

**BIOENERGETICS, BEHAVIOR, AND SEA LEVEL RISE: CURRENT  
STATUS AND FUTURE IMPLICATIONS FOR WINTERING DABBING  
DUCKS IN DELAWARE**

by

Mark Charles Livolsi

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Wildlife Ecology

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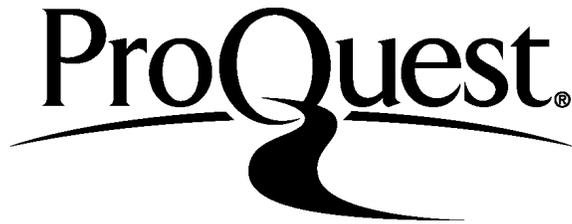
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## ABSTRACT

Waterfowl migrating and overwintering in the Atlantic Flyway depend on adequate availability of wetlands and associated habitats to survive and fuel subsequent breeding efforts. Long-term declines in some wintering waterfowl populations, such as American black ducks (*Anas rubripes*), have prompted researchers to investigate the bioenergetics of such species in an attempt to inform effective habitat management. Bioenergetics models typically seek to estimate energetic carrying capacity based on energy supply and demand. However, little effort has been made to explicitly and comprehensively assess the relative value of managed coastal impoundments vs. unmanaged tidal salt marshes to wintering waterfowl in the mid-Atlantic region in terms of both use and energetic potential. To address these questions, I sampled dabbling duck foods, observed behavior, and conducted point-transect counts on 7 managed impoundments and 3 unmanaged tidal salt marshes along the Delaware Bayshore. My objectives were to 1) estimate wintering dabbling duck population density and abundance between habitats and at the state-level, 2) characterize species-specific differences in behavior between habitats, and 3) estimate the current bioenergetic carrying capacity of wintering dabblers between habitats and extrapolate to the state-level, and 4) predict future trends in carrying capacity based on anticipated sea level rise (SLR) scenarios.

I estimated population density in impoundments and salt marshes in Delaware over the winter period via point-transect counts ( $n = 2,128$ ) and aerial survey counts.

In general, I found that most dabblers tended to concentrate in higher densities on either freshwater or brackish impoundments compared with unmanaged salt marshes. Black ducks presented a notable exception, as both point counts and aerial surveys suggested black duck densities were higher on salt marshes than impoundments. I quantified the proportion of time spent in any given behavior for each dabbler species based on instantaneous scan samples ( $n = 6,400$  scanning efforts per year) conducted alongside point-transect counts, November–March, 2011–2013. I observed dabbler behavior in four time periods (morning crepuscular, diurnal, evening crepuscular, nocturnal) in an attempt to capture behavioral variation over the 24-hr day. Using behavioral data, I constructed time-activity budgets for each habitat type, and compared behavioral proportions between habitats. I converted behavioral proportions into hourly energy expenditure (*HEE*) and daily energy expenditure (*DEE*) estimates based on activity-specific multipliers of resting metabolic rate. I estimated the range of dabbler *DEE* values over the winter period to be between 111.84–349.79 kcal/bird/day, the majority of which typically stemmed from flying and feeding behaviors. My *DEE* estimates were higher than previously reported values, and produced similar results to a mass-based allometric model.

I estimated waterfowl food biomass in impoundments and various tidal salt marsh habitat types over the winter period by collecting soil core ( $n = 1,364$ ), nekton ( $n = 426$ ), and salt marsh snail (*Melampus* spp.;  $n = 87$ ) samples in October, January, and April, 2011–2013. I converted biomass estimates to energy using true metabolizable energy (TME) values. I found that food energy density was highest in

freshwater impoundments (range: 183,344–562,089 kcal/ha) for nearly all dabblers, and typically higher in brackish impoundments (range: 112,399–357,160 kcal/ha) than most salt marsh habitats, whereas mudflat (range: 50,745–137,473 kcal/ha) and subtidal (range: 51,402–136,326 kcal/ha) habitats typically contained the least energy. Extrapolating to the state-level, I estimated between  $2.38 \times 10^9$ – $1.14 \times 10^{10}$  kcal available in total within a 16 km buffer from the Delaware Bayshore, depending on species. Combining *DEE* and energy supply values, I estimated between  $8.73 \times 10^6$ – $7.06 \times 10^7$  duck use-days (*DUD*) available over the winter period. I used the Sea Level Affecting Marshes Model (SLAMM) to predict changes in habitat availability based on 4 SLR scenarios. I estimated that carrying capacity is likely to decrease in the future under all but the most conservative SLR scenario, due to the gradual replacement of high energy density natural habitat (i.e., low marsh, high marsh) with low energy density habitat (i.e., subtidal, mudflat).

