants in State Wildlife Action Plans, NatureServe. 27.

Stewart, P. M., Swinford, T. O., Pratt, J. R., Bowers, N., & Stauffer, J. R. (1995). Identification of sediment and nutrient sources impacting a critically endangered mussel species' habitat in a small agricultural stream. *Making Environment Science. A Festschrift in honor of John Cairns, Jr. ECOPRINT, Portland, OR*, 45-64.

Stork, Nigel E. 2018. How many species of insects and other terrestrial arthropods are there on earth? Annual Review of Entomology Vol. 63:31-45 https://doi.org/10.1146/annurev-ento-020117-043348

Strayer, D. L. (1999). Effects of alien species on freshwater mollusks in North America. *Journal of the North American Benthological Society*, *18*(1), 74-98.

Strayer, D. L. (1999b). Use of flow refuges by unionid mussels in rivers. *Journal of the North American Benthological Society*, *18*(4), 468-476.

Tarter, A. A., Ford, D. F., Symonds, D. E., Ford, N. B., & Schwalb, A. N. (2023). Impact of extreme climatic events on unionid mussels in a subtropical river basin. *Hydrobiologia*, *850*(6), 1427-1442.

Tibbetts, J. 2007. Rising Tide Will Climate Change Drown Coastal Wetlands? Coastal Heritage. 21: 3-12. Accessed online on September 11, 2024 at https://www.scseagrant.org/wp-content/uploads/Coastal-Heritage-Winter-2007.pdf

Tracy, B.H. 2018. The distributional status of seven nonindigenous species in the Yadkin-Pee Dee River drainage in North Carolina. American Currents 43(1): 5-12.

Tracy, B.H., F.C. Rohde, S.A. Smith, J.L. Bissette and G.M. Hogue. 2024. A Guide to North Carolina's Freshwater Fishes. The University of North Carolina Press. Chapel Hill, North Carolina. 455 pp.

Transue, L., Monczak, A., Tribble, C., Marian, A. et al. 2023. The biological and anthropogenic soundscape of an urbanized port- the Charleston Harbor Estuary, South Carolina, USA. PLoS One 18(4): e0283848. https://doi.org/10.1371/journal.pone.0283848

Travlos, I.S., J.M. Montull, G. Kukorelli, G. Malidza, M.N. Dogan, N. Cheimona, N. Antonopoulos, P.J. Kanatas, S. Zannopoulos, and G. Peteinatos, 2019. Key aspects on the biology, ecology and impacts of Johnsongrass [Sorghum halepense (L.) Pers] and the role of glyphosate and non-chemical alternative practices for the management of this weed in Europe, Agronomy, 9(11):717.

Tribble, C., Monczak, A., Transue, L., Marian, A. et al. 2023. Enhancing interpretation of cetacean acoustic monitoring: investigating factors that influence vocalizations patterns of Atlantic bottlenose dolphins in an urbanized estuary, Charleston Harbor, South Carolina, USA. Aquatic Mammals 49(6): 519-549.

Trimble, S.W., 1974. Man-Induced Soil Erosion on the Southern Piedmont, 1700-1970, Ankeny, IA: Soil Conservation Society of America.

Tucker, J. K. (1996). Post-flood strandings of unionid mussels. *Journal of Freshwater Ecology*, *11*(4), 433-438.

United States Fish and Wildlife Service (USFWS). 2011. Endangered and threatened wildlife and plants; partial 90-day finding on a petition to list 404 species in the southeastern United States as endangered or threatened with critical habitat. *Federal Register* 76: 59836–59862.

United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service, and South Carolina Department of Natural Resources. 2001. Santee-Cooper Basin diadromous fish passage restoration plan. 72 pp.

United States Fish and Wildlife Service (USFWS). 2012. News Release: North American bat death toll exceeds 5.5 million from white-nose syndrome. U.S. Fish and Wildlife Service, Arlington, Virginia. https://www.whitenosesyndrome.org/press-release/north-american-bat-death-tool-exceeds-5-5-million-from-white-nose-syndrome

United States Fish and Wildlife Service (USFWS). 2021. Recommended Best Practices for Communication Tower Design, Siting, Construction, Operation, Maintenance, and Decommissioning. Accessed on <August 29, 2024>.

United States NABCI Committee. 2000. Bird conservation region descriptions: A supplement to the North American Bird Conservation Initiative Bird Conservation Regions Map. USFWS, Washington, DC. Accessed online on August 15, 2005 at http://www.nabci-us.org/aboutnabci/bcrdescrip.pdf

Urquhart, F.A. and N.R. Urquhart, 1976. Migration of Butterflies Along the Gulf Coast of Northern Florida, Journal of the Lepidopterist's Society, 30(1):59-61.

