CLIMATE-RELATED CHANGES IN MIGRATORY WATERFOWL BEHAVIOR ALONG THE ATLANTIC FLYWAY

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ABSTRACT

Back Bay National Wildlife Refuge (NWR) is a key refuge along the Atlantic Flyway of the United States, that provides feeding and resting habitats for migratory birds. Three important species that occur in the Atlantic Flyway and Back Bay NWR are the American Widgeon, the American Black Duck, and the Tundra Swan. These species of migratory waterfowl are threatened by many factors; however, threats from climate change could cause changes in the behaviors and dynamics of these birds. Increased temperatures and saltwater intrusion are some of the largest concerns for these species of migratory birds, which could result in reduced stop-over rates in Back Bay NWR and decreased population size. Implementation of recommendations such as restoration based on maintaining ecosystem function and increased long-term decision making would be advantageous to Back Bay NWR. This would allow the largest amount of migratory birds to stop-over in Back Bay NWR while maintaining the refuge's core ecosystem functions under the threat of climate change.

INTRODUCTION

The Atlantic Flyway is an area situated on the Mid-Atlantic coast (MAC) of the United States, encompassing some of the western hemisphere's most productive forest, beach, and coastal wetland ecosystems. This area attracts a variety of migratory birds because it provides wintering habitat for at least 20 species of waterfowl, including ~70% of Black Ducks, ~80% of Atlantic Brant, ~80% of greater snow geese, and ~80% of Atlantic and North Atlantic Flyway populations of Canada geese (National Audubon Society).

The coastal wetlands include a complex and diverse assemblage of freshwater swamps and marshes, mangrove swamps, salt marshes, mud flats, sandbars, hypersaline lagoons, sandy beaches, rocky shorelines, and seagrass beds. Although the coastal wetlands comprise just 5% of the global terrestrial land mass, their potential for productivity and accessibility to the public has made these areas attractive sites for development (U.S. Fish & Wildlife Service). Thus, many cities are in coastal areas. For example, 52% of the United States' population resides within 80 kilometers of the coast (U.S. Fish & Wildlife Service). Some estimate that 70% of the world's population in coastal zones (U.S. Fish & Wildlife Service). Coastal wetlands rank among the most productive of all natural ecosystems. However, because of prolonged human contact, coastal and interior wetlands have been modified by humans in numerous ways. Large water bodies within agricultural regions furnish important winter needs of migratory birds in coastal and interior regions. Three important species that occur in these habitats are the American Widgeon, the American Black Duck, and the Tundra Swan.

The Back Bay NWR was established on June 6, 1938 as an 1857-hectare refuge (U.S. Fish & Wildlife Service). It provides feeding and resting habitats; not only for migratory birds, but also for several threatened and endangered wildlife species. Since 1988, it has grown to over 3743 hectares, and continues to serve as a critical habitat area for wildlife (U.S. Fish and Wildlife Service). It includes a thin strip of barrier island coastline typical of the Atlantic and Gulf coasts, yet other habitats to be found here include beaches, dunes, woodlands, agricultural fields, and emergent freshwater marshes. Most of its refuge marshes are located on islands. Here, thousands of Tundra Swans, Snow Geese, Canada Geese, and various duck species visit during fall and winter migrations. These migratory waterfowl populations generally peak during the months of December and January (U.S. Fish and Wildlife Service).

This area is noted and acclaimed as a prime waterfowl hunting area. Harvest estimates (based on recorded data from ten major waterfowl hunting clubs in Back Bay and Currituck Sound between 1872 and 1962) suggest that 5,000,000 ducks and 560,000 Canada Geese were harvested during that 90-yr period (Settle and Schwab, 1991). Dabbling Ducks in this region show variable numbers from 1954 to 1990. For example, the Diving Duck species has been declining from 1954 to 1990, as contrasted to a comparably stable trend at the Virginia and Atlantic Flyway levels (Settle and Schwab, 1991). The population of Tundra Swan also declined from 1954 to 1990, while the Atlantic Flyway population has increased (Settle and Schwab 1991). Overall, total waterfowl numbers have declined between 1954 and 1990 due to natural and hunting mortality, nesting/brood habitat conditions and distribution, and the conditions of migratory and wintering habitats.

AMERICAN BLACK DUCKS

American Black Ducks (*Anas rubripes,* Fig. 1) breed in freshwater wetlands and saltmarshes throughout northeastern North America (Fig. 2, Ducks Unlimited). They winter in saltwater wetlands, beaver ponds, flooded timber forests, agricultural fields, and riverine habitats. They often take refuge from hunting and other disturbances by moving to fresh or brackish impoundments in conservation land. They eat mostly plant matter, but also consume insects during their breeding season (Ducks Unlimited). In shallows, they forage like typical dabbling ducks by submerging their heads and tipping their tails up to reach underwater plant life. In deeper waters, they may dive more than 12 feet deep for plant tubers and other food items (Ducks Unlimited). While migrating, they eat the seeds, foliage, and tubers of aquatic plants; the agricultural grains, seeds and fruits of wild terrestrial plants; invertebrates, and small fish and amphibians. Generally, these ducks eat plant parts in freshwater habitats, and add mussels, zooplankton, and small fish while residing in marine habitats. Nesting starts in February in the southern part of their range, and delay nesting until late May in their northern range. Some nest in or near Back Bay NWR instead of migrating to more northern areas.

The *North American Breeding Bird Survey* recorded a decline of ~84% between 1966 and 2014, but this decline has been slowed since 2004 (All About Birds). The farming, logging, hunting, and urbanization activities in their breeding and wintering habitats may have contributed to this population decrease. Their population has declined as-much-as 60% on their wintering grounds due to this habitat degradation (Ducks Unlimited). The American Black Duck has been selected as a *species of priority concern* in the North American Waterfowl Management Plan because of this long-term population decline (All About Birds).

Figure 1. American Black Duck

Figure 2. American Black Duck Range Map

THE AMERICA WIGEON

The America Wigeon (*Anas Americana*, Fig. 3) is found throughout North America (Fig. 4, All About Birds). Habitats include shallow freshwater wetlands such as those surrounding ponds, marshes, and rivers. They consume aquatic plants and insects, and add mollusks to their diet during the breeding season (All About Birds). To feed on vegetation below the water surface, they submerge their heads and tip their tails up. In the Back Bay, they are dependent upon submerged aquatic vegetation (SAV) food production.

There are conflicting reports on American Wigeon populations. According to the *North American Breeding Bird* Survey, populations declined by 2.5% annually between 1966 and 2014, resulting in a cumulative decline of 71% (All About Birds). Due to an extended drought in prairie regions, their population declined by ~ 50% in the 1980s. The 2014 *State of the Birds* listed them as a *Common Bird in Steep Decline*. These numbers conflict with Federal Waterfowl Surveys that show their overall population has remained stable despite the fluctuations over the last 60-year period (All About Birds). Their population has increased since 2005 (~ 20% per year from 2013 to 2014, All About Birds). This species is also widely hunted in the United States during the autumn months.

Figure 3. American Wigeon

Figure 4. American Wigeon Range Map

TUNDRA SWAN

Although the Tundra Swan (*Cygnus columbianus,* Fig. 5) breed in eastern Alaska, and winter throughout the eastern Great Lakes region and along the eastern seaboard (Fig. 6), the majority of these birds winter on the mid-Atlantic coast (All About Birds). In fall, flocks gather along the brackish shorelines of river deltas before migrating south. They pause along their migration south in wetlands and boreal forests. Wintering flocks gather on estuaries, lakes, bays, ponds, and rivers; often situated close to agricultural fields where they feed (All About Birds). They eat mainly plant matter, but also mollusks and arthropods. Plant foods include the tubers, stems, and leaves of aquatic vegetation such as Carex sedges, saltmarsh starwort, alkali grass, pondweed, and Nostoc algae (All About Birds). During their migration, and while on their wintering grounds, they may be found in fields gleaning corn, soybeans, and rice left after the harvest. They also graze on growing winter crops such as winter wheat, rye, and barley. When feeding on the water they *tip-up,* like dabbling ducks, to reach submerged vegetation. When they are not breeding, these birds form large, gregarious flocks that travel, forage, and roost together. They winter on bays and estuaries in Virginia and North Carolina and feed almost exclusively on clams. Tundra Swans are North America's most numerous swan species; their numbers fluctuating annually (particularly in the western breeding population), but populations were stable overall between 2006 and 2015 (All About Birds). U.S. Fish and Wildlife Service surveys in 2005 estimated ~117,100 Tundra Swans in the eastern population and ~56,300 in the western population (All About Birds). There is a regulated hunting season for Tundra Swans.

Figure 5. Tundra Swan

Figure 6. Tundra Swan Range Map

BACK BAY AND SAV

Currently 60%-80% (depending on SAV abundance) of the Back Bay's wintering waterfowl population use its fresh water impoundment complex (U.S. Fish and Wildlife Service, 2010). This 360-hectare complex is located on the barrier island portion of the refuge. This 10-impoundment complex consists principally of 8 moist soil management units that are flooded in the fall and winter, and drawn-down in the spring and summer. Two of the impoundments serve as water reservoirs that hold water as needed, regardless of the season. Wind tidal influences are present around its watershed, and often pose a negative hydrological influence on existing plant and animal communities (such as SAV). These wind tides typically flood adjacent wetland areas during the growing season when winds are predominantly from the south, and maintain low water levels during winter when winds are predominantly from the north (U.S. Fish and Wildlife Service, 2010). Normal surface water hydrology operates oppositely, with low levels during summer, encouraging germination and reproduction of native plant communities and related organisms. High water levels during winter buffer substrate and organisms from freezing and other cold weather impacts. A lack of disturbance to the water column provides time for turbidity to settle-out of the water column in these sheltered coves and potholes, where wave action is reduced to a minimum. Decreased turbidity permits sunlight to reach the substrate and encourages germination of the existing SAV seed-bank.

Communities of SAV are important components of many fresh, brackish, and marine aquatic ecosystems (U.S. Fish and Wildlife Service, 2010). They prevent erosion by baffling the impacts of waves, especially from storms. These aquatic plant communities remove nutrients and other pollutants from rivers and other runoff inputs to coastal areas, preventing their entry into surrounding waters. They provide nursery habitats for fish, shrimp, and other species, as well as forage for wintering waterfowl and endangered species. Most of the bay waters currently lack SAV.

CURRENT TRENDS – THE DECLINE OF MIGRATORY WATERFOWL IN BACK BAY NATIONAL WILDLIFE REFUGE

AMERICAN BLACK DUCK

Winter surveys are widely used as a long-term index to numbers of Black Ducks in the various flyways. Winter population survey figures have declined from an average of 603,400 through 1955-1960, to 303,900 through 1981-1988 (Fig. 7, Rusch et al., 1989). This rate of decline has changed little; averaging ~ 3% yearly. In the Atlantic Flyway, figures declined ~43% during 1955- 1985, but most of the decline occurred during 1955-1959. Continental figures declined ~5% during 1979-1985 (Rusch et al., 1989).

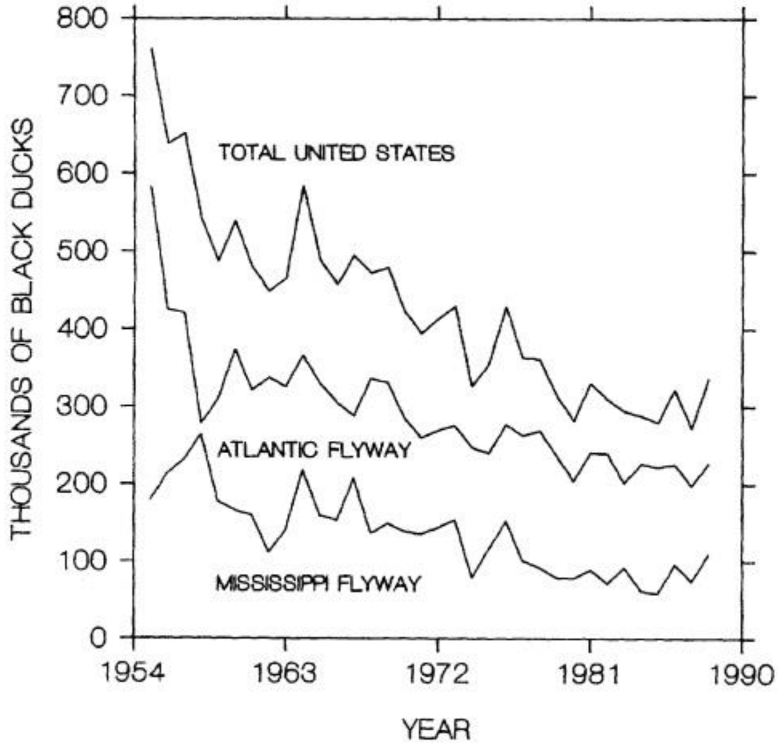

Figure 7. Trends in numbers of Black Ducks observed in the midwinter waterfowl survey in the Atlantic and Mississippi flyways and the Atlantic and Mississippi flyways and the United States, 1955-1988 (Rusch et al., 1989)

Populations tallied in winter surveys have declined steadily over the past 30 years; at an average annual rate of ~3% (Rusch et al., 1989). Reliability of the surveys is uncertain since they may not provide an adequate index to the continental population. The quality and quantity of wintering habitats have decreased substantially in some areas. Recovery rates have declined recently in the US, but not in Canada (Rusch et al., 1989). About 90% of the non-breeding population occurs within the boundaries of the *Atlantic Coast Joint Venture*, with the highest densities occurring in the mid-Atlantic region (Jones et al., 2016). According to surveys taken in by the US Fish and Wildlife Service, populations have been decreasing in Virginia since 1955, and at an even higher rate in North Carolina (Fig. 8 & 9, Jones et al., 2016).