In the future, coastal impoundments will become increasingly important, provided they are properly maintained, as they will represent a growing proportion of the available *DUD* on the landscape. This study will assist managers in meeting population goals by highlighting key areas where habitat modification would be most effective. I urge further researchers to attempt to refine my carrying capacity estimates by incorporating appropriate foraging thresholds and more detailed models of competition into bioenergetics models, and by attempting to correct for biases in population estimation methodologies.

## **Chapter 1**

### **INTRODUCTION**

Historically, waterfowl research has focused on better understanding breeding season habitat needs and demographic success (e.g., Stewart and Kantrud 1973, Hoekman et al. 2006). In recent decades, however, many researchers have noted the importance of investigating waterfowl ecology during the nonbreeding season, because the winter period may affect individual fitness and recruitment in the subsequent breeding season (Heitmeyer and Fredrickson 1981, Reinecke 1981, Kaminski and Gluesing 1987). Thus, effective management of migrating waterfowl resources necessitates an understanding of wintering ecology in addition to breeding and migration ecology.

In coastal marshes across the United States, diking and flooding wetland areas, otherwise known as impounding, is a popular management strategy aimed at improving wintering waterfowl habitat and reducing mosquito populations. Impoundments span 11% of the estimated 500,000 ha of marshland along the southeastern Atlantic Coast (Montague et al. 1987). Along the coast of Delaware, both natural salt marshes and managed impoundments are important wintering and stopover sites for waterfowl migrating through the Atlantic Flyway. Currently, ~31,000 ducks utilize the Delaware Bayshore, an area ranging from Liston Point in New Castle County to the Broadkill River in Sussex County, as estimated from the Mid-Winter Waterfowl Survey (MWS; 7-yr mean 2005–2012, Delaware Division of Fish and Wildlife).

Despite the prevalence of actively managed impoundments in the United States, there are both advantages and disadvantages associated with these habitats. Impoundments are considered valuable because managers can regulate their water levels to promote the growth of desired vegetation (often high energy foods that are most beneficial to migrating or wintering waterfowl). Impoundment drawdown and re-flooding is timed to coincide with the arrival of various migratory species, providing attractive habitat for waterfowl, shorebirds and other wildlife, and keeping mosquito populations in check (Sherfy 1999). However, impoundments are often costly to maintain, and may be associated with a variety of ecological consequences, including increased risk of communicable disease in waterfowl due to increased density (Percival et al. 1987) and loss of connectivity with natural wetlands, which may impact recruitment of fish nurseries (Whitman and Cole 1987, McGovern and Wenner 1990).

In recent decades, it has become clear that sea level rise (SLR) is an unavoidable and problematic symptom of climate change (Intergovernmental Panel on Climate Change [IPCC] 2007). Maintenance of impoundments has become a growing concern in the face of SLR for habitat managers faced with long-term planning projects, due to the potential for infrastructure damage. If left unresolved, impairment of water management capabilities or breaches in impoundment walls can cause manmade impounded habitats to revert to natural tidal salt marsh regimes over time (Scarborough 2009). Because impoundments are often managed specifically to promote food growth and attract migrating waterfowl, changes in impoundment habitat availability due to SLR may have a significant impact on waterfowl food availability and spatial distribution. Stopover and wintering habitat use by waterfowl

is thought to be primarily a function of food availability; therefore, reduced food availability may cause mortality and poor body condition in migrating or wintering birds (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Raveling and Heitmeyer 1989). Additionally, although information regarding waterfowl behavior in the wintering period is lacking for most species (Turnbull and Baldassarre 1987), time-activity budgets constructed for American black ducks (*Anas rubripes*) show that impoundments may act as refugia for wintering waterfowl, providing valuable space to rest away from human disturbances (Jones 2012). Thus, SLR-based land cover changes may affect wintering waterfowl behavior, abundance, and distribution, depending on how they utilize managed impoundments compared with unmanaged salt marsh habitats. Waterfowl in Delaware may be particularly susceptible to SLR-induced changes, where the mean historic local SLR (3.35 mm/yr over the past 100 yrs) is well above the mean historic global SLR (1.7 mm/yr; IPCC 2007, DNREC Sea Level Rise Technical Workgroup 2009).

This study hopes to guide management of current and future wintering waterfowl populations in Delaware (and by extrapolation, the Atlantic Flyway) by assessing the relative value of managed impoundments and unmanaged salt marshes to waterfowl. Since these habitats likely experience different levels of use by wintering waterfowl, my first objective was to quantify waterfowl abundance and density in impoundments and salt marshes using point count and aerial survey data. My second objective was to compare waterfowl behaviors over the 24-hr period between impoundments and saltmarshes, because impoundments may have value either as feeding sources or for resting refugia. My third objective was to compare the carrying capacity of waterfowl populations between these habitats using a bioenergetics

approach, and to forecast future changes in waterfowl carrying capacities based on anticipated trends in sea level rise. I focused on seven dabbling duck species (genus *Anas*), including American black ducks, mallards (*A. platyrhynchos*), northern pintails (*A. acuta*), northern shovelers (*A. clypeata*), green-winged teal (*A. crecca*), American wigeon (*A. americana*), and gadwall (*A. strepera*). Dabbling species were selected in order to simplify grouping of energy values or food habit lists for multiple species if necessary. Additionally, this list includes species of conservation concern, including American black ducks and northern pintails, both of which have experienced population declines in recent decades (Austin et al. 2014). I place a particular emphasis on the American black duck, because it is a conservation priority in the mid-Atlantic region, due to drastic population declines potentially resulting from wetland habitat loss (Conroy et al. 1989, Conroy et al. 2002).