USEPA. (2013). Update if Ambient Water Quality Criteria for Ammonia. United States Environmental Protection Agency.

Van der Schalie, H. (1970). Hermaphroditism among North American freshwater mussels. *Malacologia*, *10*(1), 93-112.

Vaughn, C. C., Gido, K. B., & Spooner, D. E. (2004). Ecosystem processes performed by unionid mussels in stream mesocosms: species roles and effects of abundance. *Hydrobiologia*, *527*, 35-47.

Vaughn, C. C., Nichols, S. J., & Spooner, D. E. (2008). Community and foodweb ecology of freshwater mussels. *Journal of the North American Benthological Society*, *27*(2), 409-423.

Vaughn, C. C., & Spooner, D. E. (2006). Unionid mussels influence macroinvertebrate assemblage structure in streams. *Journal of the North American Benthological Society*, *25*(3), 691-700.

Vaughn, C. C., & Spooner, D. E. (2006b). Scale-dependent associations between native freshwater mussels and invasive Corbicula. *Hydrobiologia*, *568*, 331-339.

Vaughn, C. C., & Taylor, C. M. (1999). Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. *Conservation Biology*, *13*(4), 912-920.

Veysey Powell, J.S. and K.J. Babbitt. 2015. An experimental test of buffer utility as a technique for managing pool-breeding amphibians. PLOS ONE. 10(7):26 pgs.

Vilcinskas, A. 2019. Pathogens associated with invasive or introduced insects threaten the health and diversity of native species. Current Opinion in Insect Science, Vol. 33: 43-48, ISSN 2214-5745, https://doi.org/10.1016/j.cois.2019.03.004.

Voigt, C., Bernard, E., Huang, J., Frick, W., Kerbiriou, C., MacEwan, K., Mathews, F., Rodríguez-Durán, A., Scholz, C., Webala, P., Welbergen, J., Whitby, M. 2024. Toward solving the global green–green dilemma between wind energy production and bat conservation. BioScience, 74(4), 240-252. https://doi.org/10.1093/biosci/biae023

Wang, N., Ingersoll, C. G., Hardesty, D. K., Ivey, C. D., Kunz, J. L., May, T. W., ... & Barnhart, M. C. (2007). Acute toxicity of copper, ammonia, and chlorine to glochidia and juveniles of freshwater mussels (Unionidae). Environmental Toxicology and Chemistry: An International Journal, 26(10), 2036-2047.

Wang, N., Ivey, C. D., Ingersoll, C. G., Brumbaugh, W. G., Alvarez, D., Hammer, E. J., ... & Barnhart, M. C. (2017). Acute sensitivity of a broad range of freshwater mussels to chemicals with different modes of toxic action. *Environmental toxicology and chemistry*, *36*(3), 786-796.

Warren, M.L., Jr., B.M. Burr, S.J. Walsh, H.L. Bart, Jr., R.C. Cashner, D.A. Etnier, B.J. Freeman, B.R. Kuhajda, R.L. Mayden, H.W. Robison, S.T. Ross and W.C. Starnes. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. Fisheries 25(10):7-31. https://afspubs.onlinelibrary.wiley.com/doi/abs/10.1577/1548-8446%282000%29025%3C0007%3ADDACSO%3E2.0.CO%3B2

Watters, G. T. (1996). Small dams as barriers to freshwater mussels (Bivalvia, Unionoida) and their hosts. *Biological conservation*, *75*(1), 79-85.

Watters, G. T. (1999). Morphology of the conglutinate of the kidneyshell freshwater mussel, Ptychobranchus fasciolaris. *Invertebrate Biology*, 289-295.

Weakley, A.S. & Southeastern Flora Team*, 2024. Flora of the Southeastern United States, North Carolina Botanical Garden: 2024 Edition, *Southeastern Flora Team: M. Lee, S. Ward, J.C. Ludwig, B. Sorrie, D. Poindexter, R. LeBlond, J. Kees, C.A. McCormick, S. Oberreiter, E. Ungberg, R. Lance, H. Ballard, R. Carter, M. Pyne, W. Knapp, K. Bradley, S. Zona, W. Barger, L. Musselman, P. Schafran, D. Spaulding, J. Nelson, E. Keith, G. Fleming, D. Estes, L. Majure, H. Medford, E. Bridges, R. Folk, Z. Murrell, R. Peet, J. Townsend, G. Nesom, A. Floden, J. Horn, E. Schilling, J. Triplett, T. Murphy, Z. Irick, K. Schoonover McClelland, M. Alford, M. Brock, and others.

Weaver, L. R., Pardue, G. B., & Neves, R. J. (1991). Reproductive biology and fish hosts of the Tennessee clubshell Pleurobema oviforme (Mollusca: Unionidae) in Virginia. *American Midland Naturalist*, 82-89.