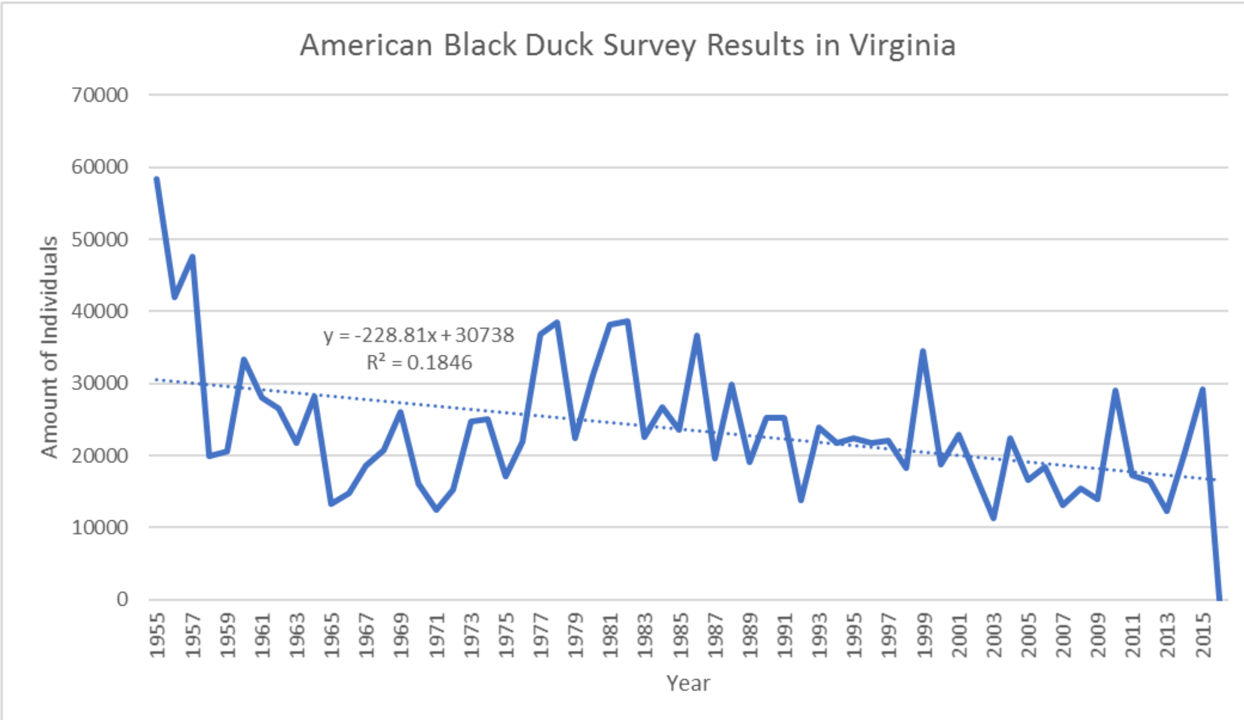

Figure 8. Amount of American Black Duck Individuals Surveyed in Virginia over time

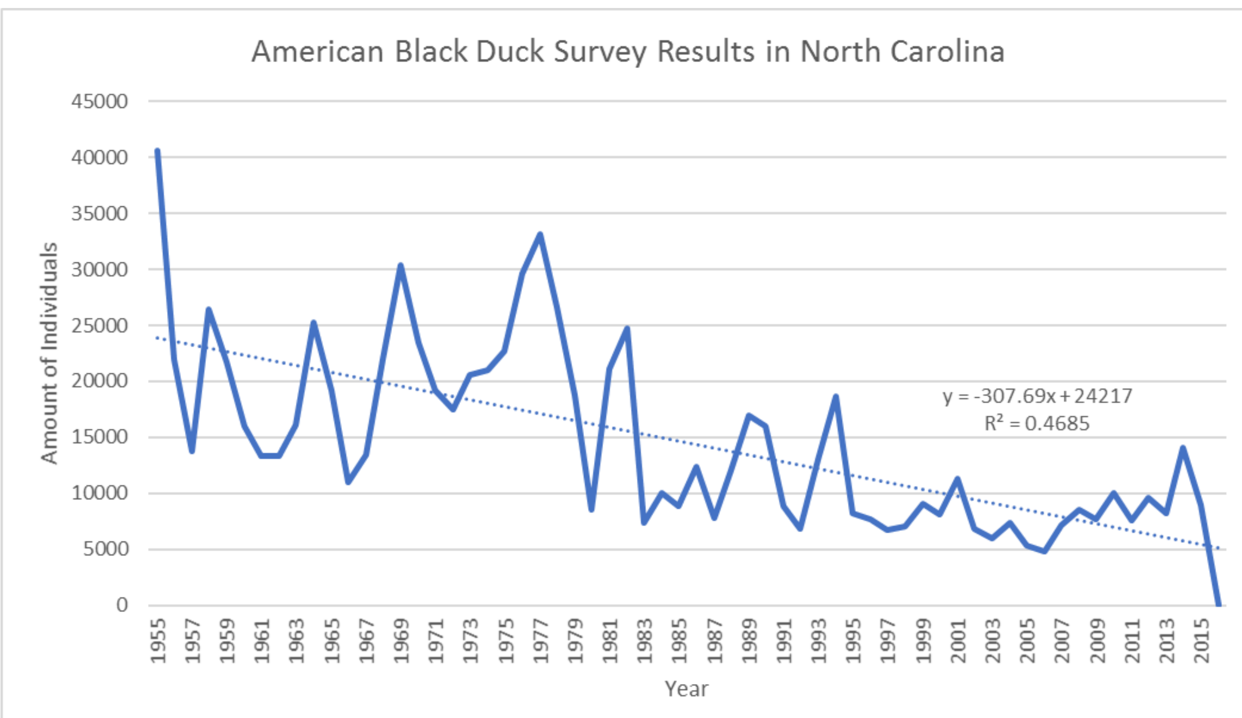

Figure 9. Amount of American Black Duck Individuals Surveyed in North Carolina over time

AMERICAN WIGEON

Populations of American Wigeon have declined between the years of 1966 to 2011 (Sauer et al., 2013). There is limited population survey data, therefore detailed information on this species cannot be provided. According to surveys completed by the US Fish and Wildlife Service, populations have been mostly constant in Virginia, and have been slightly increasing in North Carolina since 1955 (Fig. 10 & 11).

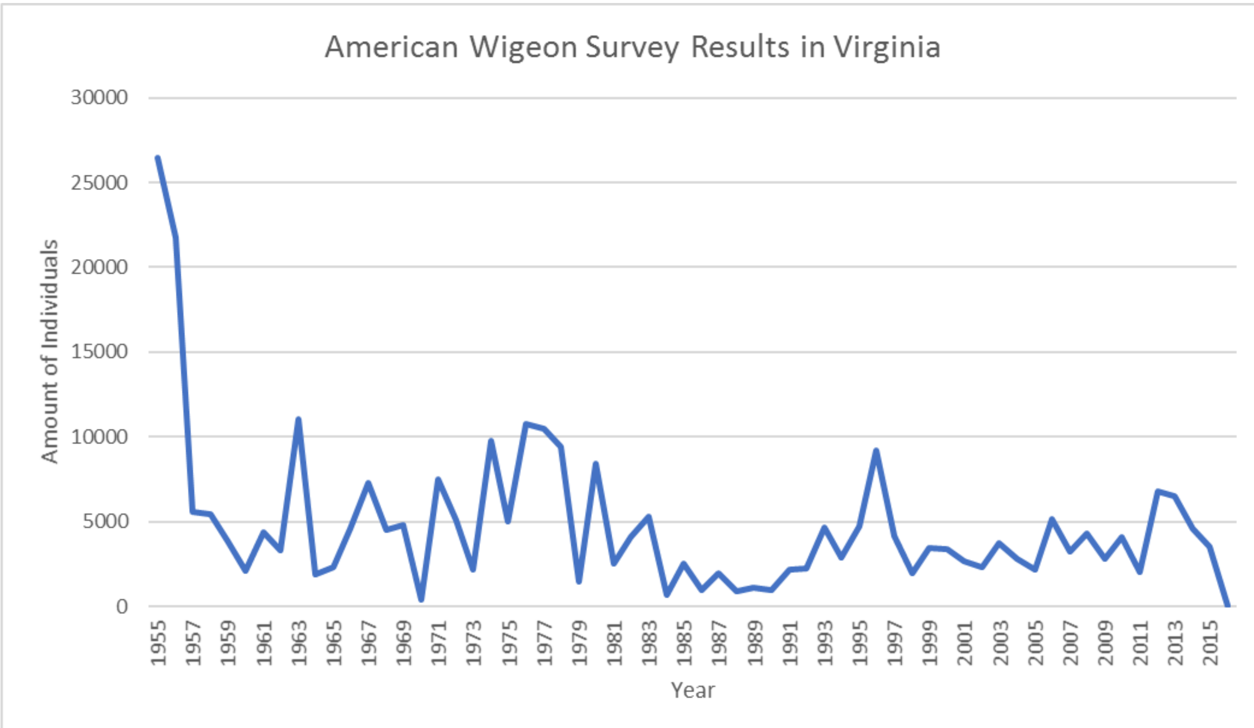

Figure 10. Amount of American Wigeon Individuals Surveyed in Virginia over time

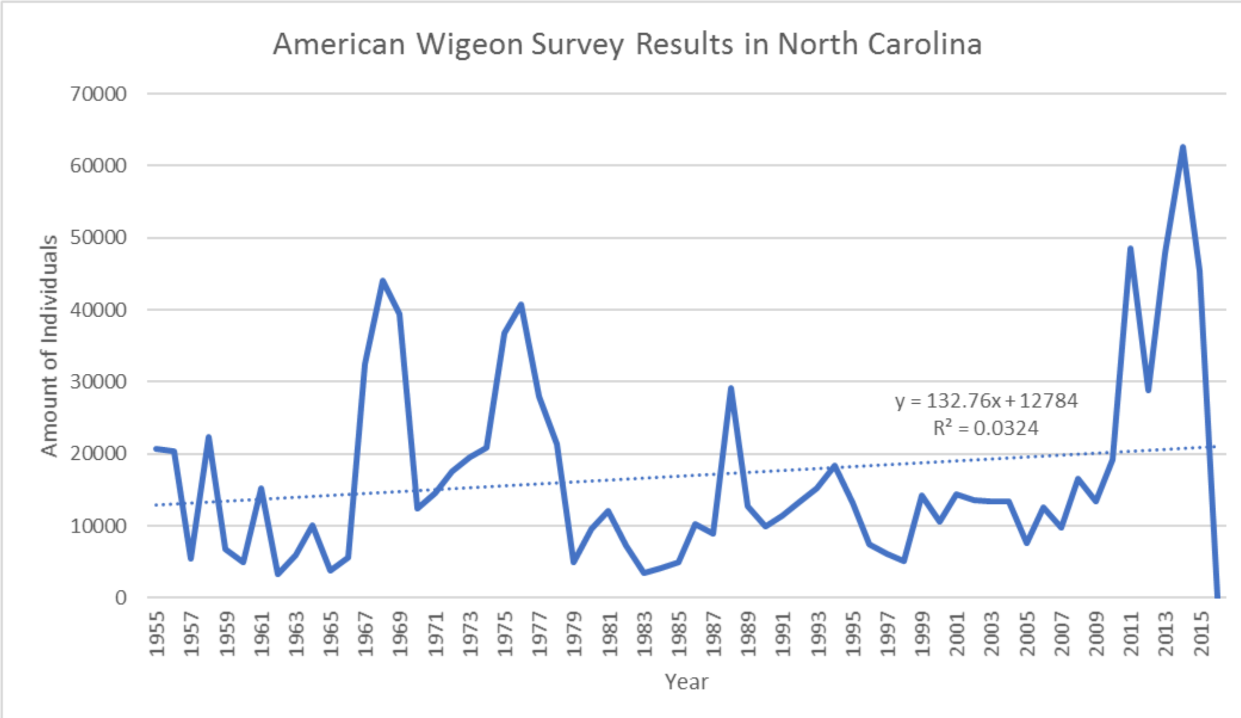

Figure 11. Amount of American Wigeon Individuals Surveyed in North Carolina over time

TUNDRA SWAN

Mid-winter waterfowl surveys indicate increasing population size (Nichols et al., 1992). Population indices from *Midwinter Waterfowl Surveys* conducted in the Atlantic and Pacific Flyways show that the Eastern Population (EP), Western Population (WP), and the total North populations have increased significantly (P <0.001) at annual rates of 2.4%, 1.8%, and 2.1 %, respectively, throughout 1955-1989 (Serie and Bartonek, 1991). Through 1980-1989, the EP continued to increase and the WP may have possibly declined resulting in overall stable numbers for the North American population. In the short term, considerable variability exists between survey periods because of inexplicable and erratic changes in population indices. The EP and WP comprise 58% and 42% of their populations, respectively (Serie and Bartonek, 1991). The states of North Carolina and California winter nearly 70% of the continent's population, and these two subpopulations continue to increase both numerically and proportionately (Serie and Bartonek, 1991). Since productivity indices have not changed significantly over the period when populations have increased, present levels of productivity should be adequate to sustain growth.

