WIND AND WATERBIRDS

Establishing sustainable mortality limits within the Atlantic Flyway

The Center for Conservation Biology

College of William & Mary

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EXECUTIVE SUMMARY

In recent years, offshore wind development has become one of the fastest growing energy sectors in the world and the focus of the clean energy movement in the United States. The Atlantic Coast offers shallow, near-shore waters in close proximity to large load centers with some of the most lucrative and rapidly expanding energy markets in the country. Wind energy along the Atlantic Coast is projected to become a 170 billion dollar industry that could significantly reduce dependency on fossil fuels. All coastal states north of South Carolina support wind development and have adopted Renewable Portfolio Standards that include an estimated 54,000 megawatts of offshore energy by 2025. To meet these collective policies with current turbine technology would require the deployment of 10-20,000 turbines in waters with less than 30-m depth over the next 15 years.

The Atlantic Flyway supports one of the largest near shore movement corridors of birds in the world including many declining species of conservation concern. Much of the bird activity along the flyway occurs within a thin veneer along the coastline. Birds funnel through the flyway from a broad geographic area and their relationships to the Atlantic Coast are diverse. In addition to using the coastline as a movement corridor, many species use portions of the Atlantic Coast as migratory staging areas, breeding grounds or wintering grounds. Of particular conservation significance are taxonomic forms or populations that depend exclusively on the Atlantic Coast for some portion of their life cycle

Buildout of the wind industry along the Atlantic Coast will result in the largest network of overwater hazards ever constructed, adding another layer of mortality to many populations that are contending with a list of human-induced sources of mortality. From a population perspective, the central question is not how many individuals are killed annually but if the focal population is able to sustain the mortality incurred and still reach management objectives. Mortality is a cumulative factor in population regulation and defining limits on human-induced mortality is a critical component of management decisions.

This report uses a form of harvest theory referred to as Potential Biological Removal (PBR) to develop a population framework for estimating sustainable limits on human-induced mortality. The approach is appropriately precautionary in using minimum population estimates and a graded recovery factor designed to allow for species recovery. The approach has the benefit of requiring relatively few demographic parameters.

Enough information was available from the literature for 46 nongame waterbird species to allow for estimates of sustainable mortality limits (from all human-caused sources). Several populations stood out as having particularly low mortality limits including the Atlantic breeding populations of roseate tern, piping plover, and American oystercatcher, the Hudson Bay population of marbled godwit that winters along the south Atlantic, the *rufa* form of the red knot that uses the Atlantic Coast as a staging area during migration, and the estimated population of common loons wintering along the Atlantic Coast. Several other species for which demographic estimates are not currently available are also likely vulnerable to elevated mortality.

BACKGROUND

Wind-energy Development

Along with many nations throughout the world, the United States is actively pursuing a diversified energy portfolio that includes a greater reliance on clean, renewable sources of energy that may be produced domestically. This new strategy is being driven by the need to have greater internal control over cost and supply but also by the need to reduce the risks of major environmental impacts such as climate change. The U.S. demand for electricity is projected to increase by 39% to 5.8 billion megawatt-hours (MWh) over the next 20 years (Lindenberg et al. 2008). Wind is expected to play an increasing role in meeting this demand with the stated objective of supplying 20% or 1.16 billion MWh of the market by 2030 (Lindenberg et al. 2008). Meeting this objective will require the development of new technologies, the construction of new infrastructures, the growth of new industries, and the formulation of new government policies.

The United States supports tremendous wind resources that if captured effectively have the potential to exceed all of the country's electricity demands for the foreseeable future. The nation supports an estimated 8,000 gigawatts (GW) of available land-based wind resources that industry suggests can be captured economically (Black and Veatch 2007). This potential along with government incentives has lead to explosive growth in the output of the domestic wind industry. Since 1998 output has increased with an average doubling time of just 2.7 years and by 2008 had exceeded 25,000 MW (Figure 1), making the United States the global leader in wind energy production (American Wind Energy Association (AWEA) 2009). Wind now makes a significant contribution to the mix of renewable energy resources and is second in output only to hydroelectric power generation (EIA 2009).

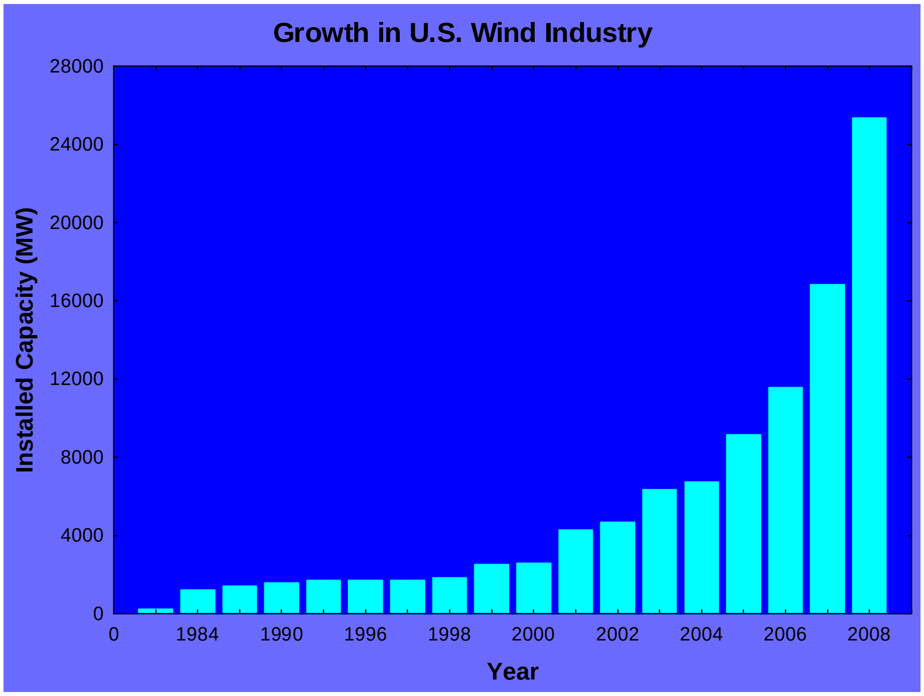

Figure 1. Growth in U.S. wind industry (1981-2008). Average, annual doubling time in capacity was 2.7 years. Adapted from AWEA (2009).

The spatial distribution of wind energy generation relative to the market continues to be a challenge within the United States. Until recently, large-scale North American wind resources were believed to be concentrated within the Great Plains, northern Canada, and central Canada (Grubb and Meyer 1993). Although these resources are large enough to meet the entire continental demand, transporting this electricity to major load centers would require significant technological advances and investments in infrastructure (Cavallo 1995). The recent realization that near-shore coastal areas of the western Atlantic support significant wind resources in close proximity to urban markets has shifted the national strategy toward offshore wind development.

Offshore Wind Energy

Offshore, wind-generated electricity has the potential to make a major contribution toward meeting the domestic energy demand in the United States. Recent developments in turbine technology allow for the deployment of turbines out to 30-m depths (Figure 2). Near-shore (< 30 m depth) waters along the Atlantic Coast from the mid-Atlantic through New England support an estimated 96 GW of potential wind energy (Butterfield et al. 2004) that may be captured with existing technology. Fully exploiting this resource could displace the entire land-based generating capacity of the coastal states from Maine through Maryland (Energy Information Administration 2004). Wind potential in deeper waters out to 50 nautical miles that may be accessible to future technologies is estimated to represent an additional 386 GW (Kempton et al. 2005). These wind resources are close to urban markets, greatly reducing transmission costs and customers within these markets currently pay the highest electrical utility rates (Energy Information Administration 2009), making them attractive to potential investors. Offshore wind along the western Atlantic Coast is believed to represent a market in excess of 170 billion dollars.

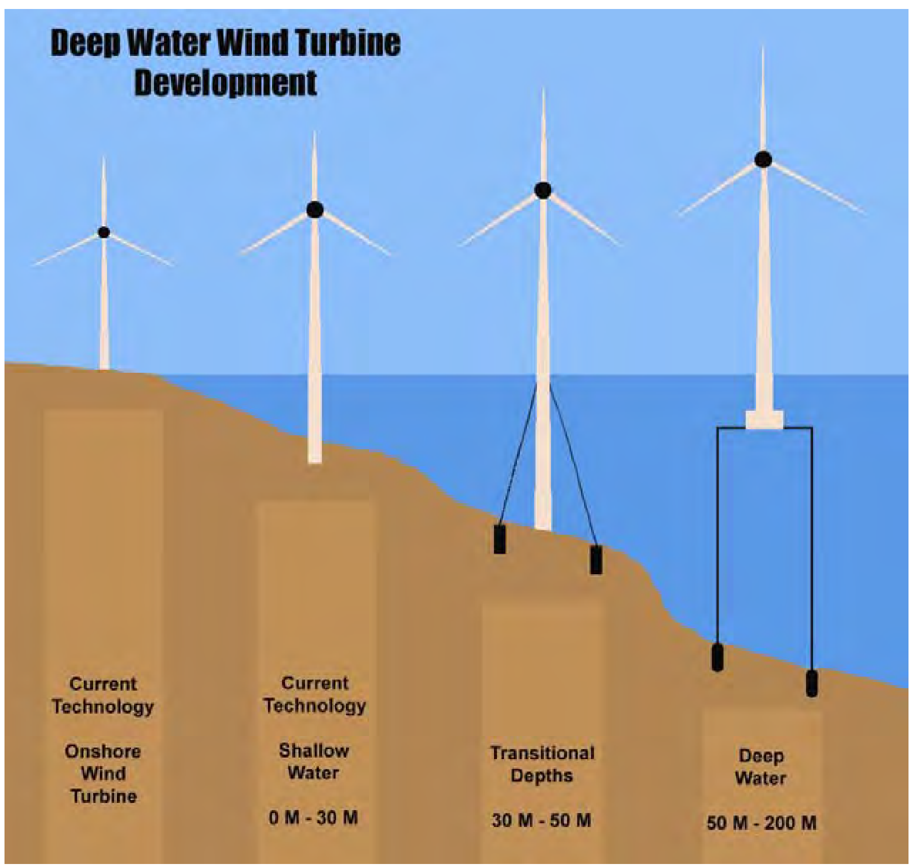

Figure 2. Development of wind turbine technology. Two on the left are existing technologies. Two on the right are anticipated, future technologies. Adapted from Musial and Butterworth (2004).

Policy Drivers

Energy policy will play a significant role in the development of the offshore wind industry. By early 2009, 33 states plus the District of Columbia had adopted Renewable Portfolio Standards that explicitly outline the percentage of energy sales to be derived from renewable sources by target dates (http:/www.epa.gove/chp/state-policy/renewable). Collectively, these policies outline the development of 76 GW of new renewable power by 2025, representing a 570% increase over 1997 levels. All of the coastal states north of South Carolina have adopted either portfolio standards or goals (Table 1). The states of South Carolina, Georgia, and Florida have not adopted formal policies, but continue to work toward renewable energy standards. Although several technologies meet the criteria for renewable energy under portfolio standards, it is expected that the expanding offshore wind industry will contribute 54,000 MW toward meeting existing policies along the western Atlantic Coast (Lindenberg et al. 2008).

Table 1. Renewable Portfolio Standards by state. Energy from RPS indicates the percentage of energy sales to be from renewable sources. Deadline indicates the target date to reach policy standards.