## Chapter 2

### STUDY AREAS

I sampled dabbling duck foods and observed dabbling behavior in managed coastal impoundments and unmanaged, tidally-regulated salt marshes in Kent and Sussex Counties, Delaware, USA (39°17'N, 75°27'W – 38°48'N, 75°12'W; Fig. 1) over the winter period in 2011–2012 and 2012–2013. My study area included 10 sites located within a 60 km range of the Delaware Bayshore that experience substantial use by wintering waterfowl, and in some cases are predicted to be impacted by future sea level rise (SLR) based on the Sea Level Affecting Marshes Model (SLAMM v. 5.0; Glick et al. 2008) and modeled SLR scenarios (DNREC Sea Level Rise Technical Workgroup 2009, Scarborough 2009). I collected food samples in 7 impoundments with varying management regimes and salinities (freshwater and brackish) and 3 unmanaged salt marshes to compare the value of these habitats to wintering dabblers.

During food sampling, I used a stratified random sampling method in unmanaged saltmarsh sites to ensure all available habitats were adequately represented. Saltmarshes were divided into 5 habitat categories defined by tidal hydrology using Delaware State Wetland Mapping Project (SWMP) land cover data (DNREC 2007), including: subtidal, mudflat, low marsh, high marsh, and quasi-tidal pools. Subtidal habitats included areas below the mean low tide line and were irregularly exposed. Mudflat areas were regularly flooded and exposed, and typically lacked vegetation. Low marsh comprised regularly flooded areas between mean high and low tide, and was typically dominated by saltmarsh cordgrass (*Spartina alterniflora*). High marsh comprised irregularly flooded areas above the mean high tide line, and was typically dominated by saltmeadow cordgrass (*S. patens*). Quasi-

tidal pools were located within high marsh habitats and comprised areas of standing water that were relatively stable landscape features experiencing some degree of tidal exchange (Cramer et al. 2012). I separated impoundments into two categories based on salinity (freshwater and brackish), and did not further stratify habitat types within them.

### **Bombay Hook National Wildlife Refuge**

Bombay Hook National Wildlife Refuge was my northernmost study area, and included 3 separate study sites: the Raymond Pool (40 ha), Sheariness Pool (193 ha), and adjacent Bombay Hook unmanaged tidal marshes (265 ha). Both the Raymond and Sheariness Pools are freshwater impoundments (average salinity  $\leq 5$  ppt) managed for moist-soil vegetative growth via drawdowns in late spring or summer and flooding in late summer or fall in order to attract waterfowl. There is no exchange of water resources between these impoundments. The tidal marsh site neighbors these impoundments and contains high marsh, low marsh, mudflat, subtidal, and quasi-tidal pool habitats. This marsh averages relatively low salinities of 8 ppt.

### **Little Creek, Ted Harvey, and Milford Neck State Wildlife Areas**

South of Bombay Hook are the Little Creek (187 ha), Ted Harvey North (89 ha), and Ted Harvey South (173 ha) Delaware State Wildlife Areas. These impoundments have brackish salinities, ranging from 5–30 ppt. All three are flooded early in October to water levels  $\leq 0.6$  m by tidal action, and remain flooded through mid-March. Between mid-March and mid-April, water is drawn down until half of the impoundment is covered by water. Water levels are maintained low throughout the summer and are regulated for low salinities. Milford Neck State Wildlife Area (70 ha)

lies further south of these impoundments, and comprises an expanse of unmanaged tidal marsh containing high marsh, low marsh, mudflat, and subtidal habitats with an average salinity of 20 ppt.

### **Prime Hook National Wildlife Refuge**

My southernmost study area was Prime Hook National Wildlife Refuge, which included 3 study sites: Prime Hook Unit I (609 ha), Unit II (703 ha), and Unit III (1,742 ha). Unit I was previously managed as a freshwater impoundment; however, breaches converted the unit to brackish water, and it eventually reverted completely to tidal marsh, which remains today. Unit I contains salinities ranging from 5–25 ppt, and comprises high marsh, low marsh, mudflat, subtidal, and quasi-tidal pool habitats. Units II and III also used to be freshwater impoundments. Breaches in the tidal regulation mechanisms of Unit II in 2009, 2010, and 2011 have resulted in a conversion to brackish salinities of 5–30 ppt. Because Unit III is connected to Unit II, Unit III is also experiencing an influx of brackish water. However, Units II and III have not yet completely reverted to tidal marsh, and are still actively managed.