Population indices from the *Midwinter Waterfowl Survey* show that their numbers have more than doubled since 1955 and currently exceed 100,000 (Serie et al., 2001). Wintering populations surrounding the Chesapeake Bay continue to decline, while numbers wintering further south along coastal North Carolina steadily increase. North Carolina winters ~70% of the Eastern Population, while Maryland has 20%; Virginia 6%; New Jersey 3%, and 1% are wintering elsewhere (Serie et al., 2001). According to surveys taken in by the U.S. Fish and Wildlife Service, populations have been increasing in abundance in Virginia since 1955, and at an even steeper rate in North Carolina (Fig. 12 & 13).

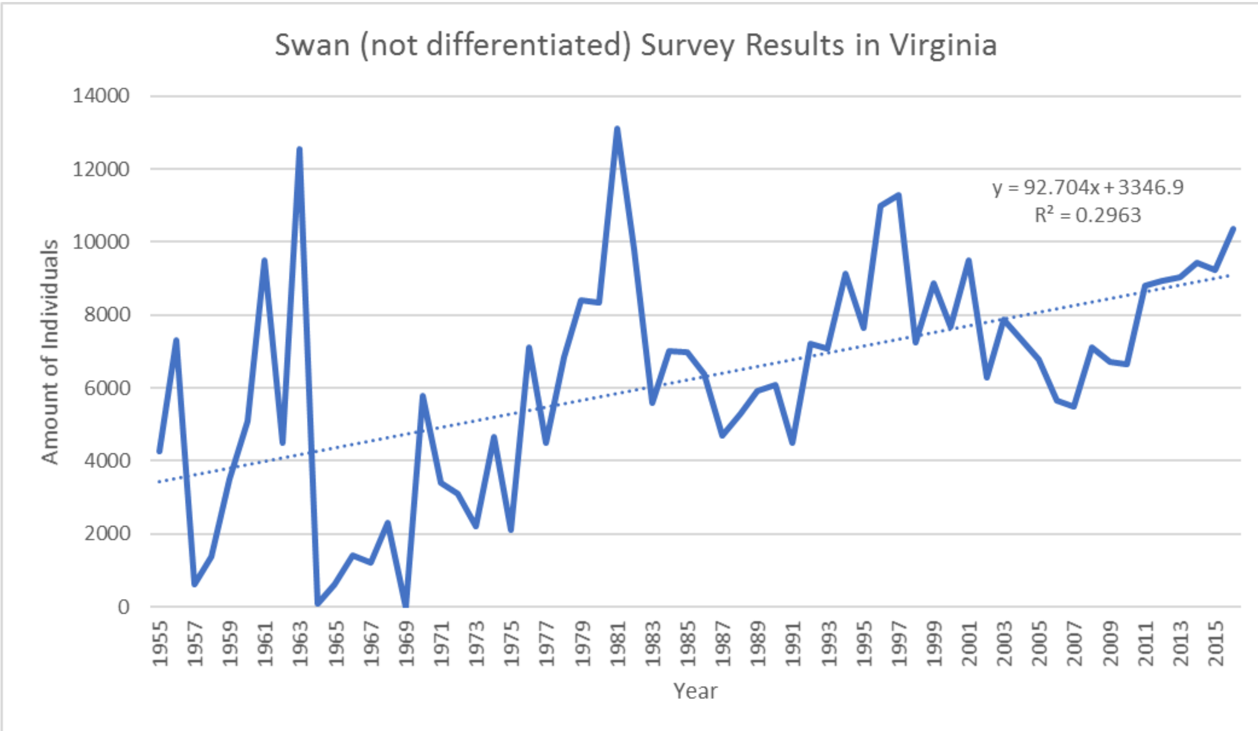

Figure 12. Amount of Tundra Swan Individuals Surveyed in Virginia over time

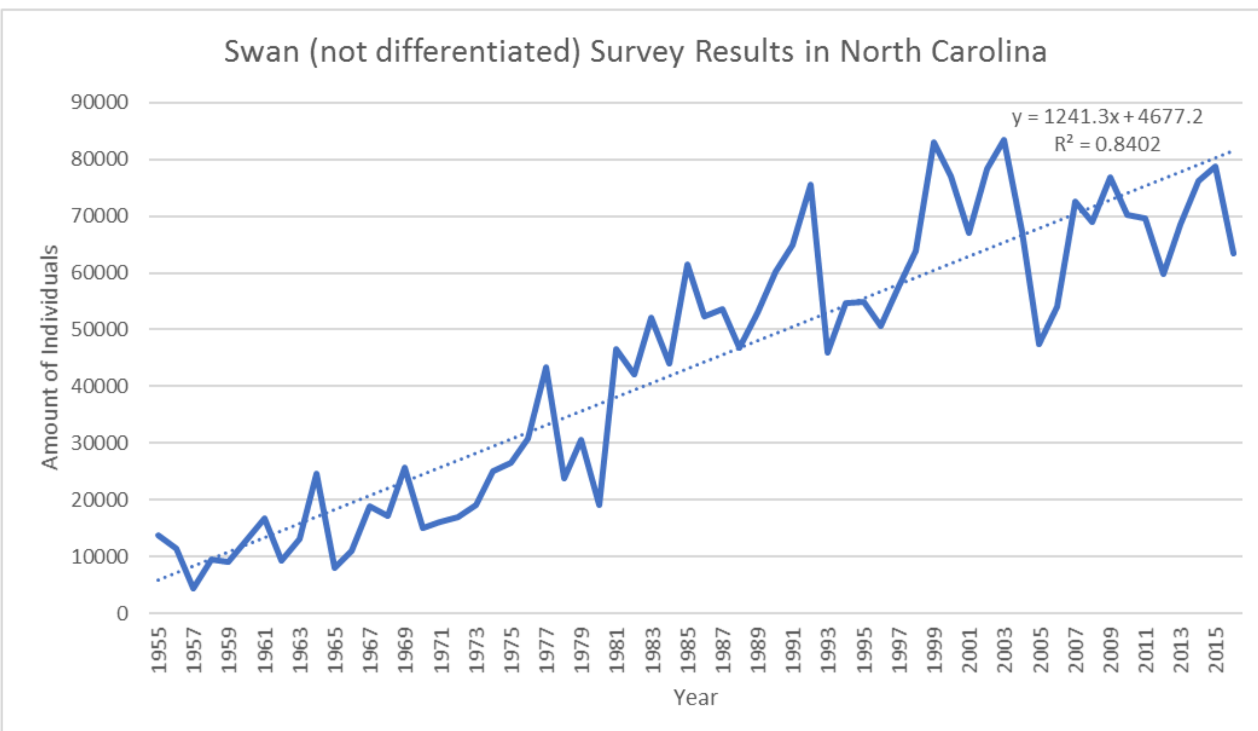

Figure 13. Figure 12. Amount of Tundra Swan Individuals Surveyed in North Carolina over time

SAV

Two periods of abundant SAV occurred from 1959 to 1964 and again from 1972 to 1981 where percent frequency of SAV equaled or exceeded 50 (Settle and Schwab, 1991). The periods of SAV decline below a 50% frequency were 1965 to 1971, and from 1982 to 1990. The 1985 through 1990 period averaged below 10% SAV frequency in Back Bay. The 1%-8% frequency of SAV noted in recent years is the lowest recorded during SAV monitoring since 1990 (Settle and Schwab, 1991). With few exceptions, it appears that when SAV is abundant in Back Bay, waterfowl numbers increase, and when SAV is scarce, waterfowl numbers decrease. Therefore, a direct relationship between SAV abundance and waterfowl numbers is likely.

HAZARDS TO THE SYSTEM

Threats to migratory birds include lead poisoning by spent shot, fishing sinkers, and mine wastes deposited in sediments (All About Birds). Waterfowl are killed by diseases, including avian cholera. Oil and gas drilling in Arctic breeding habitats and loss of wetlands at migratory stopover sites, particularly in the Midwest's prairie pothole region, are all potential threats as well (All About Birds). Concern for Black Ducks specifically has focused mainly on reducing harvest, stopping degradation and loss of wintering habitat, release of game farm mallards, and hybridization with mallards (All About Birds).

However, habitat loss, hunting, and exotic introductions are the largest threats to migratory waterfowl, affecting 73%, 48%, and 33% of threatened *Anatidae* (ducks, geese, and swans) respectively (Green, 1996). Although the habitat use patterns of all *Anatidae* are similar, inland lentic wetland and forest inhabitants are most threatened by habitat loss. Globally threatened species of *Anatidae* have various geographical distributions but share habitat loss as the most impactful threat (Green, 1996). Humans have long had a unique relationship with the *Anatidae*, reflected in their widespread harvesting for food, domestication, breeding in captivity, and their influence on human culture. In modern times conservationists, have paid particular attention to *Anatidae* to minimize the impact of recreational hunting and to attempt to resolve increasing problems of agricultural damage (Green, 1996). Life history traits such as population size, range size, extent of fragmentation, and extent of population fluctuation can confound these threats to migratory waterfowl. For example, many taxa breeding in the huge land masses of the northern Arctic and subarctic tend to have naturally wider distributions or larger population sizes and are relatively less affected by development and hunting pressure during the breeding season owing to the low density of humans in these areas.

The loss and degradation of wintering habitat has been hypothesized as a primary cause of the decline, more than 50%, of the Black Duck between 1955 and the 1990s (Jones et al., 2016). The primary causes of habitat loss and degradation during the period of rapid decline included agriculture, timber operations, environmental contaminants, introduced predators, and urban growth. Between 1953 and 1972 approximately 25,200 ha (21%) of the tidal wetlands in the northeastern states were lost to filling and diking (Jones et al., 2016). About 8% (21,900 ha) of estuarine emergent wetlands were lost between 1961 and 1996, peaking in 1960 and declining after the passage of federal and state wetland protection laws (Jones et al., 2016). The erosion of shorelines and nesting islands contributed to the decline of breeding Black Ducks in the coastal Virginia area. Additionally, between 1970 and the early 2000s, Maryland counties surrounding the

Chesapeake Bay experienced a 38% increase in the human population. Increased human population may cause increased disturbance to wintering Black Ducks, which can reduce food intake and increase energy expenditure (Jones et al., 2016).

CLIMATE CHANGE

Climate change is particularly troublesome because its effects are inherently long-term and large-scale, yet unpredictable. Climate change hazards exacerbate all previously mentioned hazards to migratory birds. Rising sea levels expose coastal ecosystems to inundation, erosion, overwash, and the accretion and migration of plant communities. Variations in climate systems of other migratory areas (stop-over and breeding grounds) affect migratory birds as well. For example, unfavorable weather conditions in northern nesting grounds can cause Canadian geese to experience poor annual production of young (Ducks Unlimited). Changing climate also may affect stream flows that could alter local salinity, nutrient loading and aquatic food webs. Additionally, heat waves and rising temperatures could have detrimental effects on both plants and animals within ecosystems such as those within Back Bay NWR, as well as other areas that are critical for migratory bird procreation and survival. Sea level rise may reduce the amount of suitable shallow water habitat for migratory species including the American Wigeon (Ducks Unlimited). Sea level rise will also destroy many salt marsh habitats, especially those along the Eastern seaboard (National Audubon Society).

During severe winters, catastrophic mortality of Black Ducks from starvation may occur. In the Chesapeake Bay, hurricanes and pollutants have dramatically changed the flora and fauna, resulting in shifts in the distribution of wintering Black Ducks (Rusch et al., 1989). For example, winter counts of Black Ducks in Maryland for the period 1955-1957 averaged 168,700, but in 1958 the tally was <50,000 Black Ducks, and registered only slight gains (58,000 in 1959, 62,800 in 1960) in subsequent years (Rusch et al., 1989). No survey since 1957 has tallied >82,300 birds (Rusch et al., 1989).

Over time, it has been shown that ecological processes are changing in response to climatic warming (Marra et al., 2005). Past studies of bird migration times have shown great variation in migratory responses to climate change (Miller-Rushing et al., 2008). Climate variables, migration distance, and date of migration explained portions of the variation in migratory changes over time. Birds have been documented to arrive and breed earlier in spring and this has been attributed to elevated spring temperatures (Marra et al., 2005). Short-distance migrants have been found to respond to changes in temperature, while mid-distance migrants responded particularly strongly to changes in the Southern Oscillation Index (Miller-Rushing et al., 2008). However, another study has found that although the onset of migration may be determined endogenously, the timing of migration is flexible and can be adjusted in response to variation in weather and/or phenology along migration routes (Marra et al., 2005). In general, it has been found that birds migrate earlier in warm years and later in colder years (Marra et al., 2005). This could mean that long-distance migratory birds would be able to respond quickly to long term warming. However, it has also been found that the timing of breeding for long-distance migrants, such as the pied flycatcher, can be mismatched with the optimal times based on breeding success (Marra et al., 2005). Therefore, mismatch may be a constraint based on inflexible arrival times of specific species.