State	Energy from RPS	Deadline
Maine	40.0%	2017
New Hampshire	25.0%	2025
Massachusetts	25.0%	2025
Rhode Island	16.0%	2019
Connecticut	27.0%	2020
New York	25.0%	2013
New Jersey	22.5%	2021
Delaware	20.0%	2019
Maryland	20.0%	2022
Virginia	15.0%	2025
North Carolina	12.5%	2121

Complying with existing policy will result in the construction of the largest number of over-water hazards ever produced during the next 15-year period. Based on current turbine technology (2.6-5.0 MW), this equates to the construction of 10,000-20,000 turbines in the near-shore (<30 m depth) environment of the western Atlantic, an infrastructure estimated to require a 10,000 – 20,000 km^2 area of sea floor. This effort is comparable to that proposed by the European Union (Edge and Blanchard 2007). However, unlike the European trajectory that was initiated with the first marine wind farm in 1991 and now supports 38 farms in nine countries (Wilkes et al. 2010), the first industrial offshore wind operation in the United States was only approved in April, 2010 with 130 turbines scheduled for deployment by the end of 2012. To comply with existing portfolio standards will require a very rapid build out over the next 15 years.

Offshore Environment

Offshore waters along the Atlantic Coast that are accessible to current turbine technology (< 30-meter depths) are limited. Accessible waters are concentrated within the shallow bays and sounds, around Cape Cod, and along the coast south of Long Island (Figure 3). North of long island, most of these waters are contained within state waters. South of Long Island, the slope of the continental shelf is more gradual and accessible depths extend well out into federal waters. These areas include more than 81,000 km^2 within both state and federal waters. The accessible area will be reduced by an unknown amount due to exclusion zones for shipping lanes, military training, and marine refuges. Excluding bays and sounds, a significant portion of this total area would be consumed by wind farms if current renewable policies are to be met (Table 2).

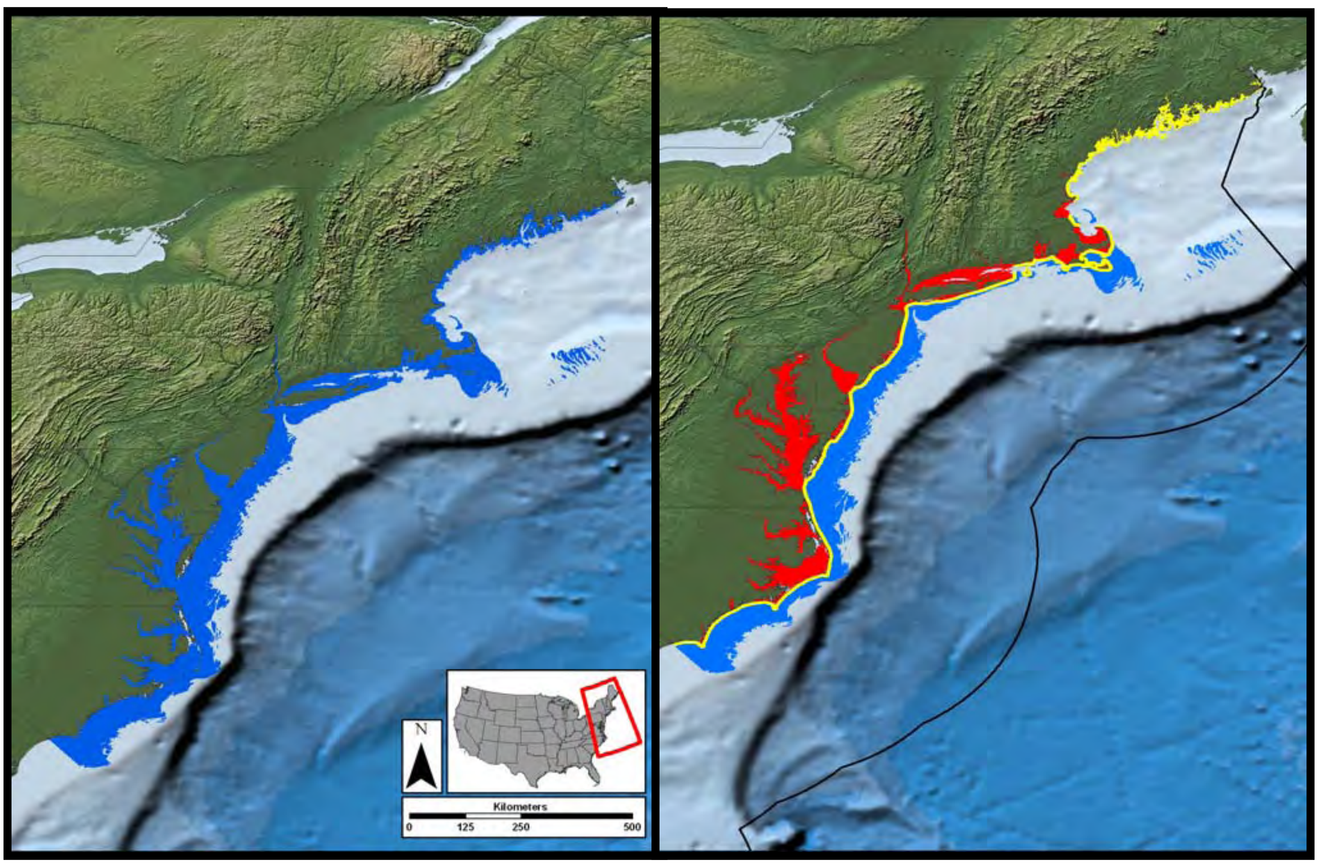

Figure 3. Map of northeastern Atlantic Coast showing the distribution of waters with less than 30-m depth (left) and an overlay of jurisdictional waters (right). Red areas indicate bays and

sounds that are in state waters, yellow areas indicate coastal state waters, and the black line indicates the seaward boundary of federal waters.

Table 2. Breakdown of bottom area in waters less than 30-m depth by state and jurisdiction. Values presented are in km^2.

State	State Waters Bays and Sounds	State Waters (0-3 miles)	Federal Waters (3-200 miles)	Total
Maine	11.7	2,758.0	15.9	2,785.6
New Hampshire	122.9	159.9	0.4	283.2
Connecticut	1,319.1	0.5	0.0	1,319.6
Massachusetts	2,429.6	2,283.5	5,989.7	10,702.8
Rhode Island	318.9	349.3	152.6	820.8
New York	2,563.4	1,250.8	2,296.5	6,110.7
New Jersey	1,460.7	1,199.0	6,306.1	8,965.8
Delaware	762.7	244.7	973.1	1,980.5
Maryland	5,186.1	258.7	1,339.4	6,784.2
Virginia	4,491.7	1,053.8	8,591.3	14,136.8
North Carolina	6,362.6	2,807.8	18,132.8	27,303.2
Total	**25,029.4**	**12,366.1**	**43,797.8**	**81,193.4**

Primary productivity in the offshore environment is not evenly distributed. Shallow bays, sounds, and shelf waters support the highest concentrations of primary productivity because they allow for full light penetration and because these waters are "fertilized" by tributaries carrying nutrients from land and marshes. These productive waters form the basis of extensive food webs that include fish, marine mammals, and birds. Well offshore in deeper waters, the Atlantic Basin supports a high biomass of consumers within the warmer gulfstream waters and in upwelling areas such as the well-known Georges Bank.

Atlantic Flyway

The Atlantic Flyway is globally significant as a major movement corridor for birds. The flyway supports hundreds of millions of birds annually including 164 species of waterbirds (Appendix 1) and a similar number of land birds, many of which are of conservation concern. The waterbird species include 33 seabirds, 36 waterfowl, 25 terns and gulls, 39 shorebirds, and a diverse mixture of herons, egrets, and rails. Greater than 35% of these species are believed to be declining. The assemblage of birds that utilize the flyway is diverse and their relationships to the Atlantic Coast are varied. The greatest volume of birds uses the flyway as a movement corridor between breeding and wintering grounds (Appendix 2). Birds funnel through the flyway from a broad geographic area ranging from the high latitudes of northern Europe to Siberia. All individuals from entire populations or species may move through the flyway making the area particularly significant for their survival. In addition to using the coastline as a movement corridor, many species use portions of the Atlantic Coast as migratory staging areas, breeding grounds or wintering grounds. Of particular conservation significance are taxonomic forms or populations that depend exclusively on the Atlantic Coast for some portion of their life cycle.

Much of the bird activity along the Atlantic Flyway occurs within a thin veneer along the coastline with waterbirds using a corridor between the shoreline and a distance of several kilometers and landbirds using a wider corridor between the shoreline and tens of kilometers inland (Appendix 2). Both groups may overlap with land or water and extend out considerable distances but the highest volume and diversity is centered on the shoreline. This pattern is often disrupted around bays and sounds or points of land that extend seaward from the coast where movement paths may be altered to reflect local conditions. During the breeding season, the distribution of waterbirds is constrained by nesting substrate along the immediate coast or on offshore islands. During the breeding season, winter season, and migratory staging periods, most activity is focused on bays, sounds, and nearshore, shallow water areas where primary productivity is high and prey is most abundant. Exceptions to this pattern include species that utilize the outer continental shelf, the shelf edge, or gulfstream where preferred prey may become available during specific times of the year.

Human-caused Bird Mortality

It is now estimated that human causes result in the mortality of 100 million to more than 1 billion bird deaths annually in the United States from sources including vehicle strikes (57 million; Banks 1979), building strikes (98-980 million; Klem 1990), communication tower strikes (40-50 million; Manville 2001), pesticides (67 million; Smithsonian Migratory Bird Center 1997), etc. Such mortality is the unintended result of our expanding infrastructure and every effort should be made to reduce their impact. Most of these mortality sources primarily involve passerines that have large geographic ranges and associated population sizes and relatively high reproductive rates. Although the increased mortality almost certainly contributes to population fluctuations, the specific linkages to population declines remain unclear.

The life history strategy of many waterbird species makes them particularly vulnerable to elevations in adult mortality (Saether and Bakke 2000, Weimerskirch 2002). Many waterbirds exhibit very high age-to-first reproduction and low fecundity such that high adult survivorship is essential to population maintenance. Even seemingly minor reductions in survivorship can lead to population declines. On a global scale, waterbirds are facing substantial sources of human-caused mortality including fisheries bycatch (Wilcox and Dolan 2007) from long-line (Klaer and Polacheck 1997, Belda and Sanchez 2001, Stehn et al. 2001) and gill-net fisheries (Davoren 2007, Benjamines et al. 2008) within all oceans, ingestion of floating plastics (Blight and Burger 1997, Derraik 2002), oil spills (Camphuysen and Heubeck 2001, Votier et al. 2005), over harvesting of fish (Furness 1982, 2003), etc. Collectively, these mortality factors have the potential to shift demographic rates and lead to population declines or species extinctions.

Offshore Wind Farms and Birds

Compared to the United States which currently has no offshore wind farms, the European research community has ongoing work investigating bird impacts within several wind farms and has developed a substantial body of research, much of which is pertinent to the western Atlantic (e.g. Exo et al. 2003, Desholm and Kahlert 2005, Desholm 2006, Drewitt and Langston 2006, Huppop et al. 2006). Although a full review of these findings is beyond the scope of this brief report, general patterns are directly relevant. Research suggests that due to ecological variation between species, the risk of wind farms to specific populations varies dramatically such that generalized mortality rates may mask the most significant impacts (Huppop et al. 2006). Investigators have identified 3 broad impact categories including 1) direct mortality from collisions or vortex injuries, 2) habitat loss or degradation, and 3) disturbance or avoidance behaviors that lead to increases in energy expenditures (Exo et al. 2003, Desholm 2006, Fox et al. 2006, Kaiser et al. 2006, Dewitt and Langston 2006). All three of these impacts may have population-level implications (Figure 4).