## Chapter 3

### METHODS

#### **Behavioral Proportions**

##### *Behavioral Observation Protocol*

In recent decades, waterfowl researchers have quantified behavior of wintering waterfowl by constructing time-activity budgets, although behavioral information is lacking for many species. I constructed time-activity budgets for dabbling ducks at my study sites using instantaneous scan sampling (Altmann 1974) November–March, 2011–2013 to characterize behavior in managed impoundments and unmanaged salt marshes during 4 time periods over the 24-hr day: morning crepuscular, diurnal, evening crepuscular, and nocturnal. The morning and evening crepuscular periods were defined as 1 hr periods 30 min before and after sunrise and sunset, respectively. Behavioral surveys were divided into 6-hr AM or PM sessions. Observers arrived at the survey site approximately 3 hrs 30 min prior to sunrise (for AM sessions) or sunset (for PM sessions), allowing 30 min to set up blinds and for birds to acclimate in case of disturbance. Observers set up blinds a minimum of 400 m apart to avoid counting individuals twice. Scan samples were collected using binoculars (8x42-magnification) during the day and night vision optics (6x-magnification) after dark to a maximum distance of 200 m to ensure correct assignment of behaviors (Heise 2012, Jones 2012). At the start of each scanning session, observers randomly selected a side (left or right) to begin scanning each flock. Observers recorded species and behavior for each individual bird observed. Behaviors were classified as: feeding, loafing, sleeping, comfort, swimming, walking, flying, agonistic, and courtship (Albright et al. 1983, Morton et al. 1989). Observers began scan sampling 3 hrs prior to sunrise or sunset,

and ended 3 hrs after sunrise or sunset. Behavioral scans were conducted every 10 min over the 6-hr period, with 20 min breaks between the crepuscular and diurnal or nocturnal periods to ensure independence of observations between time periods. Additionally, the scanning period was broken into observation blocks of four scans each. At the beginning of each observation block, observers recorded environmental covariates including wind speed, temperature, relative humidity, and tide. Each survey session thus consisted of 13 diurnal scans, 6 morning (AM sessions) or evening (PM sessions) crepuscular scans, and 13 nocturnal scans per observer ( $n = 6,400$  scanning efforts per year; Fig. 2). I surveyed my 10 study sites in random order over 10 days of PM sessions, followed by 10 days of AM sessions, repeated for the duration of the study period.

For each scan, I converted numbers of individuals engaged in each behavior to proportions by dividing by total flock size. To avoid the issue of autocorrelation between data points, which can arise if scans are not temporally independent from one another, I constructed a semivariogram for each dabbling duck species. I compared levels of autocorrelation between subsequent scans (10 min apart) up to scans that were 50 min apart (in 10 min intervals). I found that behavioral correlation largely did not occur between 10 min scans. Based on these results and prior work (Heise 2012, Jones 2012), I concluded that 10 min scans were sufficiently independent from one another.

#### *Measuring Period and Habitat Effects on Behavior*

I compared behavioral proportions between freshwater impoundments, brackish impoundments, and unmanaged salt marshes to increase sample sizes. Freshwater impoundments included the Bombay Raymond and Shearness pools,

brackish impoundments included the Ted Harvey North, Ted Harvey South, Little Creek, Prime Hook Unit II, and Prime Hook Unit III pools, and unmanaged salt marshes included the Bombay Hook tidal marsh, Milford Neck Wildlife Area, and Prime Hook Unit I marshes. Additionally, to simplify interpretation of behavioral proportions and avoid emphasizing uncommon behaviors, I chose to compare feeding, flying, swimming, and resting (defined as the sum of loafing, comfort, and sleeping behaviors). I selected these behaviors because they account for the majority of energy expenditure and, in the case of resting, may indicate which habitats are used as refugia from disturbance. I compared the proportion of time dabbling ducks spent in these behaviors between each time period (morning crepuscular, diurnal, evening crepuscular, nocturnal) and each habitat type.

Behavioral proportion data are non-normally distributed and exhibit high levels of skewness and kurtosis, so parametric tests were inappropriate (Khan and Rayner 2003). Instead, I used a nonparametric Kruskal-Wallis test ( $\alpha = 0.05$ ) to compare period and habitat effects on behavior (JMP, Version 11, SAS Institute Inc. 2014). The Kruskal-Wallis test assigns a rank to each observation and compares mean ranks between groups to test whether groups originate from the same distribution. To be valid, the Kruskal-Wallis test requires that three general assumptions are met: 1) Observations are independent from one another, 2) Observations within treatment groups originate from the same population, and 3) Treatment group populations have similar distributions (Kruskal and Wallis 1952). Although the proportions of different behaviors in the same scan are not independent from one another (because they sum to 1), proportions of the same behavior between different scans are unrelated, so the assumption of independence is met. Additionally, groups shared similar distributions.