Furthermore, the northward progression of leaf out in spring is closely linked to temperature and provide important habitat for migratory birds during spring migration (Marra et al., 2005). Leaf-out can be important both in the food it provides, as well as the protection foliage may offer to camouflage birds from predators (Marra et al., 2005). Such factors can all contribute to the rate at which migratory birds can move northward, since plants (i.e. SAV) are more sensitive to changes in temperature than are birds.

Temperature can have direct and indirect effects on insect development, which may influence food availability to migratory birds. For example, because temperature can influence plant phenology, it can also delay or stimulate insect emergence, impacting the abundance of herbivorous insects that are prey to migrating birds (Marra et al., 2005). This in turn can have important impacts on the length of bird stopover and the rate of migration. Furthermore, delays in spring arrival by migratory birds may lead to increased competition for nest sites with species arriving earlier (Walther et al., 2002). Such mismatch of fine-tuned events may negatively impact species interactions and the persistence of ecological communities across an array of ecosystems (Walther et al., 2002).

CLIMATE CHANGE IMPACTS ON BACK BAY NWR

In general, waterfowl populations of various species have been declining at Back Bay for at least a half-century (U.S. Fish and Wildlife Service, 2010). The reasons for this are complex and may be separated into local and regional factors. In the Arctic, nesting waterfowl are encountering an ever-warmer environment in which coastlines are eroding, ponds are draining from melting permafrost, food availability may no longer coincide with peak periods of need, and there is an increasing amount of human activity in this formerly unaffected landscape (U.S. Fish and Wildlife Service, 2010). The effects of climate change, which are already affecting geese and ducks breeding at high latitudes and in some coastal areas, will soon affect waterfowl throughout their range. Breeding habitat is being irreversibly degraded by wetland drainage and conversion of grassland to cropland. This will inevitably lead to a population decline when drier conditions return. The food and energy demands of non-breeding waterfowl are often met by the seasonal availability of agricultural foods, a resource with an uncertain future dependent on supply and demand, farming technology and irrigation water. Sea level rise, saltwater intrusion, nutrient loading, coastal erosion, offshore and tidal energy developments and increased urbanization, acting alone or in combination, are rapidly degrading important coastal habitats (U.S. Fish and Wildlife Service, 2010). Regional factors in decreasing Back Bay waterfowl populations may include the shifting of primary over-wintering locations in the Atlantic Waterfowl Flyway, primarily northward, out of the Back Bay area; as well as overall declines in Atlantic Flyway populations (U.S. Fish and Wildlife Service, 2010).

Survey results on population abundance of waterfowl species visiting Back Bay NWR were compiled from 2004 until 2016. The data was averaged over a calendar year to assess when specific species of waterfowl were arriving, when they were at their peak, and when they were departing. Data was grouped together from 2004 – 2009 and 2011 – 2016 (there was no data for year 2010). There was significantly less data for the American Wigeon than the other two species and Tundra Swan was automatically included with all other swan species that were surveyed during these time periods. After analyzing the shifts in peak arrival/departure, it appears that all three species have experienced at shift later in the year of ~0.5 months (Fig. 14, 15, 16, 17, 18, & 19).

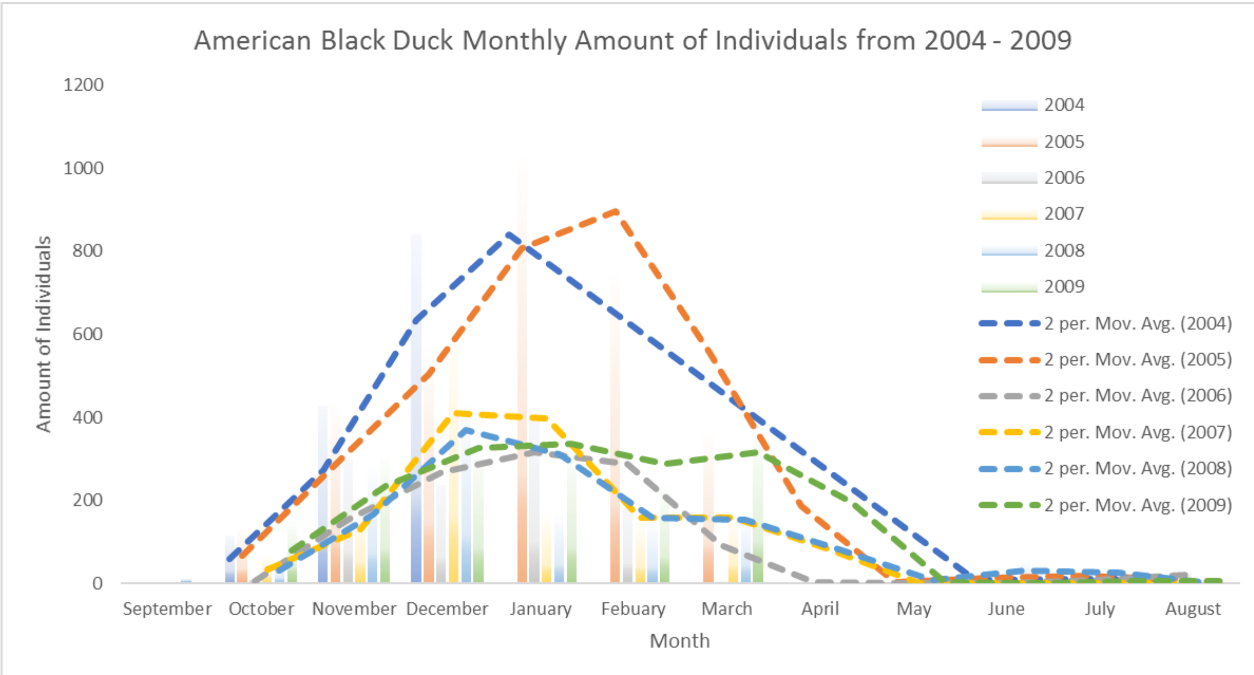

Figure 14. From 2004 – 2009 it appears that American Black Duck peak arrival is about mid-December to early January and peak departure is late January to early February

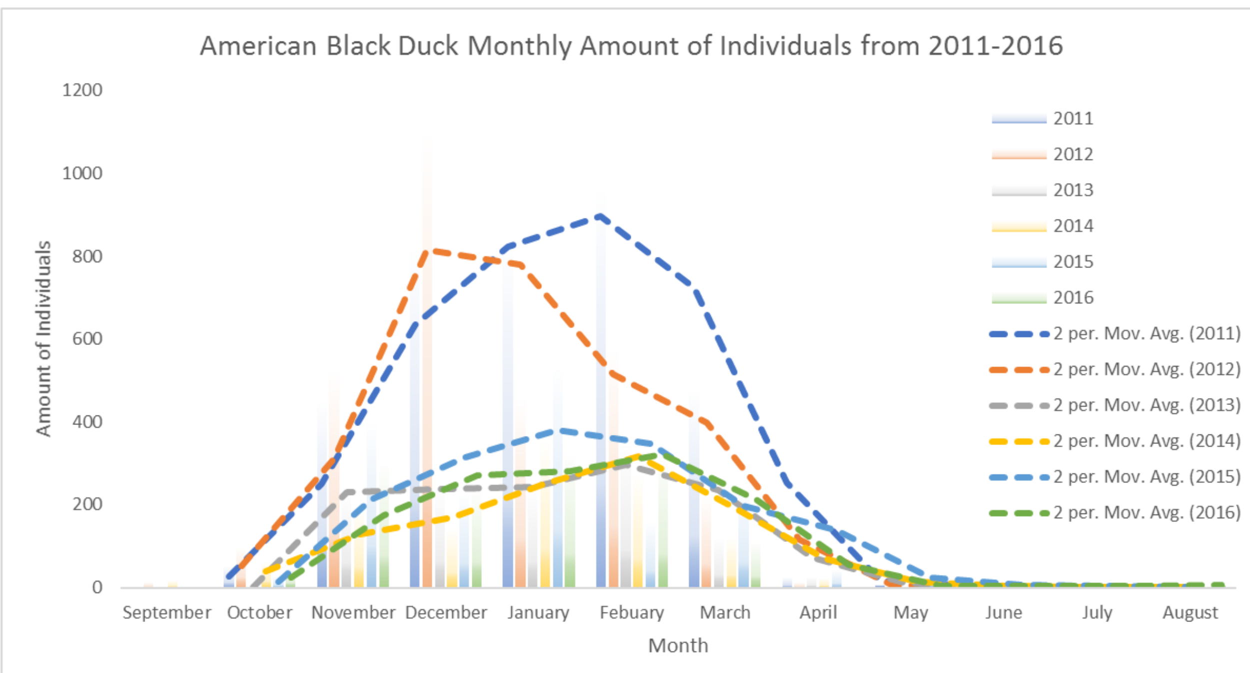

Figure 15. From 2011 – 2016 it appears that American Black Duck peak arrival is about mid-January and peak departure is late February

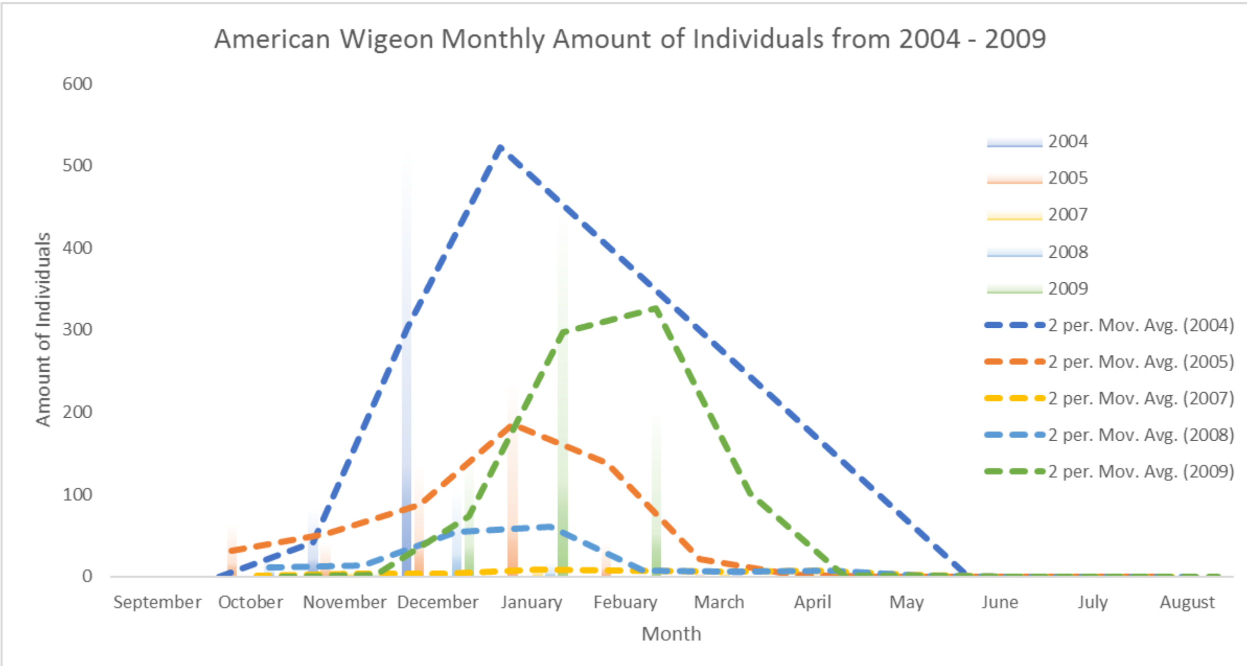

Figure 16. From 2004 – 2009 it appears that American Wigeon peak arrival is about mid-January and peak departure is mid-February