Although there is an extensive literature on rates of bird collisions with onshore wind turbines (e.g. Erickson et al. 2001, Drewitt and Langston 2006), due to the logistical difficulties of conducting direct studies, very little is available from offshore wind farms. Desholm (2006) estimated that 0.02% of the common eider population migrating near the Nysted wind farm in the Baltic Sea or 0.7 birds/turbine collided with turbines. Hatch and Brault (2007) estimated that 0.01 to 8.2 roseate terns may be killed by the wind farm proposed in Nantucket Sound off the coast of Massachusetts. Percival (2001) summarized several studies of turbine collision rates in coastal areas (though not offshore) and showed a range of 0.34 to 3.4 birds/turbine/year, many of which were waterbirds. Predicting the collision rate for offshore projects is tenuous at present due to the large number of variables that influence these rates and the lack of information from which to develop relationships. We know that mortality relationships are influenced by the position of the wind farm relative to bird migration routes and bird concentration areas (i.e. the volume of birds interacting with the wind farm), 2) the number of turbines, 3) the hub height and sweep area of turbines, and 4) species-specific avoidance behaviors and altitude profiles. Given the volume of birds using the Atlantic Flyway and the scope of proposed offshore wind development, it is very likely that annual collisions will be in the tens of thousands if not hundreds of thousands.

Direct mortality from collisions or from air turbulence injuries alone underestimates the overall impact of wind projects to waterbird populations. For species that depend on shallow, offshore waters for feeding, the construction of large wind farms within such waters represents a loss of habitat or a possible reduction in the capacity of the locality to support these species. For many species, this reduction in carrying capacity may have the greatest population-level impact (Larsen and Guillemette 2007). For species that avoid flying through or near wind farms, placement of turbines within migration corridors or between feeding and roosting areas may alter movement pathways and lead to greater energy expenditure (Desholm 2003, Masden et al. 2009). Since physical condition relates to survivorship and to breeding success, these changes likely have population-level implications.

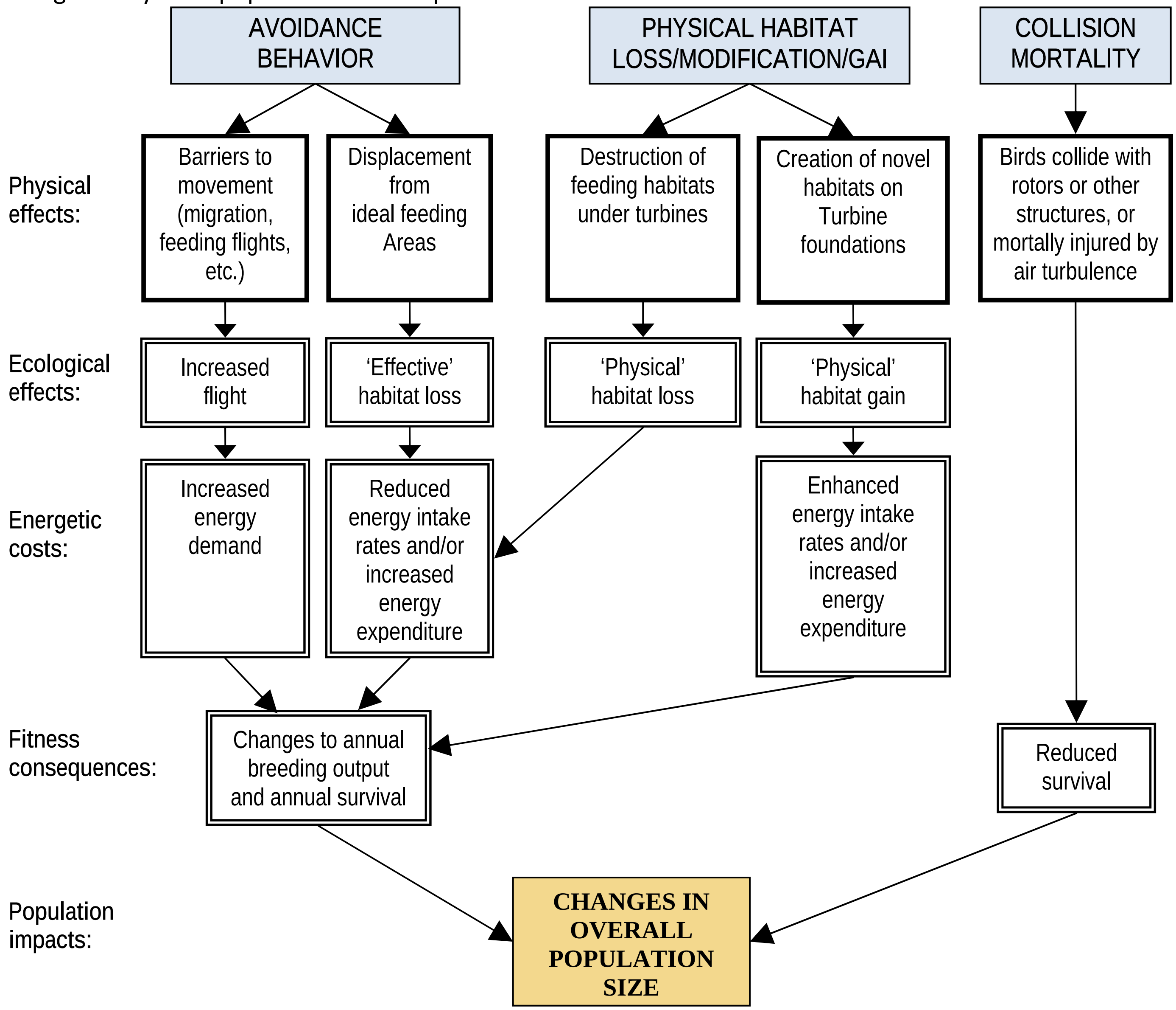

Figure 4. Chart of three classes of avian impacts from offshore wind farms linking impacts to populations (modified from Fox et al. 2006). The boxes with heavy solid frames indicate potentially measurable effects, double-framed boxes indicate processes that need to be modeled and the dark box indicates the common currency by which all impacts should be measured and compared.

Population-level Impacts

At the population level, probability of impact from a specific hazard is determined by the two independent factors 1) exposure and 2) vulnerability.

Population exposure to a hazard is the extent to which the population is expected to interact with and be impacted by the hazard. In the case of wind turbines, this includes the extent to which the population spatially overlaps with the hazard and the conditional probability that if it overlaps with the hazard that it will be impacted by the hazard. If a population has no spatial overlap with the hazard, then the likelihood of impact is expected to be 0. Minimizing exposure has been the primary strategy for reducing impacts to bird populations by deciding to place wind farms away from bird concentration areas. By doing so we reduce the exposure of populations to both direct (collision mortality) and indirect (disturbance and loss of carrying capacity) impacts. A great deal of effort has been invested and is ongoing in both Europe (Kruger and Garthe 2001, Langston and Pullan 2002, Huppop et al. 2006, King et al. 2009) and the United States (Geo-Marine 2009, Gilbert et al. 2009) in understanding the distribution of migration corridors, breeding populations, winter populations, and flight altitudes of many species. In some situations this has culminated in the production of spatially-explicit guidelines that detail the distribution of expected impacts (Garthe and Huppop 2004, Bright et al. 2008).

Population vulnerability is the susceptibility of a population to perturbations in vital demographic rates. Life history strategies are inexorably linked to vital rates. Thus, the impact of a perturbation to survival, growth, or reproduction should in part be dependent on the life history strategy of the affected population. For example, a decrease in adult survival rate should be more detrimental to population persistence in populations that are long lived with low reproductive success, than in those that are short lived with high reproductive rates. Because the response of populations to demographic perturbations are species and often population specific, we are unable to understand the significance of mortality rates associated with hazards without first understanding the sensitivity of populations to such mortality. The remainder of this report is focused on describing and applying a framework for estimating sustainable mortality limits.

POPULATION FRAMEWORK

Sustainable limits on incidental mortality

Construction of a single wind turbine virtually anywhere on the globe will result in bird collisions. Construction of large wind farms within migration corridors may result in the loss of hundreds of thousands of birds. Although some may argue that no mortality should be tolerated and minimizing mortality should always be a present goal, given the infrastructure needs of society, driving human-induced mortality to 0 is not practical. Some mortality events such as the raptor kills in Altamont Pass where significant percentages of populations are being lost to wind turbines are not acceptable and management intervention is clearly needed (Hunt et al. 1999, Hunt 2001). While we may agree that the loss of 1 individual herring gull that exists within an expanding population of millions may not be of conservation concern, what about the loss of one individual Bermuda petrel with a population estimated to contain fewer than 50 breeding pairs? From a population perspective, the central question is not how many individuals are killed annually but if the focal population is able to sustain the mortality incurred and still reach management objectives. Defining limits on human-induced mortality is critical to making management decisions. If mortality is substantially greater than established limits then the population may be vulnerable to mortality-driven declines and further monitoring, analysis and possible management intervention is needed to prevent declines. If mortality is substantially below established limits then it is unlikely that the mortality is a dominant force in population trends.

Mortality is a cumulative factor in population regulation and, as indicated above, many waterbird populations are contending with multiple sources of mortality. The impact of wind farms on waterbird populations must not be viewed in isolation. The impact of individual wind projects must be viewed within the context of the broader network of wind projects proposed along the Atlantic Flyway and within the context of other human-induced sources of mortality. Wind farms will be adding to mortality rates that in some cases may be approaching or may have already exceeded limits of sustainability. Many waterbirds that use the Atlantic Flyway are either declining or significantly below recovery goals (Appendix 1). For several long-lived seabirds, mortality rates from fisheries bycatch alone appear to be beyond sustainable limits and are suspected of causing population declines (Lewison and Crowder 2003, Oro et al. 2004, Dillingham and Fletcher 2008). Introducing additional mortality sources should be done with caution. Unfortunately, assessments of mortality rates from other human-caused sources are mostly lacking making a full analysis of cumulative impacts infeasible at present.

Using harvest theory to estimate mortality limits

Harvest theory has a long history of development and application within a wide range of resource industries involving the exploitation of biological populations. Its underlying objective is to determine the upper limit of exploitation possible without eliminating the population on which the harvest depends. Much of the early development and formal treatment of this approach involved sustainable forestry but it has since become one of the founding principles on which the management of fish and wildlife populations is based. In its simplest form sustained yield means that individuals are not being removed from a population at a rate faster than they can be replaced by reproduction. Maximum sustained yield (MSY) is the highest rate of harvest that meets this condition.

The basic rationale of MSY may be demonstrated using the discrete logistic model

$$N_{t+1} = N_t + r_{max}N_t(1 - N_t/K) - h_tN_t$$

Where N_t is the size of the population at time t, r_{max} is the maximum intrinsic rate of growth for the population, K is the carrying capacity, and h_t is the harvest rate during the time period between t and t + 1. In the absence of harvest ($h_t = 0$), this model describes a population with a sigmoid-shaped or density-dependent growth curve (Figure 5a) where small populations grow rapidly at first but then slow as they approach carrying capacity due to the influence of crowding on reproductive rates. In terms of harvest, MSY corresponds to the point on the curve that represents the maximum rate of recruitment into the population. For a symmetrical growth curve, recruitment rate peaks at the inflection point or K/2.

For populations suitable for exploitation, annual harvest 1) reduces the initial growth rate and 2) lowers the equilibrium population size at some point below the carrying capacity. The relationship between sustainable harvest and the equilibrium population size can be illustrated with a simple yield curve (Figure 5b). All points along this curve represent sustainable harvest levels and the population can be held indefinitely at the corresponding size by removing individuals from the population annually at the prescribed rate. For a population growing according to the logistic model, MSY is equal to $r_{max}/2$ and the population experiencing this harvest rate will be held at K/2.