Therefore, I concluded that the Kruskal-Wallis test was an appropriate method for testing differences between behavioral proportions. If behavioral proportions differed significantly between time periods or habitat types, I used the Steel-Dwass post-hoc pairwise comparisons method to identify significantly different categories.

### **Bioenergetic Carrying Capacity & Sea Level Rise**

I estimated energetic carrying capacity as available duck use-days (*DUD*) for dabbling ducks in freshwater impoundments, brackish impoundments, and unmanaged salt marshes along the Delaware Bayshore following Reinecke et al. (1989):

$$DUD = \frac{E}{DEE} \quad \text{Equation 1}$$

Where *E* represents energy supply (kcal) and *DEE* represents daily energy expenditure (kcal/bird/day). *DUDs* represent the number of days that a habitat can support a single duck based on available food energy and energy demand.

#### *Estimating Energy Supply*

I collected soil core, nekton, and salt marsh snail (*Melampus* spp.) samples from each site in October, January, and April 2011–2012 and 2012–2013 to estimate waterfowl food availability during the winter period. I collected soil cores using a custom PVC corer (5.1 cm diameter x 12.7 cm depth). I randomly generated sample points for each site using ArcMAP (version 10; ESRI 2011). During each season, I sampled 20 points within each impoundment site ( $n = 7$ ) and 7 points in each salt marsh habitat type (high marsh, low marsh, mudflat, subtidal, and quasi-tidal pool) where possible within each unmanaged salt marsh site ( $n = 3$ ) for a total of 1,364 soil cores. Additionally, I collected nekton samples ( $n = 426$ ) from up to 10 core sample points in each site using a nekton throw trap (1 m<sup>2</sup> x 0.5 m; James-Pirri et al. 2002).

In unmanaged salt marsh sites, I only sampled for nekton in habitat types with standing water (subtidal and quasi-tidal pools). If vegetation was present near a sample point, I opportunistically sampled for salt marsh snails by searching through a 0.5 m x 0.5 m vegetation plot by hand ( $n = 87$ ).

Upon collection, I stored samples in polyethylene bags and transported them to the laboratory to be processed by a team of technicians. Nekton and vegetation samples were refrigerated, identified, dried, and weighed  $\leq 3$  days after collection. Soil cores were refrigerated for  $\leq 3$  days and were subsequently washed and fixed with a solution of 10% formalin and Rose Bengal dye. Fixed cores were then transferred to sample cups and stored for processing at a later date. Upon processing, cores were sorted under a 6x-magnification dissecting microscope to remove waterfowl foods. Food items were identified to the lowest possible taxonomic level (typically genus or species for plant foods and family or order for animal foods), dried to constant mass in an oven at 60° C for 48 hours, and weighed to 0.0001g. I excluded bivalves too large for consumption by waterfowl ( $> 21.4$  mm; Cramer et al. 2012). Because processing soil cores is time and resource-intensive, I implemented a 25% and later 10% by mass subsampling methodology similar to Hagy et al. (2011) and Stafford et al. (2011) partway through this project. Neither 25% nor 10% by mass subsampling yielded significantly different biomass estimates than sorting 100% of the core (Livolsi et al. 2014). Soil cores were washed through a size 10 (2 mm opening) and size 60 (0.251 mm opening) sieve. Each core was then separated into “large” material (material too large to pass through the size 10 sieve) and “small” material (material too large to pass through the size 60 sieve). Technicians sorted through 100% of the “large” material and 25% or 10% of the “small” material to remove seed and invertebrate foods, which

were then identified to the lowest possible taxonomic level, dried, and weighed. I multiplied biomass of foods in the 25% and 10% subsample by 4 or 10, respectively, to estimate the biomass in the “small” material portion, and added to the biomass in the “large” portion to estimate total biomass for each food item in the soil core.

To convert food biomass to energy supply estimates, I multiplied biomass by true metabolizable energy (TME) values, which represent the amount of energy available to a bird from a given food, corrected for endogenous urinary and metabolic fecal energy (Sibbald 1976). I compiled food habits for dabbling ducks and assigned each food a TME value based on estimates from the literature. If TME values were not reported for a given food or duck species, I averaged TME values from closely related taxa. Preferred foods and justification for their assigned TME values are presented in Appendix A. I pooled food samples from each habitat type across sites, seasons, and years to estimate mean energy supply over the winter period in impoundments and salt marshes. I did not test for a year effect, as this would only be appropriate for a study spanning several years. Virtually no salt marsh snails were found in the 2012–2013 field season, potentially as a result of flooding by Hurricane Sandy; thus, samples from the 2011–2012 season were assumed to represent salt marsh snail availability.