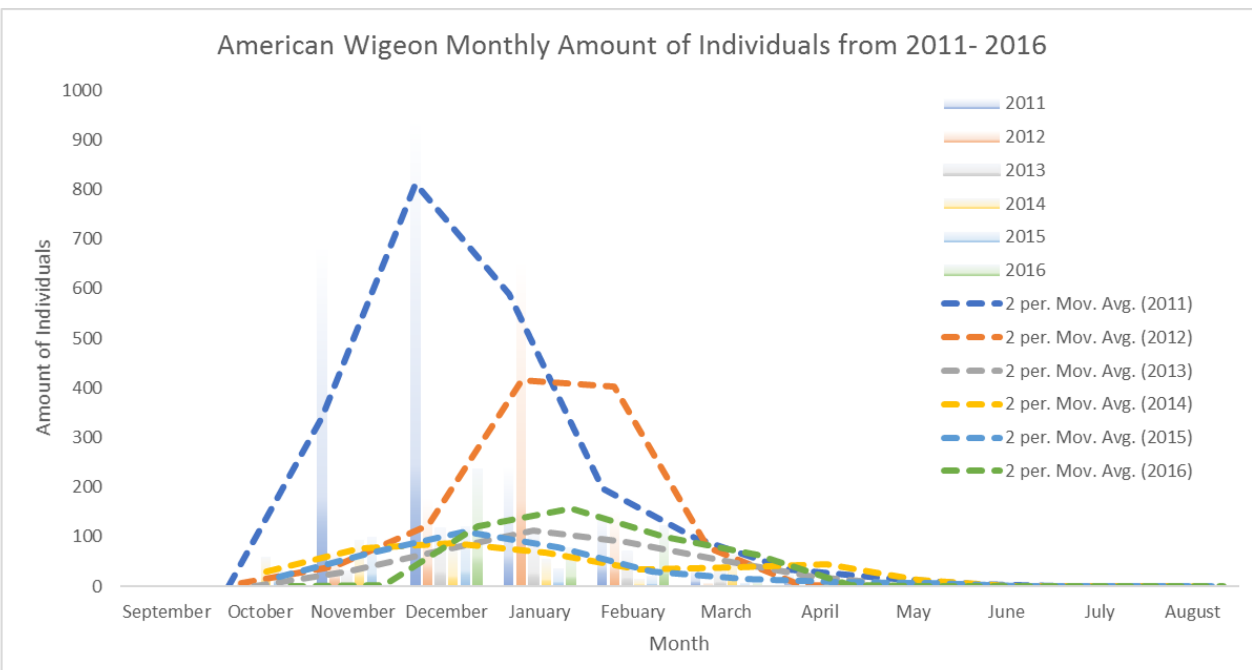

Figure 17. From 2011 – 2016 it appears that American Wigeon peak arrival is about early January and peak departure is early February

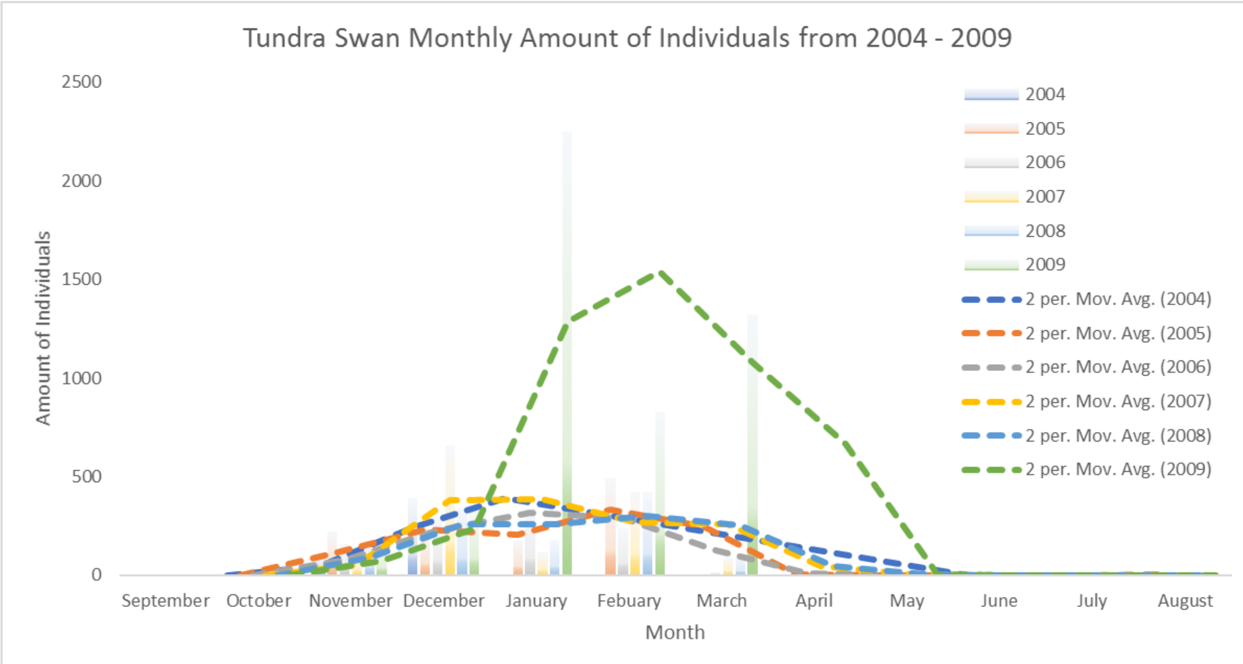

Figure 18. From 2004 – 2009 it appears that Tundra Swan peak arrival is about mid-December and peak departure is mid-March

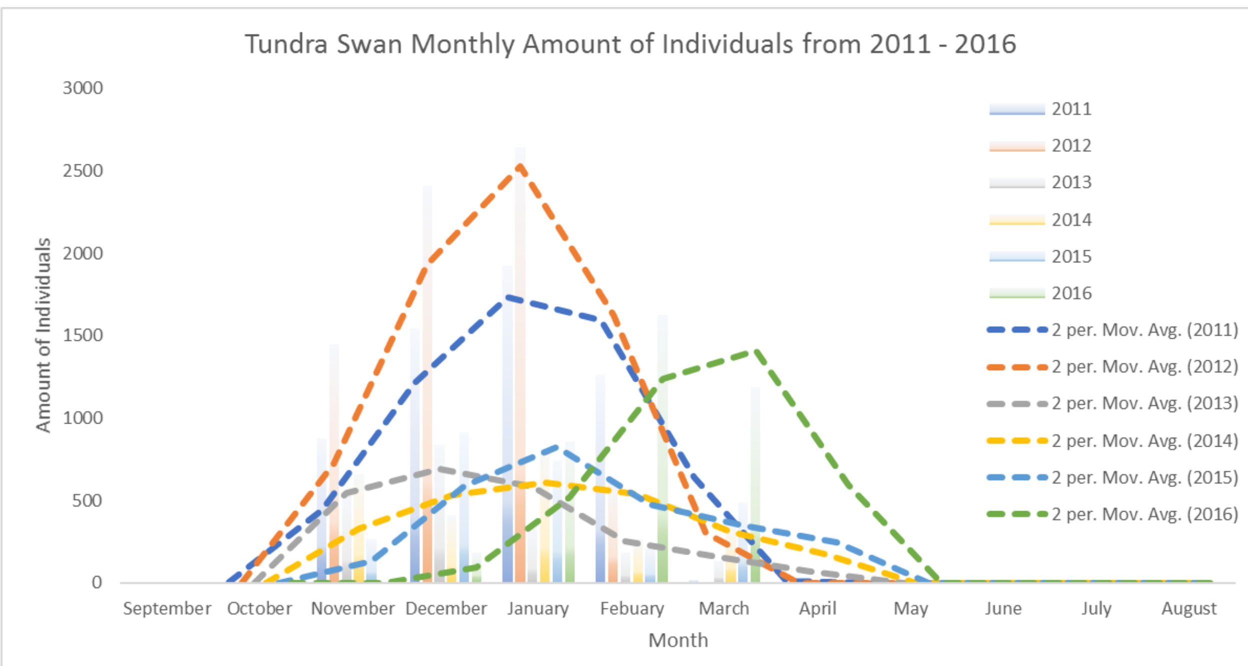

Figure 19. From 2011 – 2016 it appears that Tundra Swan peak arrival is about late December to early January and peak departure is late January to early February

Local factors include reductions in SAV, which may link to potential decreases in water quality. SAV is an important aspect to a healthy ecosystem in Back Bay. SAV provide important habitats and support a greater diversity of wildlife species, help to stabilize sediments, deter shoreline erosion and filter pollutants and dissolved nutrients (U.S. Fish and Wildlife Service, 2010). Wintering waterfowl population size is correlated with that year’s SAV production in the bay. However, SAV has been declining for many decades, which in turn results in one of the causes of low waterfowl populations (Fig. 20). Disease, run-off, changes in salinity, turbidity, weather and various natural occurrences are all likely causes for the decline of SAVs.

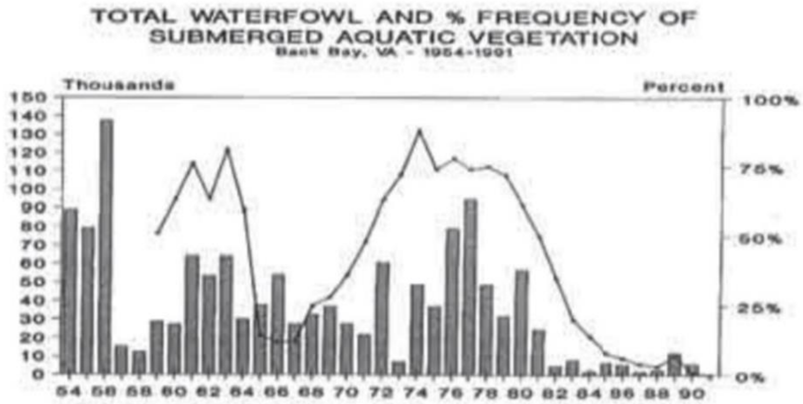

Figure 20. The amount of waterfowl overlaid with the amount of SAV in Back Bay, VA

The direct effect of temperature on plant physiology may ultimately influence community composition and latitudinal species occurrence. Increases in the concentration of dissolved inorganic carbon, including both carbon dioxide and bicarbonate, may affect submerged plants directly and may have indirect effects by increasing the growth of attached and suspended algae.

Global sea level has risen between 10 and 25 cm over the past 100 yr. The Intergovernmental Panel on Climate Change expects that average sea level will continue to increase as a result of thermal expansion and melting of glaciers and ice sheets (Stocker et al., 2013). Models using the IPCC’s best estimate values of climate sensitivity and ice melt suggest an increase in sea level of ~50 cm from the present to 2100. Continued rise in sea level will increase the depth of coastal waters and will cause inland and upstream salinity intrusion, both of which will affect SAV (U.S. Fish and Wildlife Service, 2010). Increased sedimentation from erosion has caused a dramatic decline in SAV by reducing light penetration. Furthermore, the range of plausible sea level rise by 2100 is much larger and local sea level rise may be significantly larger than the global average. These factors could result in even further damage to SAV.

All of these hazards are likely to cause shifts in species distributions, changes in the timing of life-history events for particular species, decoupling of coevolved interactions, effects on demographic rates, reductions in population size, extinction or extirpation of range-restricted or isolated species and populations, direct loss of habitat due to sea-level rise, increased fire frequency, altered weather patterns, glacial recession, direct warming of habitats, increased spread of wildlife diseases, increased populations of species that are direct competitors of focal species for conservation efforts, and increased spread of invasive or non-native species (Mawdsley et al., 2009).

VULNERABILITIES OF THE SYSTEM

Threats to migratory birds, SAV, and their habitats manifest themselves in various ways (Table 1). This is due the many different vulnerabilities of these species and their environment.

Impact if significant change occurs				
	Wetlands	**Water Quality**	**SAV**	**Birds**
Near certain CO2 increase	Possible increase in accretion	Slight pH decrease	Small	None
Very likely sea level increase	Likely flooding	Very likely higher turbidity	Likely decrease due to increased turbidity	Likely loss of intertidal habitat and decrease in food for SAV-dependent species
Likely temperature increase	Possible increase in accretion	Possible increase in anoxia and nuisance blooms; possible phytoplankton decreases	Likely species distribution changes	Possible species distribution changes
Possible precipitation and streamflow increase	Possible increase in accretion due to increased sediment input	Very likely increase in turbidity and anoxia	Very likely decrease due to increased turbidity and nutrients	Likely decrease in food for SAV-dependent species
Very likely population increase	Decrease in area due to: human development, decreased sediment supply, and increased groundwater withdrawals	Likely increase in toxic substances, nutrients and anoxia, possible turbidity decrease due to dams and bulkheads	Likely decrease due to water-quality decrease, but possible increase due to lower turbidity	Likely decrease in food for SAV-dependent species

Table 1. Summary of potential impacts of climate and population change on the mid-Atlantic coastal region (Najjar et al., 2000)

WATERFOWL SPECIES

Migratory species need dependable, high-quality breeding, wintering and migration habitats. The prairie wetlands of North America are vital to the survival of many species of waterfowl (Rusch et al., 1989). Homing rates to previous nesting areas are high for adult female waterfowl, and juvenile birds may home to natal rearing areas as well. Thus, high harvest rates of local populations may affect nesting densities and subsequent harvest in these populations. Furthermore, the inland wintering range is limited by the availability of ice-free water and food (Rusch et al., 1989). Coastal wintering areas retain a large percentage of the Atlantic Flyway population of Black Ducks. From the Maritimes to mid-Atlantic states, large tidal amplitude and sub-freezing temperatures profoundly influence the distribution and behavior of birds. Waterfowl are also sensitive to pollution and runoff that degrade water quality (All About Birds).

Many species of migratory waterfowl depend on cues from the environment to initiate migration, such as snow and ice melt in breeding grounds. For example, many of the Canadian geese wintering on the Chesapeake Bay breed in northern Quebec (U.S. Fish & Wildlife Service). On the breeding grounds, the pairs wait until the snow and ice melt before they begin nesting. The shortening of days and frosts of early autumn signal the Canada geese to prepare for a journey back to their wintering grounds. Change in the arrival of spring and/or when the ice begins to melt could result in early or late migrations.