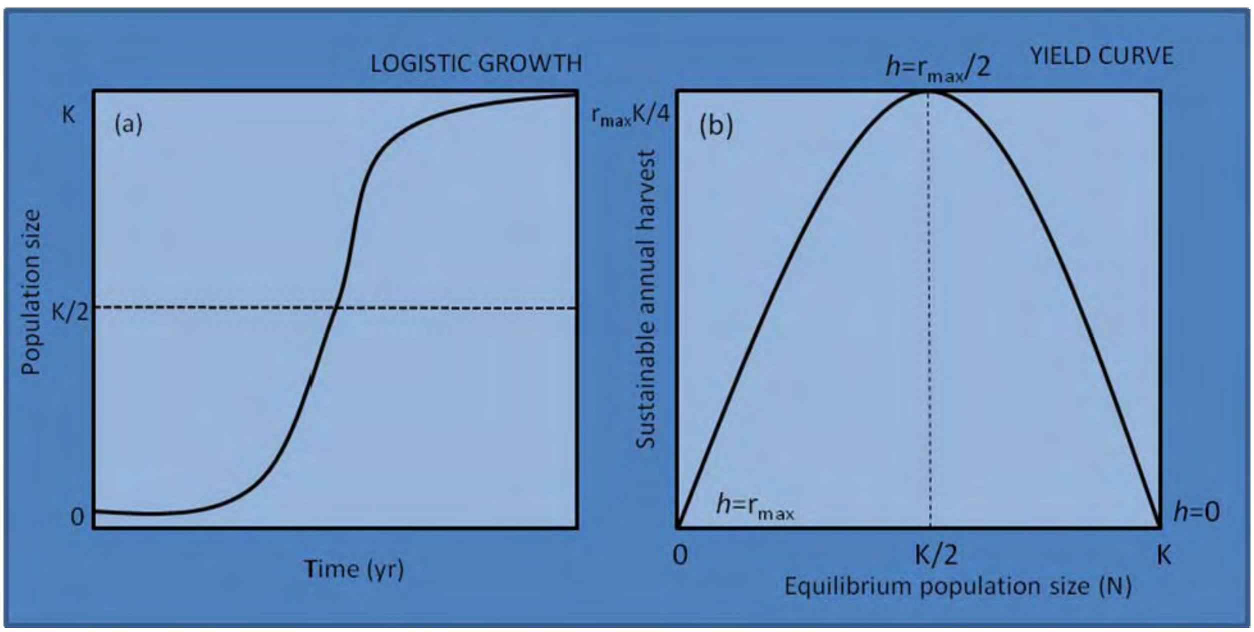

Figure 5. Simple logistic growth (a) and yield curve (b) illustrating the full range of sustainable harvest rates.

Potential Biological Removal (PBR)

In recent years, a new application of harvest theory has emerged with applications to populations of conservation concern (Wade 1998). Referred to as Potential Biological Removal (PBR) the objective of this model is to determine the levels of incidental take that will not jeopardize the focal population. As with harvest, sustained levels of incidental take have the potential to drive populations to extinction, hold populations below carrying capacity, or to change recovery trajectories. To date, this approach has been developed most fully within the marine mammal conservation community where it has been used to set sustainable limits on bycatch for the commercial fishing industry under the US Marine Mammal Protection Act (MMPA) (16 U.S.C. 1361). One of several stated objectives within MMPA is that marine mammals "should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem of which they are a part, and, consistent with this major objective, they should not be permitted to diminish below their optimum sustainable population". PBR has been used as the biological framework for evaluating limits to human-caused mortality that comply with this objective. In addition to its application to marine mammals, PBR has been suggested for use with bird species of conservation concern (Runge et al. 2004, Dillingham and Fletcher 2008) and more recently in the management of nuisance birds (Runge et al. 2009).

As a method for establishing limits on incidental take for species of conservation concern, PBR is particularly appealing because 1) it is based on data that can be collected, 2) it incorporates safeguards against uncertainties in the data, 3) it is compatible with performance criteria needed to evaluate the success of management schemes, and 4) it utilizes an approach that may be easily explained to constituencies. The incorporation of uncertainties into the approach is particularly critical because tools used to set limits on take should be precautionary to protect populations against severe declines. The formulation of PBR is

$$PBR = N_{min} \frac{1}{2} R_{max} F_R,$$

where, N_{min} is a minimum estimate of the current population size, R_{max} is the maximum population growth rate, and F_R is a recovery factor between 0.1 and 1.0. The formulation contains 2 precautionary parameters including N_{min} and F_R. Population size is set as the number of known individuals or, if multiple estimates exist, as the lower bound of a confidence interval (Wade 1998) to protect against the overestimate of sustainable take. A recovery factor is used to reduce the level of acceptable take for populations that are severely depleted. This factor is set at the discretion of managers based on the current state of the population relative to recovery goals, historic populations, or estimates of current carrying capacity. The factor is set on the low end of the range for species that are well below current capacity and on the high end of the range for species that are believed to be near capacity.

Applying PBR to waterbirds

Estimating R_{max}

R_{max} is the maximum intrinsic rate of growth for a population. This is the unfettered rate of growth with no density dependence and no harvest. It should be noted that unrestricted growth is not observable for most populations. Maximum growth is most frequently observed for species that have recently colonized a new area or that are recovering from severe declines. Since these conditions are relatively uncommon, estimates of R_{max} will typically not correspond to field measurements.

Conventional approaches to estimating R_{max} include 1) directly fitting an equation to a time series of population estimates during a period when the population is experiencing uncontrolled growth, or 2) developing a population model using estimates of demographic parameters measured during a period of rapid growth. Both of these approaches require information from species or specific populations during periods of rapid growth that are often not available.

A third approach for species where limited demographic data are available has been to estimate R_{max} using the maximum finite rate of population growth (λ) where $R_{max} = \lambda - 1$. Using the work of Cole (1954), Robinson and Redford (1991) used this approach to estimate the maximum rate of harvestable animals with minimal demographic data. Slade et al. (1998) generalized this approach by including information on pre-breeding mortality and adult survivorship. Their approach requires information on the age of first reproduction (α), age of senescence (ω), the number of offspring per reproductive adult (*b*), and if available survivorship to breeding age (l_α), and adult survival rate (*p*). Slade et al's equation is

$$1 = p\lambda^{-1} + l_\alpha b\lambda^{-\alpha} - l_\alpha bp^{(\omega-\alpha+1)}\lambda^{-(\omega+1)}$$

Although this approach is an improvement over those previously available, it is still difficult to apply to a broad list of species. The model requires several demographic parameters, making it accessible only to species that have been the subject of intensive population work.

Niel and Lebreton (2005) used a different approach to derive λ_{max}. By using the life-history invariant (Charnoff 1993) maximum growth rate per generation, $(\lambda_{max})^T$ where T is the species generation time, they were able to demonstrate that T under optimal conditions approximates $1/(\lambda_{max} - 1)$. They used two key relationships including

$\ln(\lambda_{max})T_{op} \approx 1$ and $T_{op} = \alpha + \frac{s}{\lambda_{max} + s}$

Combining these relationships (Dillingham and Fletcher 2008) yields

$$\lambda_{max} = \exp\left[(\alpha + \frac{s}{\lambda_{max} - s})^{-1} \right].$$

From this relationship, Niel and Lebreton (2005) provide an approximation of λ_{max} that requires only age to first reproduction (α) and adult survivorship (*s*).

$$\lambda_{max} \approx \frac{(s\alpha - s + \alpha + 1) + \sqrt{(s - s\alpha - \alpha - 1)^2 - 4s\alpha^2}}{2\alpha}$$

This formulation of λ_{max} was used in the current assessment with the PBR configuration of

$PBR = N_{min}F_R(\lambda_{max} - 1)$.

Assigning Fr

As envisioned by Wade (1998) and applied within an increasing number of conservation settings (e.g. Taylor et al. 2000, Niel and Lebreton 2005, Dillingham and Fletcher 2008), Fr is a recovery factor ranging from 0.1 to 1.0 that reflects management objectives and the status of a population relative to recovery goals. A value of 0.1 is typically used for highly imperiled species in order to afford the population the greatest opportunity to recover and to minimize risk of extinction. Higher values are used for populations that are closer to or have achieved conservation goals. Wade (1998) suggests that in most conservation settings Fr should not be set above 0.5 to guard against overestimation of the target population. I have adopted this recommendation here.

Values for Fr were taken from conservation scores assigned to waterbird species within the two nongame waterbird plans including North American conservation plans for shorebirds (Brown et al. 2001), waterbirds (Kushlan et al. 2002). Both the shorebird and waterbird plans provide status codes including highly imperiled, high concern, moderate concern, low concern, and not currently at risk. Fr values were assigned to conservation designations with 0.1 being assigned to species that were highly imperiled and 0.5 being assigned to species that were not currently considered to be at risk.

It should be noted that the values within the North American plans are based on continental trends and threats. Although these values often align with trends for populations tied to the Atlantic Flyway there are some species for which this may not be true. As more regional scores become available, recovery factors should be adjusted accordingly.

Estimates of Population Size

The network of wind operations proposed along the Atlantic Flyway and the mortality that will result is most relevant to bird populations that directly utilize the flyway. However, birds are extremely mobile and how the Atlantic Coast figures into the annual cycle of waterbirds is species-specific (Appendix 2). The source populations for many migrant, overwintering, and oversummering populations are not fully defined. Birds observed within specific locations in different seasons may have originated from different populations. Similarly, birds occurring together during the nonbreeding seasons may represent a complex mixture of source populations. Our ability to link human-caused mortality to the dynamics of particular populations, as well as, our ability to set appropriate mortality limits will improve with time as our understanding of these complex relationships advance.

Estimates of population size were taken from various literature sources. Most of these estimates were not the result of systematic surveys with known error rates but were compiled opportunistically and so vary in quality and time frame. Where possible and as appropriate, estimates are provided for populations specific to the Atlantic Flyway (Appendix 1). Global and continental estimates are provided for context. Taxa that are largely dependent on the western Atlantic Basin are highlighted. Estimates from the various sources were often presented in different units. For example, in the waterbird plan (Kushlan et al. 2002) population estimates are presented in units of breeding adults reflecting the fact that the majority of these estimates were made from surveys of breeding pairs. By comparison, the shorebird plan (Brown et al 2001) and the more recent update to these estimates (Morrison et al. 2006) presents estimates as total individuals. For the application here, the most appropriate unit would be total individuals. Although units are reported along with estimates, there has been no attempt here to convert estimates from breeding adults to total individuals. Although these conversions are clearly possible, the demographic data needed to project stable age structure is currently lacking for many species.

To avoid overexploitation of a species due to overestimation of population size, PBR requires the use of conservative population estimates that are based on the best scientific information available and provide a reasonable assurance that the population size is equal to or greater than the estimate. Wade (1998) suggested using the lower bound of a 60% confidence interval for the minimum population estimate. Virtually none of the population estimates available for waterbirds are based on samples with known variance estimates. For point estimates, Wade (1998) assumed that the population estimate followed a log-normal distribution with known coefficients of variation ($CV_N = \sigma_N/N$) where the pth percentile estimate is given by

$$N_p = \hat{N}\exp(Z_p\sqrt{\ln(1+CV_N^2)})$$

Where Z_p is the pth standard normal variate. Dillingham and Fletcher (2008) derive an approximation for N_{MIN} that is valid for $CV_N < 0.6$.

$$N_{\min} = \hat{N}\exp(Z_{0.2}CV_N)$$

This approximation was used here to convert published population estimates to N_{min} for use in PBR calculations.

Parameter Uncertainties

The analyses and resulting mortality limits presented here use fixed parameter estimates. Although safeguards are built into the PBR approach for population size and the specific conservation setting, it should be noted that demographic parameters exhibit inherent variation. Uncertainties in demographic parameters was not explored in this report. As more demographic information becomes available and allows for the assessment of more species and a deeper assessment of those treated here, future iterations of this exercise should evaluate the importance of parameter uncertainties in setting sustainable bounds on incidental mortality.

MORTALITY LIMITS FOR WATERBIRD WITHIN THE ATLANTIC FLYWAY

The majority (78%) of the 164 species of waterbirds were evaluated to determine if enough information was available to assess PBR. The remaining species including waterfowl, rails, and 2 shorebird species were excluded from consideration since they are actively hunted and harvest levels are evaluated and set annually by regulatory agencies. Of the remaining 118 species, enough information was found in the literature for 46 species to evaluate sustainable mortality limits (Appendix 3 and 4).