I extrapolated energy to the hectare level and summed mean energy (kcal/ha) from soil core, nekton, and salt marsh snail samples to determine energy density for each habitat type. I log-transformed food energy data as necessary to achieve normality. I first tested for temporal depletion of food energy between seasons (fall, winter, spring) for each species and habitat. If I observed no temporal depletion, I pooled samples across seasons to increase sample sizes. I then tested for differences

in available food energy from soil cores for each focal species between habitat types using a one-way ANOVA ( $\alpha = 0.05$ ). If a significant effect was detected, I used Tukey's HSD post-hoc test to identify significant pairwise differences between groups (JMP, Version 11, SAS Institute Inc. 2014). I then added mean energy per ha from nekton in impoundment, quasi-tidal pool, and subtidal habitats, and mean energy from salt marsh snail samples to soil core energy estimates for each habitat type. Because salt marsh snails were considered preferred foods for all focal species, and only one TME value was reported, salt marsh snail energy was the same for all dabblers.

I scaled per ha energy density estimates to the state-level. I used ArcMAP (version 10; ESRI 2011) to estimate the amount of each habitat available within a 16 km (10 mi) buffer of the Delaware Bayshore based on Delaware State Wetlands Mapping Project (SWMP) data. I selected a 16 km buffer because 1) this study focuses on coastal habitat use, and the vast majority of saltmarsh habitat in Delaware lies within this buffer, 2) to avoid overestimation of habitat availability, and 3) because prior telemetry work has suggested that foraging flights are typically limited to < 20 km (Bossenmaier and Marshall 1958, Reed 1971). I determined that there were approximately 19,718 ha of low marsh, 9,432 ha of high marsh, 3,858 ha of impoundments, 428 ha of mudflat, and 15 ha of quasi-tidal pool habitat available within this buffer. I estimated 6,044 ha of subtidal habitat after reducing estimates by removing non-forageable areas (>1 m depth; Cramer 2009) using digital elevation models (DEM) for the Delaware Bay (NGDC 2012). I assumed that energy resources are evenly distributed across the landscape; thus, I multiplied per ha energy estimates for each habitat type by the number of ha available and summed to estimate total available energy. Additionally, I attempted to estimate carrying capacity in the face of

interspecific competition (between focal species). To estimate the effects of competition, I first determined which food resources were shared among focal species using food habit lists compiled from the literature. I then rationed each food in each core between the species known to consume that food using a weighted proportion determined by the relative abundance of each species sharing that particular food on the landscape, based on 10-yr MWS mean population estimates (USFWS 2004–2014).

### *Estimating Energy Expenditure*

I estimated *DEE* for each focal species over the 24-hr period using a method similar to Albright et al. (1983), Cramer (2009), and Jones (2012):

$$DEE = \sum_{hr=1}^n \sum_{i=1}^n [(RMR \times a_i) + CT] \times T_i \quad \text{Equation 2}$$

Where *RMR* represents the Resting Metabolic Rate (kcal/bird/hr), *a<sub>i</sub>* represents the activity-specific multiplier of *RMR* for a given behavior, *CT* represents the cost of thermoregulation (kcal/bird/hr), and *T<sub>i</sub>* represents the proportion of time spent in a given behavior, informed by behavioral proportions obtained via instantaneous scan samples. All values are summed across behaviors and hours within the 24-hr period to estimate total *DEE*.

I used species-specific estimates of *RMR*, predicted by the following allometric equation given by Miller and Eadie (2006):

$$RMR = a \times Mass^b \quad \text{Equation 3}$$

Where *a* represents a mass-proportionality coefficient, *Mass* represents body mass (kg), and *b* represents the slope of the regression line on a log scale. I obtained the values for *a* and *b* reported for “dabbling ducks” (*a* = 457, *b* = 0.77; Miller and Eadie 2006). I obtained estimates for the *Mass* term by averaging mean values available from Bellrose (1980) for adult male and female birds. I used values of *a<sub>i</sub>* presented in

Wooley (1976) as multipliers of *RMR*:  $a_{feeding} = 1.7$ ;  $a_{sleeping} = 1.2$ ;  $a_{resting} = 1.2$ ;  $a_{comfort} = 2.1$ ;  $a_{swimming} = 2.2$ ;  $a_{alert} = 2.2$ ;  $a_{flying} = 12.5$ ,  $a_{walking} = 1.7$ ,  $a_{agonistic} = 2.4$ ,  $a_{courtship} = 2.4$ .