SAV

Unfortunately, submerged aquatic plant communities are also susceptible to long-term environmental changes that are predicted to accompany global climate change, most notably from widespread deterioration of water quality. Because many waterfowl species are relatively short lived, migratory patterns and habitats could be negatively influenced by several years of poor food production on the wintering grounds (Settle and Schwab, 1991).

EXPECTED CHANGES AND FORESIGHT

The Earth's climate has warmed by approximately 0.6 °C over the past century with two main periods of warming (Walther et al., 2002). The rate of warming during the latter period has been approximately double that of the first period. Organisms, populations and ecological communities respond to the regional changes that occur due to the increased average global temperatures. These regional changes vary largely in various areas of the globe (Fig. 21). In many regions, there is an unevenness in the warming that will contribute to ecological dynamics across systems. The freeze-free periods in most mid- and high-latitude regions are lengthening and satellite data reveal a 10% decrease in snow cover and ice extent since the late 1960s (Walther et al., 2002). Changes in precipitation have also varied largely (Fig. 21).

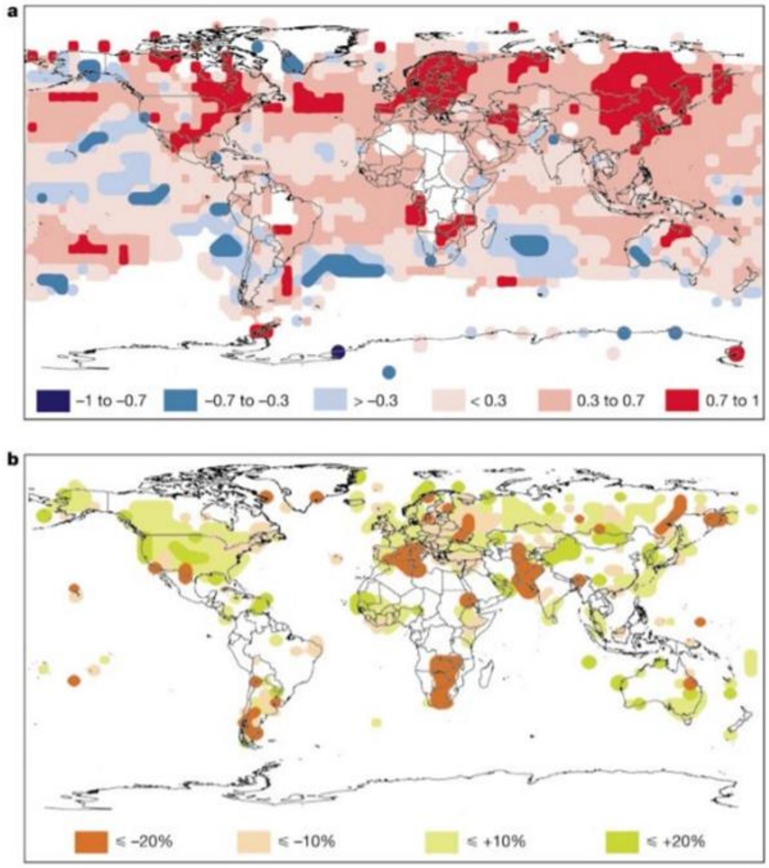

Figure 21. Spatial variability of annual trends in temperature and precipitation since 1976. (a) Temperature (°C per decade), (b) precipitation (% per decade). (Walther et al., 2002)

When considering possible future scenarios, the IPCC report has found that Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C, and even 2°C, relative to 1850 to 1900 (Stocker et al., 2013). Warming will most likely vary between each year, as well as each decade, and will not be regionally uniform (Fig. 21). Changes in the global water cycle in response to the warming over the 21st century will not be uniform either (Fig. 22, Stocker et al., 2013). The contrast in precipitation between wet and dry regions and wet and dry seasons will increase. Extreme precipitation events over most of the mid-latitude land masses will very likely become more intense and more frequent by the end of this century, as global mean surface temperature increases (Stocker et al., 2013).

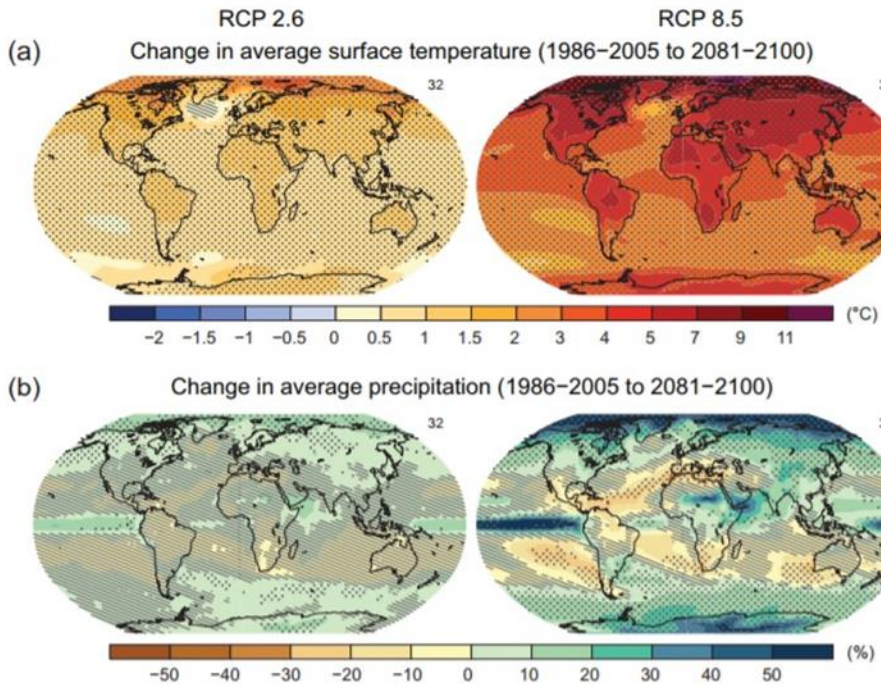

Figure 22. (a) annual mean surface temperature change, (b) average percent change in annual mean precipitation relative to 1986–2005 (Stocker et al., 2013)

The current landscape provides little flexibility for ecosystems to adjust to rapid environmental changes (Walther et al., 2002). Species in many areas today must move through a dangerous landscape that has been created by human activity. Because of the widespread loss and fragmentation of habitats, many areas, which may become climatically suitable with future warming are isolated from current distributions, and beyond the dispersal capacity of many species. Consequently, species with low adaptability and/or dispersal capacity will be caught by the dilemma of climate-forced range change and low likelihood of finding distant habitats to colonize, ultimately resulting in increased extinction rates compared to those we see today.

Climate models generally agree that the greatest warming due to the enhanced greenhouse effect may occur at northern high latitudes, such as the tundra, and in particular in the winter season (Erwin, 2009). In addition, the precipitation over high latitude regions is mostly expected to increase, both in summer and in winter. For water resources, all climate scenarios lead to the large-scale loss of snowpack at moderate elevations by mid-century, bringing large reductions in summer flow in all streams and rivers that depend on snowmelt. Where reliable water supply is available during most of the thawed season that exceeds the demands of evaporation and outflow losses, the soil remains saturated and a high water table is maintained (Erwin, 2009). However, a continued warming trend under climatic change will eliminate these lingering snow banks. Then, many meltwater-fed wetlands will diminish or disappear. Although the combined effect of higher temperatures and precipitation is still uncertain, it seems likely that snow cover in these areas will decrease, and evapotranspiration will increase (Erwin, 2009).

For migratory waterfowl, hydrological changes in prairie wetlands may have profound implications. In other regions, sea-level rise with increasing erosion of coastal marshes, and changes in the ecology of permafrost ponds in the North will impact waterfowl habitats (Jones et al., 2016). The effects of climate change, which are already affecting geese and ducks breeding at high latitudes and in some coastal areas, will soon affect waterfowl throughout their range. Directional change in ecological systems (e.g., sea level rise, a warming climate) could threaten critical habitats. Rising sea levels are one of the most certain consequences of climate change. Sea-level rise is expected to accelerate by two to five times the current rates due to both ocean thermal expansion and the melting of glaciers and polar ice caps (Stocker et al., 2013). Impacts from sea-level rise include land loss through submergence and erosion of lands in coastal areas; migration of coastal landforms and habitats, increased frequency and extent of storm-related flooding, wetland losses, and increased salinity in estuaries and coastal freshwater aquifers (Jones et al., 2016). In addition, patterns of precipitation and evaporation may be altered, leading to more severe weather, shifts in ocean circulation, as well as adverse impacts to economies and human health. At the species level, climate change could lead to behavioral changes, range shifts in response to changing climatic and habitat conditions, and possible species extinction for small, specialized populations (Jones et al., 2016). Habitats may change, with some species shifting their range northward or dying out, with other animals and vegetation moving in to take their place. Ducks and other waterfowl could lose breeding habitat due to stronger and more frequent droughts. Changes in the timing of migration and nesting could put some birds out of sync with the life cycles of their prey species (Jones et al., 2016). Animal and insect species historically found farther south may colonize new areas to the north as winter climatic conditions moderate. Sea level rise is currently causing salt water intrusion into estuaries and threatens freshwater resources in parts of the mid-Atlantic region.

A 2008 SLAMM (Sea Level Affecting Marshes Model) analysis by the National Wildlife Federation (NWF) used GIS models to predict sea level rise impacts for the next 100 yr. The model for Back Bay determined that a rise of 27.2 inches by 2100 would cause major changes to the ecosystem makeup of the refuge (Jones et al., 2016). Estuarine open ocean habitat cover would increase from 38% to 77% of the refuge, while other habitats, including undeveloped dry land, inland freshwater marsh, and salt marsh, would decrease in percent coverage of the refuge. Back Bay Wildlife Refuge's coastal location is an important variable in predicting the impact of climate change in the near future. Rising sea levels would increase erosion rates of coastal beaches, thereby reconfiguring coastal shorelines and dune profiles. The inundation of coastal wetlands could change wetland community composition and push stressed wetland ecosystems further inland (Jones et al., 2016). Salinization of waters as sea levels rise could have a large impact on the oligohaline (low salinity) estuary system of Back Bay.

Looking to the future, urbanization and sea-level rise due to global climate change probably pose the greatest risk to migratory waterfowl habitats. Between 2004 and 2009, the U.S. lost >18,000 hectares of estuarine emergent wetlands, which constituted a faster rate of loss than observed between 1998 and 2004 (Jones et al., 2016). The nests of breeding Black Ducks on the Virginian Islands are susceptible to loss due to flooding from extreme tides and storm events, both of which are expected to increase with sea-level and global temperatures. By 2100, sea-level rise along the Atlantic Coast is estimated to average 4 mm/yr., but the accretion rate is estimated at 2 mm/yr., which will result in a large-scale alteration of the amount, distribution and structure of coastal marsh of coastal marsh systems including the high marsh, low marsh and mud flats (Jones et al., 2016). These areas are critically important to American Black Ducks, and non-breeding American Wigeon and Tundra Swan because they provide important food resources and refugia from human disturbance. Cumulative changes in temperature and precipitation, sea level, and storm frequency, intensity, timing, and distribution will have both direct and indirect effects on coastal and interior wetlands. Direct effects, for example, may include those relatively short-term population and ecosystem responses (e.g., mortality, nutrient pulses, etc.) to excess precipitation, flooding, and high winds, whereas indirect effects may include long-term or delayed population and ecosystem responses to disease and insects, salt stress, habitat modification, fire, and other secondary factors (Michener et al., 1997).

AVIAN POPULATIONS

Hurricanes affect wetland avifauna in numerous ways. Avian communities inhabiting coastal wetlands are characterized by their high population densities and considerable species richness. Many are numerically dominated by waterfowl (*Anseriformes*), long-legged wading birds (*Ciconiiformes*), and gulls, terns, and shorebirds (Michener et al., 1997). At many sites, numbers of birds increase substantially during fall and spring migration, when some localities host significant portions of entire species' populations. Many birds appear to be resilient to disturbances. Other birds are not resilient to disturbances, including populations of local endemic and endangered species, for which hurricanes present a real and present danger (Michener et al., 1997). Hurricanes kill birds directly, both because of excessive wind and rain, and by drowning. Storm-induced mortality appears to be greatest when hurricanes strike during the breeding season (Michener et al., 1997). Brackish and freshwater marsh-nesting birds fare somewhat better than dune-and beach-nesting species and those that nest in the canopy (due to wind), because marshes are often buffered from tropical storms by dune ridges, and because many of the species nest above the ground in herbaceous and woody vegetation (Michener et al., 1997). Species are affected by the extent to which the vegetation they nest in is damaged by the storm, as well as by their ability to reconstruct destroyed nests.

Furthermore, hurricanes may move birds indirectly afterward by creating new habitats for displaced and invading species. Hurricane damage to vegetation also alters feeding opportunities of birds (Michener et al., 1997). Flooding can affect species whose prey base is directly destroyed by the flood, either from drowning or osmotic stress, or whose prey base is dispersed by flooding and is no longer readily available as a food resource. Herbivorous birds tend to be affected more so than insectivorous species (Michener et al., 1997). Waterfowl overwintering in impounded freshwater wetlands along the Santee River in coast-al South Carolina, for example, were severely affected by saltwater intrusion of the area that lead to the destruction of their food resource. Many insectivorous species benefit from increases in the numbers of detritivorous insects feeding on downed vegetation.