Estimated limits for sustainable mortality varied dramatically between species from more than 100,000 to less than 50 individuals (Appendix 3). In terms of absolute mortality rates, the species that were the least able to sustain mortality included the Atlantic breeding populations of roseate tern, piping plover, and American oystercatcher, the Hudson Bay population of marbled godwit that winters along the south Atlantic, the *rufa* form of the red knot that uses the Atlantic Coast as a staging area during migration, and the estimated population of common loons wintering along the Atlantic Coast. All of these populations that depend on the Atlantic Coast and Flyway are vulnerable to low rates of incidental mortality.

For the species evaluated here, sustainable mortality limits average approximately 4% of estimated population size. This equates to a rate of 500 for an estimated population size of 12,500 and may serve as a course rule of thumb for species where demographic information is not available to estimate PBR. Based on this approximation, several waterbird species associated with the Atlantic Flyway would be vulnerable (sustainable mortality rate below 200) to the cumulative sources of incidental mortality currently acting within the flyway. Of particular concern are several species of pelagic seabirds that are some of the most endangered birds in the world but for which we have little life history information.

All of the species of highest concern in appendix 3 have distributions that are focused on the nearshore. These species would be most vulnerable to wind farms established within state waters and caution should be taken when considering operations within these areas. The exception to this pattern is the pelagic seabirds that are associated with deep, offshore waters that are currently beyond the reach of current turbine technologies. When technology evolves to the point of realistic floating turbines, care should be taken to avoid specific waters that are used by these globally endangered species.

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APPENDIX 1. Population estimates for waterbird species that regularly use the Atlantic Flyway. Units include total individuals (t) and breeding individuals (b). Species in bold indicate unique taxonomic forms and underlined species indicate Atlantic Coast populations.

Species/Subspecies (population)	Common Name	AOU	Global Population	N. A . Population	Reference Population	Trend
Podiceps grisegena holboellii (w.A. wintering)	Red-necked Grebe	20	150,000-370,000t	45,000t	20,000t	Stable/unknown
Podiceps auritus cornutus	Horned Grebe	30	160,000-2,100,000t	>100,000t	100,000t	Declining
Podilymbus podiceps podiceps	Pied-billed Grebe	60	110,000-130,000t	125,000t	125,000t	Declining
Gavia immer (w.A. wintering)	Common Loon	70	580,000t	575,000t	7,400t	Declining
Gavia stellata	Red-throated Loon	110	490,000-1,500,000t	375,000t	70,000t	Declining
Fratercula arctica arctica (w.A. breeding)	Atlantic Puffin	130	5,700,000-6,000,000t	750,000-760,000b	6,898b	Increasing
Cepphus grylle arcticus (w.A. breeding)	Black Guillemot	270	400,000-700,000t	100,000-200,000b	36,097b	Increasing
Uria aalge aalge (w.A. breeding)	Common Murre	300	18,000,000t	4,250,000t	63,200b	Stable/unknown
Uria lomvia (w.A. breeding)	Thick-billed Murre	310	22,000,000t	8,000,000b	1,660b	Stable/unknown
Alca torda torda (w.A. breeding)	Razorbill	320	1,500,000t	75,000b	75,000b	Stable/unknown
Alle alle alle	Dovekie	340	16,000,000-36,000,000t	1,000b	unknown	Stable/unknown
Stercorarius skua	Great Skua	350	10,000-20,000t	unknown	unknown	Stable/unknown
Stercorarius maccormicki	South Polar Skua	352	10,000-20,000t	unknown	unknown	Stable/unknown
Stercorarius pomarinus	Pomarine Jaeger	360	50,000-100,000t	20,000-40,000b	20,000b	Stable/unknown
Stercorarius parasiticus	Parasitic Jaeger	370	500,000-1,000,000t	unknown	unknown	Stable/unknown
Stercorarius longicaudus	Long-tailed Jaeger	380	100,000-500,000t	>150,000t	150,000t	Stable/unknown
Rissa tridactyla tridactyla (w.A. breeding)	Black-legged Kittiwake	400	17,000,000-18,000,000t	3,126,000b	108,700b	Declining
Larus hyperboreus leucereles	Glaucous Gull	420	200,000-2,000,000t	160,430b	70,000b	Stable/unknown
Larus glaucoides kumlieni	Iceland Gull	430	190,000-400,000t	>100,000t	100,000t	Stable/unknown
Larus marinus (w.A. breeding)	Great Black-backed Gull	470	630,000-720,000t	160,430b	152,918b	Increasing
Larus fuscus fraellsii	Lesser Black-backed Gull	500	680,000-750,000t	unknown	unknown	Stable/unknown
Larus argentatus smithsoniaunus	Herring Gull	510	2,600,000-3,000,000t	>246,000b	246,000b	Stable/unknown
Larus delawarensis	Ring-billed Gull	540	2,600,000t	1,700,000t	1,700,000t	Increasing
Larus ridibundus ridibundus	Black-headed Gull	551	7,300,000-11,000,000t	40b	40b	Stable/unknown

Species/Subspecies (population)	Common Name	AOU	Global Population	N. A . Population	Reference Population	Trend
Larus atricilla megalopterus	Laughing Gull	580	810,000-840,000t	528,000-538,000b	528,000b	Increasing
Larus philadelphia	Bonaparte's Gull	600	260,000-530,000t	260,000-530,000t	260,000b	Stable/unknown
Larus minutus	Little Gull	601	570,000-1,700,000t	100-200b	100b	Declining
Xema sabina sabina	Sabine's Gull	620	330,000-700,000t	200,000-400,000b	200,000b	Increasing
Gelochelidon nilotica aranea (w.A. breeding)	Gull-billed Tern	630	79,000-310,000t	6,000-8,000b	2,418b	Declining
Hydroprogne caspia (w.A. migratory)	Caspian Tern	640	180,000-320,000t	66,000-70,000b	19,500b	Increasing
Thalasseus maximus maxima (w.A. breeding)	Royal Tern	650	280,000-310,000t	100,000-150,000b	66,000b	Stable/unknown
Thalasseus sandvicensis acuflavidus (w.A. breeding)	Sandwich Tern	670	460,000-500,000t	75,000-100,000b	9,000b	Increasing
Sterna forsteri litoricola (w.A. breeding)	Forster's Tern	690	120,000t	120,000t	16,690b	Declining
Sterna hirundo hirundo (w.A. breeding)	Common Tern	700	1,100,000-4,500,000t	300,000b	173,240b	Increasing
Sterna paradisaea (w.A. breeding)	Arctic Tern	710	1,000,000t	500,000t	180,000t	Declining
Sterna dougallii dougallii (w.A. breeding)	Roseate Tern	720	78,000-82,000t	16,000b	6,930b	Declining
Sternula antillarum antillarum (w.A. breeding)	Least Tern	740	65,000-70,000t	unknown	16,018b	Declining
Onychoprion fuscatus	Sooty Tern	750	21,090,000t	3,360,000-4,380,000b	Unknown	Stable/unknown
Onychoprion anaethelus recognita	Bridled Tern	760	774,000t	8,700-14,700b	Unknown	Declining
Chlidonias niger surinamensis	Black Tern	770	45,000-1,300,000t	100,000-500,000b	Unknown	Stable/unknown
Anous stolidus	Brown Noddy	790	1,375,000t	286,000-298,000b	286,000b	Increasing
Rynchops niger niger (w.A. breeding)	Black Skimmer	800	120,000-210,000t	65,000-70,000b	10,058b	Declining
Fulmarus glacialis auduboni	Northern Fulmar	860	8,000,000-32,000,000t	2,100,000b	2,100,000b	Stable/unknown
Calonectris diomedea borealis	Cory's Shearwater	880	280,000-420,000t	unknown	unknown	Stable/unknown
Puffinus gravis	Greater Shearwater	890	16,500,000t	unknown	unknown	Stable/unknown
Puffinus puffinus puffinus	Manx Shearwater	900	500,000-600,000t	360b	500,000t	Stable/unknown
Puffinus lherminieri lherminieri	Audubon's Shearwater	920	60,000t	6,000-10,000b	6,000b	Declining
Puffinus griseus	Sooty Shearwater	950	>20,000,000t	2,800,000t	2,800,000t	Declining
Pterodroma arminjoniana	Herald Petrel	960	<2,000b	unknown	unknown	Declining
Pterodroma feae	Fea's Petrel	970	<1,500b	unknown	unknown	Stable/unknown

Species/Subspecies (population)	Common Name	AOU	Global Population	N. A . Population	Reference Population	Trend
Pterodroma cahow	Bermuda Petrel	980	60b	unknown	unknown	Increasing
Pterodroma hasitata	Black-capped Petrel	1000	2,000-4,000b	unknown	unknown	Declining
Oceanodroma leucorhoa leucorhoa (w.A. breeding)	Leach's Storm Petrel	1060	8,000,000t	unknown	220,718b	Declining
Oceanodroma castro	Band-rumped Storm Petrel	1062	unknown	unknown	unknown	Stable/unknown
Oceanites oceanicus oceanicus	Wilson's Storm Petrel	1090	6,000,000t	unknown	unknown	Stable/unknown
Phaethon lepturus	White-tailed Tropicbird	1120	<10,000b	unknown	unknown	Declining
Phaethon aethereus	Red-billed Tropicbird	1130	<5,000b	unknown	unknown	Declining
Morus bassanus (w.A. breeding)	Northern Gannet	1170	530,000t	155,456b	107,640b	Increasing
Anhinga anhinga	Anhinga	1180	20,000-34,000b	20,000-34,000b	20,000b	Stable/unknown
Phalacrocorax carbo carbo	Great Cormorant	1190	1,000,000-1,600,000t	12,300b	12,300b	Stable/unknown
Phalacrocorax auritus auritus	Double-crested Cormorant	1200	1,100,000-2,200,000t	>740,000b	740,000b	Increasing
Pelecanus occidentalis carolinensis	Brown Pelican	1260	unknown	191,600-193,700b	1,008b	Increasing
Mergus merganser americanus	Common Merganser	1290	1,352,500t	1,000,000t	1,000,000t	Increasing
Mergus serrator	Red-breasted Merganser	1300	545,000t	250,000t	250,000t	Increasing
Lophodytes cucullatus	Hooded Merganser	1310	350,000t	350,000t	350,000t	Increasing
Anas Platyrhynchos platyrhynchos	Mallard	1320	22,930,000t	13,000,000t	13,000,000t	Stable/unknown
Anas rubripes	American Black Duck	1330	910,000t	910,000t	910,000t	Declining
Anas strepera	Gadwall	1350	4,965,000t	3,900,000t	3,900,000t	Increasing
Anas americana	American Wigeon	1370	3,100,000t	3,100,000t	3,100,000t	Increasing
Anas discors	Blue-winged Teal	1390	7,240,000t	7,240,000t	7,240,000t	Stable/unknown
Anas crecca carolinensis	Green-winged Teal	1400	3,900,000t	3,900,000t	3,900,000t	Increasing
Anas clypeata	Northern Shovelor	1420	5,690,000t	3,800,000t	3,800,000t	Increasing
Anas acuta acuta	Northern Pintail	1430	5,900,000t	3,600,000t	3,600,000t	Declining
Aix sponsa (eastern population)	Wood Duck	1440	4,600,000t	4,600,000t	4,400,000t	Increasing
Aythya americana	Redhead	1460	1,200,000t	1,200,000t	1,200,000t	Stable/unknown
Aythya valisineria	Canvasback	1470	740,000t	740,000t	740,000t	Stable/unknown