I calculated *CT* following McKinney and McWilliams (2005) to incorporate wind speed and the effect of contact with both air and water into estimates of thermoregulatory cost. I calculated effective ambient temperature ( $T_{ef}$ ), the temperature reflecting the immediate microclimate of the animal, as:

$$T_{ef} = T_b - (T_b - T_a) \times (0.474 + 0.239 \times \sqrt{u} - 0.023 \times u) \text{ Equation 4}$$

Where  $T_b$  represents body temperature (°C),  $T_a$  represents ambient temperature (°C), and  $u$  represents wind speed (m/sec). I compared  $T_{ef}$  to a Lower Critical Temperature (LCT) value for each species. If  $T_{ef}$  was lower than LCT, a thermoregulatory component was included in estimates of energy expenditure. Metabolic heat production ( $H_{T+u}$ ) was estimated as:

$$H_{T+u} = a + b\sqrt{u} \text{ Equation 5}$$

Where  $b$  is a coefficient based on body size and temperature, calculated as:

$$b = 0.0092M^{0.66} \times \Delta T^{0.32} \text{ Equation 6}$$

Where  $M$  represents body mass (g) and  $\Delta T$  represents the difference between LCT and effective temperature. Although McKinney and McWilliams (2005) calculated  $\Delta T$  as the difference between LCT and ambient temperature ( $T_a$ ), in certain cases where  $T_a$  is higher than LCT but  $T_{ef}$  is lower, the use of  $T_a$  results in a negative value of  $\Delta T$ .

Because negative numbers cannot be raised to fractional exponents, I used  $T_{ef}$  to calculate  $\Delta T$ . I calculated the coefficient  $a$  as:

$$a = H_T - b\sqrt{0.06} \text{ Equation 7}$$

Where  $H_T$  represents the adjusted metabolic rate (kcal/hr) at  $T_a$ , and is calculated based on heat loss ( $Q_i$ ) from the head, neck, breast, body, and ventral surface of the animal as:

$$H_T = RMR + Q_{head} + Q_{neck} + Q_{breast} + Q_{body} + Q_{avs} \quad \text{Equation 8}$$

I used a heat transfer coefficient of 0.102 cal/cm/°C in all heat loss calculations except for  $Q_{avs}$ , for which I used 0.160 cal/cm/°C to account for increased heat loss due to contact with water on the ventral surface (Jenssen et al. 1989, McKinney and McWilliams 2005). Thermoregulatory costs for flying and walking behaviors presented an exception. For these behaviors, I used 0.102 cal/cm/°C to calculate  $Q_{avs}$  because no part of the bird was in contact with water (McKinney and McWilliams 2005). Morphometric measurements used to calculate energy expenditure for each dabbling species are presented in Appendix B.

I converted the proportion of the flock engaged in a particular behavior for each scan into an energy expenditure value using Equation 2. I summed energy expenditure across behaviors to determine hourly energy expenditure ( $HEE$ ) for each observation period in freshwater impoundments, brackish impoundments, and salt marshes. I compared  $HEE$  values between periods and habitats using a Kruskal-Wallis test ( $\alpha = 0.05$ ) for each species. I used a Steel-Dwass post-hoc test to identify pairwise differences in  $HEE$  between habitat category and period (JMP, Version 11, SAS Institute Inc. 2014). I then scaled average  $HEE$  for each observation period by the average length of each period over the winter session and summed these values to determine a single winter  $DEE$  value for each dabbling duck species.

### *Effects of Sea Level Rise on Carrying Capacity*

Over the next century, sea level rise (SLR) is likely to change the availability of various wetland habitats in Delaware, which in turn may lead to changes in carrying capacity estimates for wintering waterfowl. Thus, I forecasted changes in carrying capacity for each dabbling duck species at the landscape level based on a range of SLR estimates. I used data layers for the Chesapeake Bay Region commissioned by the National Wildlife Federation using the Sea Level Affecting Marshes Model (SLAMM v. 5.0; Glick et al. 2008), which predicts land cover changes in wetland habitats based on various climate change scenarios, accounting for processes such as marsh erosion and accretion. I evaluated the impacts of SLR on estimates of carrying capacity in Delaware for the years 2025, 2050, and 2075, and 2100 based on four SLR scenarios of varying severity:

- 1) IPCC A1B Mean Scenario (39 cm rise by 2100)
- 2) IPCC A1B Max Scenario (69 cm rise by 2100)
- 3) 1 m rise by 2100
- 4) 1.5 m rise by 2100

Scenarios 1 and 2 were developed by the Intergovernmental Panel on Climate Change (IPCC) and are based on varying projections for worldwide economic growth and technological development in the energy sector (IPCC 2007). Scenarios 3 and 4 were considered based on recommendations by the DNREC Sea Level Rise Technical Workgroup (2009). For all scenarios, developed lands were protected from SLR by dikes or levees.

I calculated carrying capacity for dabbling ducks under each SLR scenario using Equation 1. To inform energy supply, I determined the amount of salt marsh habitat available under each SLR scenario. I identified the SLAMM land cover types

that best corresponded with low marsh, high marsh, mudflat, subtidal, and quasi-tidal pool habitat categories. I included the Salt Marsh, Brackish Marsh, Tidal Flat, Estuarine Beach, and Estuarine Open Water SLAMM land cover types because they overlap spatially with these habitat categories and are biologically significant. Estuarine Open Water corresponded well with subtidal habitats, and was therefore assigned the energy value for subtidal habitats. Tidal Flat and Estuarine Beach corresponded well with mudflat habitats, and so were assigned the energy value for mudflat habitats. Salt Marsh and Brackish Marsh did not correspond well with a single habitat category, and were assigned an energy value based on the average of low marsh, high marsh, and pool habitats. I reduced the Estuarine Open Water category using various DEMs (NGDC 2012). I removed non-forageable Estuarine Open Water habitat (>1 m depth), adjusted for estimated SLR at each time step. I evaluated each SLR scenario twice: once allowing impoundments to revert to salt marsh, and again assuming impoundments are actively protected from SLR.