Welti, E.A.R., Zajicek, P., Frenzel, M., Ayasse, M., Bornholdt, T., Buse, J., Classen, A., Dziock, F., Engelmann, R.A., Englmeier, J., Fellendorf, M., Förschler, M.I., Fricke, U., Ganuza, C., Hippke, M., Hoenselaar, G., Kaus-Thiel, A., Kerner, J., Kilian, D., Mandery, K., Marten, A., Monaghan, M.T., Morkel, C., Müller, J., Puffpaff, S., Redlich, S., Richter, R., Rojas-Botero, S., Scharnweber, T., Scheiffarth, G., Yáñez, P.S., Schumann, R., Seibold, S., Steffan-Dewenter, I., Stoll, S., Tobisch, C., Twietmeyer, S., Uhler, J., Vogt, J., Weis, D., Weisser, W.W., Wilmking, M. and Haase, P. 2022. Temperature drives variation in flying insect biomass across a German malaise trap network. Insect Conserv Divers, 15: 168-180. https://doi.org/10.1111/icad.12555

Weyand, C.A. and K.R. Piller. 2019. Assessing phylogeographic variation in the Rosyside Dace (Teleostei, Leuciscidae), a widespread morphologically variable taxon. Zoologica Scripta 49: 563-574.

Whelan, N. V., Johnson, N. A., Williams, A. S., Perkins, M. A., Beaver, C. E., & Mays, J. W. (2023). Hidden in the hills: phylogeny of the freshwater mussel genus Alasmidonta (Bivalvia: Unionidae) and description of a new species. *Zoological Journal of the Linnean Society*, *198*(2), 650-676.

White SL, Kazyak DC, Darden TL, Farrae DJ and others (2021) Establishment of a microsatellite genetic baseline for North American Atlantic sturgeon (Acipenser o. oxy rinchus) and range-wide analysis of population genetics. Conserv Genet 22: 977–992

Williams, J. D., Bogan, A. E., & Garner, J. T. (2008). Freshwater mussels of Alabama and the mobile basin in Georgia, Mississippi and Tennessee. *(No Title)*.

Williams, J. D., Warren Jr, M. L., Cummings, K. S., Harris, J. L., & Neves, R. J. (1993). Conservation status of

freshwater mussels of the United States and Canada. *Fisheries*, *18*(9), 6-22.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras-Balderas, J.D. Williams, M. Navarro-Mendoza, D.E. McAllister and J.E. Deacon. 1989. Fishes of North America Endangered, Threatened, or of Special Concern: 1989. Fisheries 14(6) 2-20. https://doi.org/10.1577/1548-8446(1989)014%3C0002:FONAET%3E2.0.CO;2

Winemiller, K.O. 2005. Life history strategies, population regulation, and implications for fisheries management. Canadian Journal of Fisheries and Aquatic Sci, 62(4) DOI: 10.1139/f05-040.

Wirgin, I., J.R. Waldman, J. Rosko, R. Gross, M.R. Collins, S.G. Rogers and J.E. Stabile. 2000. Genetic structure of Atlantic sturgeon populations based on mitochondrial DNA control region sequences. Trans. Am. Fish. Soc. 29:476-486.

Wrobleski, A., S. Ernst, T. Weber, and A. Delach, 2023. The impact of climate change on endangered plants and Lichen, PLOS Climate, 2(7):e0000225.

Youngflesh C, Montgomery GA, Saracco JF, Miller DAW, Guralnick RP, Hurlbert AH, Siegel RB, LaFrance R, Tingley MW. Demographic consequences of phenological asynchrony for North American songbirds. Proc Natl Acad Sci U S A. 2023 Jul 11;120(28):e2221961120. doi: 10.1073/pnas.2221961120. Epub 2023 Jul 3. PMID: 37399376; PMCID: PMC10334763.

Yue XiLiu, Y. X., & Gao QingXian, G. Q. (2018). Contributions of natural systems and human activity to greenhouse gas emissions.

Zale, A. V., & Neves, R. J. (1982). Reproductive biology of four freshwater mussel species (Mollusca: Unionidae) in Virginia. *Freshwater Invertebrate Biology*, *1*(1), 17-28.

Zanatta, D. T., & Murphy, R. W. (2006). Evolution of active host-attraction strategies in the freshwater mussel tribe Lampsilini (Bivalvia: Unionidae). *Molecular Phylogenetics and Evolution*, *41*(1), 195-208.

Zimmerman, L.L., and R.J. Neves. 2002. Effects of temperature on duration of viability for glochidia of freshwater mussels (Bivalvia:Unionidae). *American Malacological Bulletin* 17:31-35.