Species/Subspecies (population)	Common Name	AOU	Global Population	N. A . Population	Reference Population	Trend
Aythya marila mariloides	Greater Scaup	1480	1,410,000t	800,000t	800,000t	Stable/unknown
Aythya affinis	Lesser Scaup	1490	4,400,000t	4,400,000t	4,400,000t	Declining
Aythya collaris	Ring-necked Duck	1500	2,000,000t	2,000,000t	2,000,000t	Increasing
Bucephala clangula americana	Common Goldeneye	1510	4,600,000t	1,345,000t	1,345,000t	Stable/unknown
Bucephala islandica (eastern population)	Barrow's Goldeneye	1520	256,500t	255,000t	5,000t	Stable/unknown
Bucephala albeola	Bufflehead	1530	1,400,000t	1,400,000t	1,400,000t	Increasing
Clangula hyemalis	Long-tailed Duck	1540	6,200,000t	1,000,000t	1,000,000t	Declining
Histrionicus histrionicus (eastern population)	Harlequin Duck	1550	271,250t	254,000t	4,000t	Stable/unknown
Somateria mollissima dresseri	Common Eider	1590	2,900,000t	1,050,000t	300,000t	Stable/unknown
Somateria spectabilis	King Eider	1620	1,215,000t	575,000t	575,000t	Declining
Melanitta nigra americana	Black Scoter	1630	2,300,000t	400,000t	400,000t	Declining
Melanitta fusca deglandi	White-winged Scoter	1650	2,200,000t	600,000t	600,000t	Declining
Melanitta perspicillata	Surf Scoter	1660	600,000t	600,000t	600,000t	Declining
Oxyura jamaicensis jamaicensis	Ruddy Duck	1670	1,110,000t	1,100,000t	1,100,000t	Increasing
Chen caerulescens atlanticus	**Snow Goose (Greater)**	1699	4,045,200t	4,045,200t	702,700t	Increasing
Chen rossii	Ross's Goose	1700	619,000t	619,000t	619,000t	Increasing
Anser albifrons frontalis	Greater White-fronted Goose	1710	1,212,500t	1,212,500t	802,200t	Stable/unknown
Branta canadensis canadensis	Canada Goose	1720	5,200,000t	5,200,000t	1,178,300t	Increasing
Branta bernicla hrota	**Atlantic Brant**	1730	518,500t	306,500t	163,800t	Stable/unknown
Dendrocygna bicolor	Fulvous Whistling Duck	1780	260,000t	Unknown	Unknown	Increasing
Cygnus olor	Mute Swan	1782	587,700t	20,000t	20,000t	Increasing
Cygnus columbianus (eastern population)	Tundra Swan	1800	300,000t	186,300t	103,400t	Increasing
Ajaia ajaja	Roseate Spoonbill	1830	103,500t	20,500b	6,800b	Stable/unknown
Eudocimus albus	White Ibis	1840	>200,000b	>200,000b	100,000b	Increasing
Plegadis falcinellus falcinellus	Glossy Ibis	1860	1,100,000-3,300,000t	13,000-15,000b	13,000b	Increasing
Mycteria americana	Wood Stork	1880	114,000t	32,000b	32,000b	Declining

Species/Subspecies (population)	Common Name	AOU	Global Population	N. A . Population	Reference Population	Trend
Botaurus lentiginosus	American Bittern	1900	3,000,000t	3,000,000t	3,000,000t	Declining
Ixobrychus exilis exilis	Least Bittern	1910	>130,000t	128,000t	128,000t	Declining
Ardea herodias herodias	Great Blue Heron	1940	unknown	83,000b	42,232b	Increasing
Ardea alba egretta	Great Egret	1960	550,000-1,900,000t	180,000b	9,146b	Increasing
Egretta thula thula	Snowy Egret	1970	unknown	143,555b	15,774b	Declining
Egretta tricolor ruficolis	Tricolored Heron	1990	unknown	<194,000b	194,000b	Declining
Egretta rufescens	Reddish Egret	1980	unknown	6,000b	6,000b	Stable/unknown
Egretta caerulea	Little Blue Heron	2000	unknown	200,000-300,000b	200,000b	Declining
Bubulcus ibis ibis	Cattle Egret	2001	3,800,000-6,700,000t	>750,000-1,500,000t	750,000b	Increasing
Butorides virescens virescens	Green Heron	2010	unknown	unknown	unknown	Increasing
Nycticorax nycticorax hoactii	Black-crowned Night Heron	2020	430,000-3,600,000t	>50,000b	50,000b	Declining
Nyctanassa violacea violacea	Yellow-crowned Night Heron	2030	85,000-160,000t	50,000-100,000b	50,000b	Stable/unknown
Porphyrio martinica	Purple Gallinule	2180	100,000-1,000,000t	unknown	unknown	Stable/unknown
Gallinula chloropus cachinnans	Common Moorhen	2190	1,700,000-3,300,000t	unknown	unknown	Increasing
Fulica americana americana	American Coot	2210	3,000,000t	3,000,000t	3,000,000t	Increasing
Grus canadensis	Sandhill Crane	2060	652,500t	652,500t	4,000t	Stable/unknown
Aramus guarauna	Limpkin	2070	unknown	unknown	unknown	Declining
Rallus elegans	King Rail	2080	unknown	unknown	unknown	Declining
Rallus longirostris	Clapper Rail	2110	unknown	unknown	unknown	Stable/unknown
Rallus limicola	Virginia Rail	2120	unknown	unknown	unknown	Declining
Porzana carolina	Sora	2140	unknown	unknown	unknown	Declining
Coturnicops noveboracensis	Yellow Rail	2150	unknown	unknown	unknown	Stable/unknown
Laterallus jamaicensis	Black Rail	2160	unknown	unknown	unknown	Declining
Phalaropus fulicaria	Red Phalarope	2220	1,250,000t	1,250,000t	1,250,000t	Declining
Phalaropus lobatus	Red-necked Phalarope	2230	3,500,000t	2,500,000t	2,500,000t	Declining
Phalaropus tricolor	Wilson's Phalarope	2240	1,500,000t	1,500,000t	1,500,000t	Declining

Species/Subspecies (population)	Common Name	AOU	Global Population	N. A . Population	Reference Population	Trend
Recurvirostra americana	American Avocet	2250	450,000t	450,000t	4,500t	Stable/Unknown
Himantopus mexicanus	Black-necked Stilt	2260	175,000t	175,000t	175,000t	Stable/Unknown
Scolopax minor	American Woodcock	2280	3,500,000t	3,500,000t	3,500,000t	Declining
Gallinago delicata	Wilson's Snipe	2300	2,000,000t	2,000,000t	2,000,000t	Declining
Limnodromus griseus griseus (Hudson Bay)	Short-billed Dowitcher	2310	153,000t	153,000t	78,000t	Declining
Limnodromus scolopaceus	Long-billed Dowitcher	2320	400,000t	400,000t	400,000t	Stable/Unknown
Calidrisa himantopus	Stilt Sandpiper	2330	820,000t	820,000t	820,000t	Stable/Unknown
Calidris canutus rufa	Red Knot	2340	120,000t	120,000t	20,000t	Declining
Calidris maritima belcheri	Purple Sandpiper	2350	95,000t	15,000t	15,000t	Stable/Unknown
Calidris melanotos	Pectoral Sandpiper	2390	1,000,000t	400,000t	400,000t	Stable/Unknown
Calidris fuscicollis	White-rumped Sandpiper	2400	1,120,000t	1,120,000t	1,120,000t	Declining
Calidris bairdii	Baird's Sandpiper	2410	300,000t	300,000t	300,000t	Declining
Calidris minutilla	Least Sandpiper	2420	700,000t	700,000t	37,300t	Declining
Calidris alpina hudsonia	Dunlin	2430	6,400,000t	750,000t	225,000t	Declining
Calidris pusilla	Semipalmated Sandpiper	2460	2,000,000t	2,000,000t	1,500,000t	Declining
Calidris mauri	Western Sandpiper	2470	3,500,000t	3,500,000t	3,500,000t	Stable/unknown
Calidris alba	Sanderling	2480	600,000t	300,000t	300,000t	Declining
Limosa fedoa fedoa (Hudson Bay)	Marbled Godwit	2490	175,000t	175,000t	2,226t	Declining
Limosa Haemastica (James Bay)	Hudsonian Godwit	2510	70,000t	70,000t	10,000t	Declining
Tringa melanoleuca	Greater Yellowlegs	2540	100,000t	100,000t	100,000t	Stable/Unknown
Tringa flavipes	Lesser Yellowlegs	2550	400,000t	400,000t	20,100t	Declining
Tringa solitaria solitaria	Solitary Sandpiper	2560	150,000t	150,000t	21,000t	Declining
Tringa semipalmata semipalmatus	Willet	2580	250,000t	250,000t	90,000t	Stable/Unknown
Bartramia longicauda	Upland Sandpiper	2610	350,000t	350,000t	350,000t	Declining
Tryngites subruficollis	Buff-breasted Sandpiper	2620	30,000t	30,000t	30,000t	declining
Actitis macularius	Spotted Sandpiper	2630	150,000t	150,000t	150,000t	Stable/Unknown

Species/Subspecies (population)	Common Name	AOU	Global Population	N. A . Population	Reference Population	Trend
Numenius americanus	Long-billed Curlew	2640	55,000-123,500t	55,000-123,500t	55,000t	Declining
Numenius phaeopus hudsonicus	Whimbrel	2650	2,000,000t	66,000t	40,000t	Declining
Pluvialis squatarola cynosurae	Black-bellied Plover	2700	692,000t	200,000t	150,000t	Stable/Unknown
Pluvialis domimica	American Golden Plover	2720	200,000t	200,000t	200,000t	Declining
Charadrius vociferus	Killdeer	2730	1,000,000t	1,000,000t	1,000,000t	Declining
Charadrius semipalmatus	Semipalmated Plover	2740	150,000t	150,000t	150,000t	Stable/Unknown
Charadrius melodus melodus	Piping Plover	2770	5,945t	5,945t	2,953t	Increasing
Charadrius wilsonia	Wilson's Plover	2800	unknown	6,000t	6,000t	Stable/Unknown
Arenaria interpres interpres	Ruddy Turnstone	2830	500,000t	105,000t	45,000t	Declining
Haematopus palliatus	American Oystercatcher	2860	11,650t	11,000t	11,000t	Stable/unknown

APPENDIX 2. The seasonal occurrence of waterbird species within the Atlantic Flyway and the expected distribution relative to the coastline. There is latitudinal segregation for most species during the winter and summer such that they only occur in portions of area. Letter codes refer to breeding (B), summering (S), wintering (W), and migration (M). Summering individuals are resident during the summer but not breeding.