In many instances, observed population declines appear to represent the displacement of individuals rather than mortality, with populations rebounding soon after their food resources reappear. For example, Hurricane Joan, which left fewer than 20% of the trees standing in an Atlantic Coast rain forest in Nicaragua, resulted in the virtual absence of birds for several months (Michener et al., 1997). Within a year and a half, however, neither species richness nor overall avian density appeared to have been affected by the storm, suggesting that displaced birds returned when food resources became available. Birds are well known vectors of plant propagules, and those propagules transported by birds during storms may seed the areas in which they finally settle (Michener et al., 1997). Hurricane-induced damage to vegetation can affect competitive dynamics within the avian community, as well as increase vulnerability to natural predation, human persecution, water and airborne epizootic diseases, and brood parasitism.

SAV

While there is uncertainty regarding the influence of global warming on the frequency and intensity of storm events, sea-level rise alone has the potential for increasing the severity of storm surge, particularly in areas where coastal habitats and barrier shorelines are rapidly deteriorating (USGS, 1997). Overwashes from storms frequently deposit sandy sediments in SAV beds growing leeward or behind protective barrier islands. Increased storm disturbances and overwash will alter the community composition of gulf SAV beds by promoting increases in the abundance of manatee grass (USGS, 1997). Since different species of SAV support different food webs, changes in the community composition of SAV will be propagated into changes at higher levels in the food chain. Frequent severe overwash and barrier island erosion may even lead to total loss of all SAV from an area. As sea level rises, many communities of fresh and brackish SAV will experience salinity increases. In some cases, an inland migration of communities might be possible, but in other cases salinity stress will change the community composition. Where salinities increase from freshwater to oligohaline (0.5-5.0 parts per thousand), community composition will be dominated by species which are strong competitors for light, nutrients, and other factors (USGS, 1997). Under mesohaline (5-18 parts per thousand salinity) conditions, community structure will be strongly governed by the salinity tolerances of the species (USGS, 1997). Salt-tolerant species such as wild-celery, widgeon grass, and sago pondweed (*Potamogeton pectinatus*) are predicted to dominate SAV communities at higher salinities. Salinity induced changes in community composition will induce changes in animal communities adapted to specific plant associations.

ECOSYSTEM PATTERNS AND PROCESSES

Wetland productivity is directly related to hydro-periods and freshwater input. Changes in the frequency, intensity, and timing of hurricanes at a site may alter the effective wetland area by decreasing or episodically increasing the area flooded and flooding frequency for portions of the floodplain that are infrequently flooded (Michener et al., 1997). Changes in the frequency and extent of inundation could alter nutrient cycling within the wetland by affecting the size of the area that experiences sedimentation and anoxic conditions following hurricanes. Stress to vegetation caused by waterlogging can be attributed to many factors. Anoxic soil conditions reduce the growth rates of many plants, both directly through oxygen deficiencies in the roots, and indirectly as a result of biochemical production of toxins (Michener et al., 1997). As might be expected, the impact of flooding depends on the magnitude, timing, and duration of inundation. Salt stress, which injures plants through osmotic stress, ion imbalance, and induced nutrient deficiency, can work synergistically with waterlogging to reduce the primary productivity of coastal wetlands.

In non-alluvial coastal environments, where storm surges accompany hurricanes, the effects of the storms on ecosystem function may be longer lasting. Alteration of salinity regimes may shift forests and wetlands from sources to sinks for nutrients and organic material, reduce the transport of nutrients and organic material to the coastal ocean that are necessary for supporting oceanic production, and alter the quantity of biogenic gases emitted to the atmosphere (Michener et al., 1997). Salts transported in the surge have converted brackish marsh to salt marsh, and fresh to brackish marsh, and have significantly enhanced the storm damage in terrestrial systems.

Because different species are likely to respond differently to global climate change, existing ecological communities may eventually be replaced by entirely new assemblages of species. The extent to which disturbance in general can affect rates of invasion in ecosystems has been suggested that exotic species may also increase in importance with climate change (Michener et al., 1997). Further, there is a growing consensus that one of humankind's greatest effects on natural systems has been to hasten the spread of exotic species. The challenges may be both to estimate which communities will be affected or what percentage of colonists will become established invaders, and to predict the likely impact of such invasions on ecosystem processes (Michener et al., 1997). Based on the synergistic effect of multiple stressors, the management and restoration of wetland habitats may be more difficult in the future due to the present availability of many more efficient colonizer species such as *Phragmites*, *Melaleuca quinquenervia*, *Lygodium microphyllum*, and *Imperata cylindrical* (Erwin, 2009). Given the individualistic responses of the numerous endemic species supported by these habitats, a wide range of subtle environmental changes could reduce their sustainability and increase the risk of species extinction.

CASE STUDY

A case study for Delaware based on digital elevation models suggests that, by the end of the 21st century, 1.6% of its land area and 21% of its wetlands will be lost to an encroaching sea (Najjar et al., 2000). Sea-level rise will also result in higher storm surges, causing 100-yr floods to occur 3 or 4 times more frequently by the end of the 21st century. Streamflow increases could substantially degrade water quality, with significant negative consequences for submerged aquatic vegetation and birds (Najjar et al., 2000). Though climate change may have some positive impacts on the MAC region, such as increased coastal tourism due to warming and some ecological benefits from less-frequent harsh winters, most impacts are expected to be negative (Najjar et al., 2000).

Bay temperature is expected to be highly correlated with the estimation of mean surface air temperature over the Susquehanna River Basin (Najjar et al., 2000). This suggests that the warming of surface air masses in the northeastern US will be tracked by nearshore MAC waters. During the summer, water temperatures in shallow areas may increase less than air temperatures as a result of evaporative cooling (Najjar et al., 2000). In deeper, less-restricted MAC waters, the temperature change is likely to be smaller because of the greater volume to be heated and the larger influence of ocean circulation and mixing. Estimates of the magnitude and seasonal timing of the precipitation increase vary considerably among models, suggesting significant uncertainty in these predictions. The combined effect of higher sea level and more precipitation would very likely result in greater coastal flooding.

As sea level rises, the ocean will encroach landward and estuarine salinity will increase. Such a salinity change could have significant negative impacts on drinking water quality and estuarine ecosystems in and around Delaware Bay during the 21st century (Najjar et al., 2000). They used a 1-dimensional numerical model to evaluate the impact of a 73 cm sea-level rise (expected near the end of the 21st century) on salinity above a 1965 baseline (Najjar et al., 2000). The maximum 30-day average chloride concentration increased from 135 to 305 mg/l at one location in the upper Bay. The rapid change in salinity in the horizontal direction was predicted to move upstream by 11 km.

Current water-quality conditions in mid-Atlantic estuaries are typically poor. Mid-Atlantic estuaries are generally characterized as high in chlorophyll concentration (a measure of phytoplankton abundance), nutrients and turbidity, and low in submerged aquatic vegetation (SAV) and dissolved oxygen (Najjar et al., 2000). A significant increase of phytoplankton biomass has occurred during the last 40 to 50 yrs. in MAC waters. Nuisance algae are reported for half of the mid-Atlantic estuaries and toxic algal blooms have had resource impacts in 4 bays, 3 of which are in North Carolina

The single most important climatic influence on estuarine water quality is streamflow. For several reasons, water quality degrades as streamflow increases (Najjar et al., 2000). First, the vertical stability of the water column increases as fresher water overrides denser saltier water, decreasing the ability of winds and tides to vertically mix water, thereby decreasing the replenishment of oxygen from the atmosphere to deeper waters of the estuary. Second, nutrient inputs from associated watersheds increase, increasing plankton production and the rain of organic debris to deeper levels, causing additional oxygen consumption as bacteria and other fauna degrade the debris. Third, increased particle loads in shallow areas may hinder filter feeding by invertebrates and cause water clarity and photosynthesis by SAV to decrease. Fourth, increased nutrient loading (and warming) stimulates growth in epiphytic algae on the blades of the SAV, reducing the light available to the SAV (Najjar et al., 2000). Losses in SAV and their physical buffering of wave action along shorelines can contribute to increases in coastal erosion, which may further decrease water clarity.

Waterfowl use of the Chesapeake Bay and Back Bay has changed tremendously in the last 50 yr. Wintering population sizes of most duck species have declined steadily since the 1950s, while population sizes of Canada geese and snow geese have increased (Najjar et al., 2000). Most of these changes are attributed to changes in waterfowl food resources in and around the Bay, particularly the widespread decline of SAV. Projections of warming Bay waters, possible streamflow increases, and increasing coastal populations suggest that water quality and therefore SAV will continue to decline, leading to further declines in SAV-dependent waterfowl. Diving ducks and many other birds could also be negatively impacted by the anoxia-induced declines in shellfish (Najjar et al., 2000). Seeing as the American Black Duck, American Wigeon, and Tundra Swan all depend on SAV as a food source, a decline in SAV in Back Bay NWR will heavily impact these species.

Factors outside the mid-Atlantic will likely play a role as well. For example, the warmer and drier projections for the prairie pothole region of the north-central US and south-central Canada could cause the number of pothole wetlands and, correspondingly, the number of ducks breeding in the region to be reduced (Najjar et al., 2000). In turn, this could reduce waterfowl abundance in MAC waters because many of the ducks that winter there breed in the pothole region. Declining breeding population sizes and fewer young produced under increasing drought conditions on the prairies coupled with likely declines in wintering habitat quality due to climate change bode poorly for future *Anatidae* populations on MAC waters.

STAKEHOLDERS AND DECISION MAKING

Historically, the greatest successes in waterfowl management were motivated by crisis. Widespread drought and declining waterfowl populations during the 1930s led to the creation of the U.S. Migratory Bird Hunting and Conservation Stamp ("Duck Stamp") and related investments in habitat conservation (U.S. Fish and Wildlife Service, 2012). Important nongovernment waterfowl conservation organizations were founded during the same decade, and set to work on both domestic habitat programs and internationally funded habitat projects in Canada as well.

In the 1980s, drought, poor nesting cover, and declining duck populations prompted a bold response from the waterfowl management community, the establishment of the North American Waterfowl Management Plan (NAWMP, U.S. Fish and Wildlife Service, 2012). International agreement over shared objectives and a vision for public-private partnerships evolved into Joint Ventures. This regional partnership-based approach to conservation has been widely emulated and universally acclaimed. The Joint Ventures in existence today encompass most of North America, and have expanded in geography and broadened their taxonomic focus to include all birds. Joint Ventures have developed decision support tools that are now essential for biological planning and evaluation, and their habitat delivery programs are the backbone of the NAWMP.

Migratory Bird Joint Ventures are voluntary, cooperative, regional partnerships of private industry and private landowners working alongside federal and state agencies, non-profit organizations, tribes, academia, businesses, conservation organizations, individual citizens, and other partners (Migratory Bird Joint Ventures). For example, the Atlantic Coast Joint Venture is concerned with the conservation of habitat for native birds in the Atlantic Flyway. Joint venture partners work together to build and sustain a healthy world for birds, other wildlife, and people. Partnership organizations such as joint ventures are an impactful stakeholder for migratory birds.

Another key NGO group is the Friends of Back Bay. They helped in gaining approval for the expansion and obtaining $24 million of funds from the Land and Water Conservation Fund to purchase land from willing sellers within the acquisition boundary (U.S. Fish & Wildlife Service). The expansion provided a buffer against development, thus reducing erosion and runoff of fertilizers and chemicals that pollute Back Bay. Thus, water quality, has improved, there has been a marked increase in the amount of submerged aquatic vegetation and the numbers of ducks, geese and other waterfowl have increased.

Local, state, and federal agencies are also important stakeholders for migratory birds. The government has aided in passing important acts such as the Endangered Species Act and the Migratory Bird Treaty Act of 1918 (U.S. Fish & Wildlife Service). Agencies within the various branches of the government include the U.S. Fish & Wildlife Service (FWS), the United States Department of Agriculture, the Transportation Sector, the Army Corps of Engineers, Water Management, and many more agencies.

Other conservation achievements can be tied to policies and programs supported by the general public and not directly targeted to waterfowl. In the United States, the Clean Water Act has protected many wetlands through regulation (U.S. Fish and Wildlife Service, 2012). Another U.S. policy initiative, the Farm Bill, enacted programs such as the Conservation Reserve Program (CRP) and the Wetlands Reserve Program (WRP) that have restored large expanses of grasslands and wetlands, and contributed significantly toward reaching NAWMP goals. Similarly, the Agricultural Policy Framework in Canada enhanced awareness of environmental issues through the Environmental Farm Planning initiative, and created incentives for restoring wetlands and converting cultivated uplands to permanent cover through the National Farm Stewardship and Greencover Canada programs. Collectively, the Agricultural Policy Framework in Canada and the U.S. Farm Bill have funded and incentivized the conservation of hundreds of thousands of hectares of waterfowl habitat.