			Seasonal Occurrence					Seasonal Distribution					
Species/Subspecies (population)	**Common Name**	**AOU #**	**Breeding**	**Summering**	**Wintering**	**Fall Migration**	**Spring Migration**	**Inland**	**Bays and Sounds**	**Coastline**	**Nearshore (0-5 km)**	**Offshore (5-20 km)**	**Pelagic**
Podiceps grisegena holboellii	Red-necked Grebe	20			X	X	X				W,M		
Podiceps auritus cornutus	Horned Grebe	30			X	X	X	M,W	M,W		M,W		
Podilymbus podiceps podiceps	Pied-billed Grebe	60	X		X	X	X	M,W	M,W				
Gavia immer	Common Loon	70			X	X	X		M,W		M,W		
Gavia stellata	Red-throated Loon	110			X	X	X				M,W	M,W	
Fratercula arctica arctica	Atlantic Puffin	130	X	X	X	X	X			B	B,S,W,M	M,W	M,W
Cepphus grylle arcticus	Black Guillemot	270	X	X	X	X	X			B	B,S,W,M	M,W	M,W
Uria aalge aalge	Common Murre	300	X	X	X	X	X			B	B,S,W,M	M,W	M,W
Uria lomvia	Thick-billed Murre	310	X	X	X	X	X			B	B,S,W,M	M,W	M,W
Alca torda torda	Razorbill	320	X	X	X	X	X			B	B,S,W,M	M,W	M,W
Alle alle alle	Dovekie	340	X	X	X	X	X			B	B,S,W,M	M,W	M,W
Stercorarius skua	Great Skua	350			X	X	X					M,W	M,W
Stercorarius maccormicki	South Polar Skua	352				X	X					M	M
Stercorarius pomarinus	Pomarine Jaeger	360			X	X	X					M,W	M,W
Stercorarius parasiticus	Parasitic Jaeger	370			X	X	X					M,W	M,W
Stercorarius longicaudus	Long-tailed Jaeger	380				X	X					M	M
Rissa tridactyla tridactyla	Black-legged Kittiwake	400			X	X	X				M,W	M,W	M,W
Larus hyperboreus leucereles	Glaucous Gull	420			X	X	X				M,W		
Larus glaucoides kumlieni	Iceland Gull	430			X	X	X				M,W		
Larus marinus	Great Black-backed Gull	470	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M		
Larus fuscus fraellsii	Lesser Black-backed Gull	500			X	X	X			W,M	W,M		

			Seasonal Occurrence					Seasonal Distribution					
Species/Subspecies (population)	**Common Name**	**AOU #**	**Breeding**	**Summering**	**Wintering**	**Fall Migration**	**Spring Migration**	**Inland**	**Bays and Sounds**	**Coastline**	**Nearshore (0-5 km)**	**Offshore (5-20 km)**	**Pelagic**
Larus argentatus smithsoniaunus	Herring Gull	510	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M		
Larus delawarensis	Ring-billed Gull	540		X	X	X	X		S,W,M	S,W,M	S,W,M		
Larus ridibundus ridibundus	Black-headed Gull	551	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M		
Larus atricilla megalopterus	Laughing Gull	580	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M	B,S,W,M	
Larus philadelphia	Bonaparte's Gull	600			X	X	X		W,M		W,M	W,M	W,M
Larus minutus	Little Gull	601			X	X	X						
Xema sabina sabina	Sabine's Gull	620			X	X	X						
Gelochelidon nilotica aranea	Gull-billed Tern	630	X			X	X		B,M	B,M	B,M	M	
Hydroprogne caspia	Caspian Tern	640	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M	M	
Thalasseus maximus maxima	Royal Tern	650	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M	M	
Thalasseus sandvicensis acuflavidus	Sandwich Tern	670	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M	M	
Sterna forsteri litoricola	Forster's Tern	690	X		X	X	X		B,W,M	B,W,M	B,W,M	M	
Sterna hirundo hirundo	Common Tern	700	X			X	X		B,M	B,M	B,M	M	
Sterna paradisaea	Arctic Tern	710	X			X	X		B	B	B	M	M
Sterna dougallii dougallii	Roseate Tern	720	X			X	X		B	B	B	M	
Sternula antillarum antillarum	Least Tern	740	X			X	X		B,M	B,M	B,M	M	
Onychoprion fuscatus	Sooty Tern	750		X		X	X				S,M	S,M	S,M
Onychoprion anaethelus recognita	Bridled Tern	760		X		X	X					S,M	S,M
Chlidonias niger surinamensis	Black Tern	770		X		X	X				S,M	S,M	S,M
Anous stolidus	Brown Noddy	790		X		X	X				S,M	S,M	S,M
Rynchops niger niger	Black Skimmer	800	X		X	X	X		B,W,M	B,W,M	B,W,M	M	
Fulmarus glacialis auduboni	Northern Fulmar	860			X	X	X					W,M	W,M
Calonectris diomedea borealis	Cory's Shearwater	880		X		X	X						S,M
Puffinus gravis	Greater Shearwater	890		X		X	X						S,M
Puffinus puffinus puffinus	Manx Shearwater	900		X	X	X	X						S,W,M

			Seasonal Occurrence					Seasonal Distribution					
Species/Subspecies (population)	**Common Name**	**AOU #**	**Breeding**	**Summering**	**Wintering**	**Fall Migration**	**Spring Migration**	**Inland**	**Bays and Sounds**	**Coastline**	**Nearshore (0-5 km)**	**Offshore (5-20 km)**	**Pelagic**
Puffinus lherminieri lherminieri	Audubon's Shearwater	920		X	X	X	X						S,W,M
Puffinus griseus	Sooty Shearwater	950		X	X	X	X						S,W,M
Pterodroma arminjoniana	Herald Petrel	960		X		X	X						S,M
Pterodroma feae	Fea's Petrel	970		X		X	X						S,M
Pterodroma cahow	Bermuda Petrel	980		X		X	X						S,M
Pterodroma hasitata	Black-capped Petrel	1000		X		X	X						S,M
Oceanodroma leucorhoa leucorhoa	Leach's Storm Petrel	1060	X	X		X	X			B	B	S,M	S,M
Oceanites oceanicus oceanicus	Wilson's Storm Petrel	1090		X	X	X	X		W,M		W,M	S,W,M	S,W,M
Oceanodroma castro	Band-rumped Storm Petrel	1062		X		X	X						S,M
Phaethon lepturus	White-tailed Tropicbird	1120		X		X	X						S,M
Phaethon aethereus	Red-billed Tropicbird	1130		X		X	X						S,M
Morus bassanus	Northern Gannet	1170	X	X	X	X	X						S,M
Anhinga anhinga	Anhinga	1180	X	X	X	X	X	B,S,W	B,S,W				
Phalacrocorax carbo carbo	Great Cormorant	1190	X	X	X	X	X			W,M	W,M		
Phalacrocorax auritus auritus	Double-crested Cormorant	1200	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	B,S,W,M		
Pelecanus occidentalis carolinensis	Brown Pelican	1260	X	X	X	X	X		B,S,W,M	B,S,W,M	B,S,W,M		
Mergus merganser americanus	Common Merganser	1290	X		X	X	X	B,W,M	B,W,M				
Mergus serrator	Red-breasted Merganser	1300	X		X	X	X	B	B,W,M	W,M	W,M		
Lophodytes cucullatus	Hooded Merganser	1310	X		X	X	X	B,W,M	B,W,M				
Anas platyrhynchos platyrhynchos	Mallard	1320	X		X	X	X	B,W,M	B,W,M				
Anas rubripes	American Black Duck	1330	X		X	X	X	B,W,M	B,W,M	B,W,M	W,M		
Anas strepera	Gadwall	1350	X		X	X	X	B,W,M	B,W,M				
Anas americana	American Wigeon	1370			X	X	X	W,M	W,M				
Anas discors	Blue-winged Teal	1390	X		X	X	X	B,W,M	B,W,M				
Anas crecca carolinensis	Green-winged Teal	1400			X	X	X	W,M	W,M				

			Seasonal Occurrence					Seasonal Distribution					
Species/Subspecies (population)	**Common Name**	**AOU #**	**Breeding**	**Summering**	**Wintering**	**Fall Migration**	**Spring Migration**	**Inland**	**Bays and Sounds**	**Coastline**	**Nearshore (0-5 km)**	**Offshore (5-20 km)**	**Pelagic**
Anas acuta acuta	Northern Pintail	1430			X	X	X	W,M	W,M				
Aix sponsa	Wood Duck	1440	X		X	X	X	B,W,M	B,W,M				
Aythya americana	Redhead	1460			X	X	X	M	W,M				
Anas clypeata	Northern Shoveler	1420			X	X	X	W,M	W,M				
Aythya valisineria	Canvasback	1470			X	X	X	M	W,M				
Aythya marila mariloides	Greater Scaup	1480			X	X	X	M	W,M		W,M		
Aythya affinis	Lesser Scaup	1490			X	X	X	M	W,M		W,M		
Aythya collaris	Ring-necked Duck	1500	X		X	X	X	B,W,M	B,W,M				
Bucephala clangula americana	Common Goldeneye	1510	X		X	X	X		B,W,M		W,M		
Bucephala islandica	Barrow's Goldeneye	1520			X	X	X		W,M		W,M		
Bucephala albeola	Bufflehead	1530			X	X	X		W,M				
Clangula hyemalis	Long-tailed Duck	1540			X	X	X		W,M		W,M	W,M	
Histrionicus histrionicus	Harlequin Duck	1550			X	X	X		W,M		W,M	W,M	
Somateria mollissima	Common Eider	1590	X		X	X	X				W,M	W,M	
Somateria spectabilis	King Eider	1620			X	X	X				W,M	W,M	
Melanitta nigra americana	Black Scoter	1630			X	X	X				W,M	W,M	
Melanitta fusca deglandi	White-winged Scoter	1650			X	X	X				W,M	W,M	
Melanitta perspicillata	Surf Scoter	1660			X	X	X				W,M	W,M	
Oxyura jamaicensis jamaicensis	Ruddy Duck	1670			X	X	X		W,M		M		
Dendrocygna bicolor	Fulvous Whistling Duck	1780	X	X	X			B,S,W	B,S,W				
Chen caerulescens atlanticus	Snow Goose (Greater)	1699			X	X	X	W,M	W,M	W,M	M		
Chen rossii	Ross's Goose	1700			X	X	X	W,M	W,M	W,M			
Anser albifrons gambelli	Greater White-fronted Goose	1710			X	X	X	W,M	W,M	W,M			
Branta canadensis canadensis	Canada Goose	1720	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Branta bernicla hrota	Atlantic Brant	1730			X	X	X		W,M	W,M	M		
Eudocimus albus	White Ibis	1840	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		

			Seasonal Occurrence					Seasonal Distribution					
Species/Subspecies (population)	**Common Name**	**AOU #**	**Breeding**	**Summering**	**Wintering**	**Fall Migration**	**Spring Migration**	**Inland**	**Bays and Sounds**	**Coastline**	**Nearshore (0-5 km)**	**Offshore (5-20 km)**	**Pelagic**
Plegadis falcinellus falcinellus	Glossy Ibis	1860	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Ajaia ajaja	Roseate Spoonbill	1830	X			X	X	B.M	B.M		M		
Cygnus olor	Mute Swan	1782	X	X	X			B,S,W	B,S,W				
Cygnus columbianus	Tundra Swan	1800			X	X	X	W,M	W,M	W,M	M		
Mycteria americana	Wood Stork	1880	X	X	X	X	X	B,S,W,M	B,S,W,M				
Botaurus lentiginosus	American Bittern	1900	X		X	X	X	B,W,M	B,W,M		M		
Ixobrychus exilis exilis	Least Bittern	1910	X		X	X	X	B,W,M	B,W,M		M		
Ardea herodias herodias	Great Blue Heron	1940	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Ardea alba egretta	Great Egret	1960	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Egretta thula thula	Snowy Egret	1970	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Egretta tricolor ruficolis	Tricolored Heron	1990	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Egretta rufescens	Reddish Egret	1980	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Egretta caerulea	Little Blue Heron	2000	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Bubulcus ibis ibis	Cattle Egret	2001	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Butorides virescens virescens	Green Heron	2010	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Nycticorax nycticorax hoactii	Black-crowned Night Heron	2030	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Nyctanassa violacea violacea	Yellow-crowned Night Heron	2030	X	X	X	X	X	B,S,W,M	B,S,W,M	B,S,W,M	M		
Porphyrio martinica	Purple Gallinule	2180	X		X	X	X	B,W,M	B,W,M				
Gallinula chloropus cachinnans	Common Moorhen	2190	X		X	X	X	B,W,M	B,W,M				
Fulica americana americana	American Coot	2210	X		X	X	X	B,W,M	B,W,M				
Grus canadensis	Sandhill Crane	2060	X	X	X			B,S,W	B,S,W				
Aramus guarauna	Limpkin	2070	X	X	X			B,S,W	B,S,W				
Rallus elegans	King Rail	2080	X		X	X	X	B,W,M	B,W,M		M		
Rallus longirostris	Clapper Rail	2110	X		X	X	X	B,W,M	B,W,M		M		
Rallus limicola	Virginia Rail	2120	X		X	X	X	B,W,M	B,W,M		M		
Porzana carolina	Sora	2140	X		X	X	X	B,W,M	B,W,M		M		

			Seasonal Occurrence					Seasonal Distribution					
Species/Subspecies (population)	**Common Name**	**AOU #**	**Breeding**	**Summering**	**Wintering**	**Fall Migration**	**Spring Migration**	**Inland**	**Bays and Sounds**	**Coastline**	**Nearshore (0-5 km)**	**Offshore (5-20 km)**	**Pelagic**
Coturnicops noveboracensis	Yellow Rail	2150	X		X	X	X	B,W,M	B,W,M		M		
Laterallus jamaicensis	Black Rail	2160	X		X	X	X	B,W,M	B,W,M		M		
Phalaropus fulicaria	Red Phalarope	2220			X	X	X	M	M		M	W,M	W,M
Phalaropus lobatus	Red-necked Phalarope	2230		X		X	X	M	M		M	S,M	S,M
Phalaropus tricolor	Wilson's Phalarope	2240				X	X	M	M		M	M	M
Recurvirostra americana	American Avocet	2250			X	X	X		W,M	W,M	M		
Himantopus mexicanus	Black-necked Stilt	2260	X		X	X	X		B,W,M	B,W,M	M		
Scolopax minor	American Woodcock	2280	X		X	X	X		B,W,M	B,W,M	M		
Gallinago gallinago	Common Snipe	2300	X		X	X	X		B,W,M	B,W,M	M		
Limnodromus griseus	Short-billed Dowitcher	2310			X	X	X		W,M	W,M	M		
Limnodromus scolopaceus	Long-billed Dowitcher	2320			X	X	X		W,M	W,M	M		
Calidrisa himantopus	Stilt Sandpiper	2330			X	X	X		W,M	W,M	M		
Calidris canutus	Red Knot	2340			X	X	X		W,M	W,M	M		
Calidris maritima	Purple Sandpiper	2350			X	X	X		W,M	W,M	M		
Calidris melanotos	Pectoral Sandpiper	2390				X	X	M	M	M	M		
Calidris fuscicollis	White-rumped Sandpiper	2400				X	X	M	M	M	M		
Calidris bairdii	Baird's Sandpiper	2410				X	X	M	M	M	M		
Calidris minutilla	Least Sandpiper	2420			X	X	X	W,M	W,M	W,M	M		
Calidris alpina	Dunlin	2430			X	X	X	W,M	W,M	W,M	M		
Calidris pusilla	Semipalmated Sandpiper	2460				X	X	M	M	M	M		
Calidris mauri	Western Sandpiper	2470			X	X	X	W,M	W,M	W,M	M		
Calidris alba	Sanderling	2480			X	X	X		W,M	W,M	M		
Limosa fedoa	Marbled Godwit	2490			X	X	X		W,M	W,M	M		
Limosa haemastica	Hudsonian Godwit	2510					X		M	M	M		
Tringa melanoleuca	Greater Yellowlegs	2540			X	X	X	W,M	W,M	W,M	M		
Tringa flavipes	Lesser Yellowlegs	2550			X	X	X	W,M	W,M	W,M	M		

			Seasonal Occurrence					Seasonal Distribution					
Species/Subspecies (population)	Common Name	AOU #	Breeding	Summering	Wintering	Fall Migration	Spring Migration	Inland	Bays and Sounds	Coastline	Nearshore (0-5 km)	Offshore (5-20 km)	Pelagic
Tringa solitaria	Solitary Sandpiper	2560				X	X	M	M				
Tringa semipalmata	Willet	2580	X		X	X	X		B,W,M	B,W,M	M		
Bartramia longicauda	Upland Sandpiper	2610	X			X	X	B,M	B,M				
Tryngites subruficollis	Buff-breasted Sandpiper	2620				X	X	M	M				
Actitis macularius	Spotted Sandpiper	2630	X		X	X	X	B,W,M	B,W,M	B,W,M	M		
Numenius americanus	Long-billed Curlew	2640			X	X	X		W,M	W,M	M		
Numenius phaeopus	Whimbrel	2650			X	X	X		W,M	W,M	M		
Pluvialis squatarola	Black-bellied Plover	2700		X	X	X	X	B,M	W,M	W,M	M		
Pluvialis domimica	American Golden Plover	2720				X	X	M	M				
Charadrius vociferus	Killdeer	2730	X		X	X	X	B,W,M	B,W,M	B,W,M			
Charadrius semipalmatus	Semipalmated Plover	2740	X		X	X	X	B,W,M	B,W,M	B,W,M	M		
Charadrius melodus	Piping Plover	2770	X		X	X	X		B,W,M	B,W,M	M		
Charadrius wilsonia	Wilson's Plover	2800	X		X	X	X		B,W,M	B,W,M	M		
Arenaria interpres	Ruddy Turnstone	2830		X	X	X	X		S,W,M	S,W,M	M		
Haematopus palliatus	American Oystercatcher	2860	X	X	X	X	X		B,S,W,M	B,S,W,M	M		

APPENDIX 3. Table of demographic parameters, population estimates, and PBR estimates. Species in bold indicate unique taxonomic forms and underlined species indicate Atlantic Coast populations. Numbered citations are listed in Appendix 4.

Species/Subspecies/population	Common Name	AOU #	1st Breeding	Adult Survival	Growth Rate	Recovery Factor	Population Estimate	60%CI	PBR	Citations
Podiceps grisegena holboellii	Red-necked Grebe	20	3	0.805	1.1981	0.4	20,000	13,740	1,089	1
Gavia immer	Common Loon	70	5	0.92	1.0985	0.4	7,400	5,084	200	2,3,4,5
Gavia stellata	Red-throated Loon	110	5	0.89	1.1107	0.4	70,000	48,090	2,130	2,5,6
Fratercula arctica arctica	Atlantic Puffin	130	5	0.95	1.0820	0.5	750,000	515,250	21,120	7,8,9,10
Cepphus grylle arcticus	Black Guillemot	270	4.7	0.87	1.1228	0.5	100,000	68,700	4,219	10,11,12
Uria aalge aalge	Common Murre	300	5	0.945	1.0852	0.3	1,200,000	824,400	21,063	13,14,15
Uria lomvia	Thick-billed Murre	310	5.7	0.89	1.1008	0.3	3,000,000	2,061,000	62,314	16,17
Alca torda torda	Razorbill	320	5	0.9	1.1070	0.3	75,000	51,525	1,653	18,19,20,21
Stercorarius pomarinus	Pomarine Jaeger	360	4	0.89	1.1296	0.4	20,000	13,740	712	10,22
Stercorarius longicaudus	Long-tailed Jaeger	380	4	0.83	1.1520	0.4	150,000	103,050	6,267	10,23
Rissa tridactyla	Black-legged Kittiwake	400	5	0.835	1.1273	0.5	500,000	343,500	21,860	24,25
Larus hyperboreus	Glaucous Gull	420	5	0.84	1.1260	0.5	70,000	48,090	3,029	26,27
Larus argentatus smithsoniaunus	Herring Gull	510	5	0.9	1.1070	0.4	246,000	169,002	7,231	10,28,29
Larus delawarensis	Ring-billed Gull	540	4	0.88	1.1340	0.5	1,700,000	1,167,900	78,223	10,30,31
Hydroprogne caspia	Caspian Tern	640	3	0.89	1.1583	0.4	19,500	13,397	848	32,33
Thalasseus maximus maxima	Royal Tern	650	5	0.95	1.0820	0.3	66,000	45,342	1,115	4,34
Thalasseus sandvicensis acuflavidus	Sandwich Tern	670	4	0.7	1.1836	0.5	9,000	6,183	568	4,35,36
Sterna hirundo hirundo	Common Tern	700	3	0.88	1.1640	0.4	106,000	72,822	4,776	4,37,38
Sterna paradisaea	Arctic Tern	710	3	0.87	1.1693	0.2	180,000	123,660	4,187	39,40
Sterna dougallii dougallii	Roseate Tern	720	3	0.74	1.2202	0.1	7,000	4,809	106	4,41,42
Sternula antillarum antillarum	Least Tern	740	3	0.88	1.1640	0.2	34,000	23,358	766	4,43,44
Chlidonias niger surinamensis	Black Tern	770	2	0.7	1.3195	0.3	100,000	68,700	6,585	10,45,46
Fulmarus glacialis auduboni	Northern Fulmar	860	10	0.969	1.0434	0.3	600,000	412,200	5,373	47,48

Species/Subspecies/population	Common Name	AOU #	1st Breeding	Adult Survival	Growth Rate	Recovery Factor	Population Estimate	60%CI	PBR	Citations
Puffinus puffinus puffinus	Manx Shearwater	900	6	0.945	1.0755	0.3	800,000	549,600	12,453	49,50,51
Oceanodroma leucorhoa leucorhoa	Leach's Storm Petrel	1060	6.9	0.937	1.0723	0.4	9,600,000	6,595,200	190,844	52,53,54
Morus bassanus	Northern Gannet	1170	5	0.94	1.0881	0.5	145,000	99,615	4,390	55,56
Phalacrocorax carbo carbo	Great Cormorant	1190	3	0.84	1.1837	0.3	17,000	11,679	644	57
Phalacrocorax auritus auritus	Double-crested Cormorant	1200	3	0.85	1.1791	0.5	210,000	144,270	12,921	58,59
Pelecanus occidentalis carolinensis	Brown Pelican	1260	4	0.88	1.1340	0.3	31,400	21,572	867	4,60,61,62
Ardea herodias herodias	Great Blue Heron	1940	3	0.781	1.2069	0.5	83,000	57,021	5,898	10,63,64
Egretta thula thula	Snowy Egret	1970	2	0.686	1.3254	0.2	26,800	18,412	1,198	65,66
Egretta tricolor ruficolis	Tricolored Heron	1990	2	0.684	1.3263	0.2	31,000	21,297	1,390	67,68
Recurvirostra americana	American Avocet	2250	2	0.845	1.2423	0.3	450,000	309,150	22,474	69,70,71
Calidris canutus rufa	Red Knot	2340	2	0.68	1.3279	0.1	20,000	13,740	451	71,72
Calidris maritima belcheri	Purple Sandpiper	2350	2	0.685	1.3259	0.4	15,000	10,305	1,343	71,73
Calidris alpina hudsonia	Dunlin	2430	3	0.79	1.2037	0.3	225,000	154,575	9,445	71,74
Calidris pusilla	Semipalmated Sandpiper	2460	2	0.7	1.3195	0.3	260,000	178,620	17,120	71,75,76
Calidris alba	Sanderling	2480	2	0.83	1.2521	0.2	300,000	206,100	10,393	71,77,78
Limosa fedoa fedoa (Hudson Bay)	Marbled Godwit	2490	3	0.915	1.1424	0.2	2,200	1,511	43	71,79
Tringa semipalmata semipalmatus	Willet	2580	3	0.86	1.1743	0.3	90,000	61,830	3,234	71,80
Actitis macularius	Spotted Sandpiper	2630	1	0.63	1.6083	0.4	150,000	103,050	25,073	71,81,82
Pluvialis squatarola cynosurae	Black-bellied Plover	2700	2	0.86	1.2319	0.3	150,000	103,050	7,169	71,83,84
Charadrius semipalmatus	Semipalmated Plover	2740	3	0.71	1.2289	0.4	150,000	103,050	9,436	71,85,86
Charadrius melodus melodus	Piping Plover	2770	2	0.737	1.3028	0.1	2,920	2,006	61	71,87
Arenaria interpres interpres	Ruddy Turnstone	2830	2	0.764	1.2895	0.2	45,000	30,915	1,790	71,88
Haematopus palliatus	American Oystercatcher	2860	3	0.85	1.1791	0.2	10,700	7,351	263	71,89

APPENDIX 4. Listing of numbered citations to accompany Appendix 3.

Number	Citation
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