Within the United States, The U.S. Fish and Wildlife Service is the principal agency charged with protecting and enhancing the populations and habitats of migratory birds that spend all or part of their lives in the United States. Cooperation and coordination with partners and stakeholders is essential to successfully protect and conserve waterfowl. State wildlife agencies, tribal organizations and subsistence users play special roles by working with the Service to co-manage waterfowl harvest (U.S. Fish and Wildlife Service, 2012). These and other partners, including other government agencies, conservation organizations, private industry, landowners, and managers at every scale contribute as stakeholders involved with migratory waterfowl. And beginning in 1955, Canadian and U.S. partners developed what is today the longest operating and most comprehensive survey of animal abundance in the world, the Waterfowl Breeding Population and Habitat Survey. The North American Wetlands Conservation Act (NAWCA), now the premier partnership-based habitat conservation effort on the continent, was enacted to support goals of the 1986 Plan with strategic investments in North America's most vital wetland ecosystems. Grants made through NAWCA have helped thousands of public-private partnerships to protect and improve the health and integrity of wetlands, providing critical habitat for waterfowl and other wetland species in the United States, Canada, and Mexico.

Habitat management and harvest regulations have been ineffective at reversing the general decline of the hunting stakeholder group. The decline in hunter numbers continues despite abundant waterfowl populations and over a decade of unprecedented hunting opportunity. U.S. waterfowl hunters have decreased 27% since the 1970s, and continue to decline (U.S. Fish and Wildlife Service, 2012). Canadian waterfowl hunter numbers decreased 55% during the same period, though their numbers appear to have stabilized. Many managers question how the current model of waterfowl conservation can be sustained if waterfowl hunter numbers continue to decline, since they bring a large sum of funding to waterfowl conservation efforts. However, recreational hobbies related to waterfowl such as waterfowl viewing and photography, has been steadily increasing. Given their growing numbers, this group of outdoor enthusiasts has the potential to be another cornerstone of waterfowl conservation.

Our society faces a more complex set of environmental and management problems, occurring across the entire ranges of waterfowl, as a result of increasingly evident socioeconomic and ecological system changes (U.S. Fish and Wildlife Service, 2012). Human objectives will span a range from a relatively narrow segment of society to the public. Within the populace are individuals with multiple motivations for their behavior. These motivations will not all be complementary, and difficult tradeoffs will be necessary. Satisfying one group of stakeholders might occasionally disadvantage another.

OPTIONS TO ADAPT AND RECOMMENDATIONS

Increased protection for existing wetlands and removal of stresses may not only reduce the sensitivity of plants and animals to small changes in temperature or precipitation but also achieve broader wetland protection and restoration goals. Other measures for achieving broader objectives and reducing climate change impacts include development setbacks for coastal and estuarine wetlands, sediment diversions for dams, linking presently fragmented wetlands and waterways to provide the corridors needed for plant and animal migration, using water control structures for some wetlands to enhance particular functions and address decreased precipitation and/or increased evaporation, long-term securement of water resources for wetland conservation, increasing management programs for exotic species, and implementing various wetland restoration measures (Burkett and Kusler, 2000).

PARTNERSHIPS

Refuge staff do not often possess the necessary skills and time to conduct landscape level work outside the Refuge. State, City, private and other Federal agencies exist that do, together with local citizens. Because of mutual interests in the same natural resources, new partnerships need to be forged, that provide mutual benefits to all partners, pool funding, and shortstop potential problems before they become problems. These partnerships should also present possible solutions to current and future habitat degradation issues. Such important field data and information may help prevent future isolations of wildlife populations, in addition to providing evidence that habitat restoration efforts are in fact working. The Refuge alone cannot accomplish the necessary major improvements, on the landscape and/or ecosystem level, that would truly make a difference to Refuge natural resources; however, specialized teams or partners can.

REDUCE PRESSURES ON SPECIES FROM SOURCES OTHER THAN CLIMATE CHANGE

This strategy seeks to reduce or remove other, non-climate stressors to give wildlife species the maximum flexibility to evolve responses to climate change. Species experience multiple stressors, and the removal of these other stressors may allow individual species the flexibility needed to adapt to climate change (Mawdsley et al., 2009). Although numerous other stressors affect species, limited resources are available to address the broad suite of stressors. Given these circumstances, there is potential for a loss of focus and much diffuse action across a broad range of stressors. The reduction of stressors causes by human activities will increase the resiliency of habitats and species to the effects of climate change and variability (Erwin, 2009). This situation is what good management already seeks to accomplish. However, a changing climate amplifies the need for managers to minimize effects these stressors have on wildlife populations.

LONG TERM PERSPECTIVE

Global climate change is recognized as a threat to species survival and the health of natural systems. Scientists worldwide are looking at the ecological and hydrological impacts resulting from climate change. Climate change will make future efforts to restore and manage wetlands more complex. Wetland systems are vulnerable to changes in quantity and quality of their water supply, and it is expected that climate change will have a pronounced effect on wetlands through alterations in hydrological regimes with great global variability. Wetland habitat responses to climate change and the implications for restoration will be realized differently on a regional and watershed level, making it important to recognize that specific restoration and management plans will require examination by habitat. Floodplains, mangroves, SAV beds, saltmarshes, arctic wetlands, peatlands, freshwater marshes and forests are very diverse habitats, with different stressors and hence different management and restoration techniques are needed. The Sundarban (Bangladesh and India), Mekong river delta (Vietnam), and southern Ontario (Canada) are examples of major wetland complexes where the effects of climate change are evolving in different ways (Erwin, 2009). Thus, successful long term restoration and management of these systems will hinge on how we choose to respond to the effects of climate change.

The global trends impacting society and migratory waterfowl often manifest themselves in the form of largescale habitat (landscape) stressors. Examples include land use changes resulting from agricultural practices, energy extraction, and climate change. Some of these stressors induce directional change in ecosystems that may confound or even invalidate the models used to manage waterfowl populations and harvest. Understanding these stressors and associated nonstationary in the system is critical to making informed management decisions (U.S. Fish and Wildlife Service, 2012). Since climate change has such a powerful impact on bird habitats and resources, it is important to understand how and where these effects will be manifested, landscapes that supports healthy bird populations can be proactively preserved (U.S. Fish & Wildlife Service). Therefore, climate change research and habitat change predictions is an extremely important option that must be implemented.

Monitoring is an essential element of ecosystem management, in that it is in intended to detect long-term ecosystem change, provide insights to the potential ecological consequences of the change, and help decision makers determine how management practices should be implemented. Monitoring may be used as a starting point to define baseline conditions, understand the range of current variability in certain parameters and detect desirable and undesirable changes over time within reserve areas and adjacent ecosystems (Erwin, 2009). Conducting medium- and long-range planning that incorporates climate change and variability would be extremely helpful in regards to habitat management. If climate change and variability are not proactively taken into account, the potential for conservation plans to succeed will likely be much reduced (Erwin, 2009). The nature of climatic and ecological changes that are likely to occur regionally must be understood to properly design wetland management and restoration plans at the watershed level.

KEY RESTORATION AREAS

Habitat restoration can be a powerful conservation tool for maintaining healthy bird populations. For example, the U.S. FWS works with partners to promote and assist with habitat restoration and conservation areas across the nation through grant programs, migratory bird management plans and various partnership initiatives (U.S. Fish & Wildlife Service). Precise and viable habitat restoration efforts in critical areas that will not be degraded frequently would provide habitat to migratory species.

Waterfowl would benefit marginally by improved SAV habitat. Furthermore, the infrequency of previously referenced water quality data collection (once every three months) presents the possibility of missed spikes or peaks in nutrients, silt, or other pollutant discharges into the watershed. A closer analysis of specific water quality parameters critical to the health and well-being of SAV beds needs to be conducted at the most critical times of year to better understand this complex issue.

Federal, state, and local governments should, on a regional basis, identify and target for active management wetlands most susceptible to small changes in climate. Wetlands, which will meet not only present but future needs (e.g., waterfowl production) under various climate change scenarios should receive high priority for protection, acquisition, and management. Wetland restoration and creation may be used to offset some of the impacts of climate change. For example, salt marsh restoration might be implemented in tidally restricted or degraded wetlands. New peat-lands might be created through impoundment in some areas. But, there will be both economic and other practical limits upon use of such methods (Burkett and Kusler, 2000). Back Bay NWR could better prepare itself from climate change related hazards and the proliferation of many species with continued land acquisition and the establishment of corridors to these areas. Additionally, to minimize losses in the future, Back Bay NWR could begin to convert a couple of the impoundments that are the most susceptible to breach and/or sea level rise to brackish water.

We must develop a strategy for selecting and managing restoration areas appropriately. As wildlife and habitats have declined across North America, the establishment of refuges, parks, and reserves has been used as a conservation strategy. However, placement of conservation areas has rarely considered potential climate change and variability. For example, in highly fragmented habitats, the placement of conservation areas on a north–south axis may enhance movements of habitats and wildlife by providing northward migration corridors (Erwin, 2009). Efforts to conserve habitats for single, or small numbers of species, should be concentrated in northern portions of their range(s), where suitable climate is more likely to be sustained.

MOVEMENT CORRIDORS, STEPPING STONES, AND REFUGIA

The impacts of climate change will differ regionally. Within some regions, a number of wetlands will disappear from the landscape, especially those drier end systems and systems that are already under stress and their resiliency has been compromised. Many wetlands may 'drift' spatially within the region due to changes in precipitation and PET rates depending upon future land use, topography and hydro-patterns (Erwin, 2009). Therefore, habitat migration must be allowed. Loss of important habitats cannot be totally avoided. One option is to create habitat that will benefit the affected species elsewhere, reducing the effects of the lost habitat(U.S. Fish & Wildlife Service). Furthermore, as climate change pressures continue, allowing habitats to move due to sustained deviations in climate norms will positively impact conservation efforts. Mapping future migratory paths under certain climate change scenarios, and then aiming to ensure reasonable habitats along these paths would be extremely advantageous, but would require changes in land use planning. This strategy would direct protection efforts toward areas and regions that have been deemed essential for climate induced wildlife movements (Mawdsley et al., 2009). Such areas might include movement corridors for terrestrial species, habitat islands that could serve as stepping stones between larger reserves, stopover areas for migratory waterfowl, or refugia where climate-change impacts are predicted to be less severe.

However, with migrating species and habitats, invasive species should always be considered. Rapidly changing climates and habitats may increase opportunities for invasive species to spread because of their adaptability to disturbance (Erwin, 2009). Invasive species control efforts will be essential, including extensive monitoring and targeted control to preclude larger impacts.

MANAGE AND RESTORE ECOSYSTEM FUNCTION

Given the global trends that will influence future land use, waterfowl habitat objectives should be developed with careful consideration for the cost of maintaining habitat features and the long-term security of the habitat. Habitat objectives that emphasize permanent protection of naturally functioning systems will likely be more sustainable than objectives achieved through intensive use of human and natural resources (U.S. Fish and Wildlife Service, 2012). Objectives should be less reliant on habitat that may be lost when economic drivers change and more dependent on natural habitat secured through cost effective means like conservation easements or public policy. Protecting coastal wetlands and accommodate sea level change will be paramount. Impacts of sea level rise can be ameliorated with acquisition of inland buffer zones to provide an opportunity for habitats and wildlife to migrate inland (Erwin, 2009). Setback lines for coastal development can be effective at establishing zones for natural coastal migration based on projected sea level rise. Storm surge should also be considered in establishing buffer zones and setback boundaries. In other cases, restoration of natural hydrology could facilitate sediment accretion and building of deltaic coastal wetlands.

This strategy focuses on the maintenance of aspects of ecosystem function in conservation areas. It de-emphasizes historical condition, historic species composition, and the condition of reference sites as sources of management information. To implement this strategy, managers would first define key variables or indicators of ecosystem function, and then undertake activities designed to keep those variables within acceptable parameters.

Ecological conditions at individual sites are likely to shift in ways that are difficult to predict and that differ from historic reference conditions. To date, those practicing ecological restoration have used historic data or undisturbed reference sites as a baseline for management (Mawdsley et al., 2009). Given the significant shifts that have and will occur in species distributions, it may be easier for managers to focus on sets of variables describing ecosystem function, rather than attempting to maintain a particular species composition or community type at a given site. For example, differences in habitats selected by mallards and American Black Ducks suggest that creation of new, small impoundments or the restoration of wetlands in agricultural areas may not benefit breeding Black Ducks as much as it helps mallards and other dabbling ducks (Rusch et al., 1989). Because ducks congregate to molt, damage to food resources in molting habitats might be more consequential than destruction of nesting and brood-rearing areas. As with breeding habitat, enhancement of wetlands in the staging and wintering areas of Black Ducks by usual techniques, e.g., by preventing drainage, controlling water levels, or reducing disturbance, seems to do less for Black Ducks than for most waterfowl. Habitat enhancement for Black Ducks may require extensive landscape alteration, raising important and difficult questions about the appropriateness and cost-effectiveness of selective actions favoring a single species.

This strategy may be difficult to implement in practice without focusing on individual ecosystem components. Shifting the focus of management from components to functions may mean some components will become extirpated or extinct (Mawdsley et al., 2009). Depending on the attributes of ecosystem function selected, it may be possible to maintain these variables within acceptable limits with a greatly reduced complement of species or even with non-native species.

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