## **Abundance & Density**

### *Aerial Surveys*

I compared the relative abundance and density of wintering dabbling ducks between various wetland habitats in Delaware using two methods: aerial surveys and point-transect counts. I obtained aerial survey data from the Delaware Division of Fish and Wildlife (DFW), which has conducted wintering waterfowl surveys for over 30 years (DFW 2012). DFW collected aerial survey count and GPS location data in October, December, January, and March 2012–2013; however, I only used surveys from December and January to estimate density, because the Atlantic Flyway MWS is

typically conducted in January, and population sizes during these months probably better represent the “winter average” than estimates from the beginning or end of the winter period. The functional transect distance (the width of the sampled area, measured perpendicular to the aircraft) was estimated to be ~300 m. To determine the density of individuals present in 7 wetland habitat types (freshwater impoundment, brackish impoundment, high marsh, low marsh, mudflat, quasi-tidal pool, subtidal) in Delaware, I first delineated the surveyed area based on a survey track file and the functional transect distance. I then divided the number of individuals in each habitat type by the total area (ha) of each habitat within the survey area to estimate density (individuals/ha).

#### *Point-Transect Counts*

Though aerial surveys are useful for detecting population abundance trends, they lack the resolution necessary to detect species present in low numbers among a larger flock of birds (Laursen et al. 2008). To correct for this bias and ensure detection of low-density focal species, I also conducted point-transect counts at each study site. During behavioral scanning sessions, in addition to recording behavioral data, observers conducted a point-transect count every 40 min at the start of a new observation block ( $n = 2,128$ ; Fig. 2). Observers recorded the species, distance, number of individuals (if birds were clustered), and weather conditions. I pooled observations between years and used program DISTANCE (Version 6.2, DISTANCE Development Team 2014) to estimate dabbling duck density (individuals/ha) accounting for imperfect detectability in freshwater impoundments, brackish impoundments, and unmanaged salt marshes. I did not delineate between specific salt marsh habitats (high marsh, low marsh, mudflat, subtidal, quasi-tidal pool) because

visibility was limited and point counts were typically conducted on flocks of birds in relatively open areas. Thus, I treated salt marshes as a single habitat category when estimating density. I fit several candidate models using various key functions and series expansion adjustments recommended by Buckland et al. (2001), which utilize various key functions and series expansion adjustments:

- 1) Half-normal key function + Cosine series expansion
- 2) Half-normal key function + Hermite polynomial series expansion
- 3) Hazard-rate key function + Cosine series expansion
- 4) Hazard-rate key function + Simple polynomial series expansion

I included distance from observer (m) in all models, and considered only observer and weather as factor covariates, because they were most likely to impact detectability.

Thus, I fit 4 candidate models for each detection function, for a total of 16 models per habitat category:

- 1) Distance
- 2) Distance + Observer
- 3) Distance + Weather
- 4) Distance + Observer + Weather

I post-stratified results to obtain density estimates for individual dabbling species. I selected the top model for each habitat type from the candidate models based on the lowest Akaike Information Criterion (AIC) score. Since no candidate models were within  $\Delta AIC \leq 2.0$  of the top model, model averaging was unnecessary. I compared density estimates between habitats for each species using a one-way Analysis of Variance (ANOVA,  $\alpha = 0.05$ ). If a significant effect was detected, I used Tukey's

Honest Significant Difference (HSD) post-hoc test to identify significant pairwise differences between groups (JMP, Version 11, SAS Institute Inc. 2014).

## Chapter 4

### RESULTS

#### *Energy Availability*

I collected soil core ( $n = 1,346$ ), nekton ( $n = 426$ ), and salt marsh snail (*Melampus* spp.;  $n = 87$ ) samples to inform dabbling duck energy availability in freshwater impoundments, brackish impoundments, and salt marsh habitats (low marsh, high marsh, quasi-tidal pool, mudflat, subtidal). Biomass estimates (kg/ha) for seed and animal foods by habitat, season, and year are presented in Table 1. One-way ANOVAs ( $\alpha = 0.05$ ) showed no temporal depletion of food energy for any dabbling species in any habitat type (Appendix C). Thus, I pooled samples across seasons to estimate food energy over the winter period. One-way ANOVAs ( $\alpha = 0.05$ ) revealed significant differences in soil core energy between habitats for all dabbling species (American black ducks [ $F_{6, 1,339} = 5.324, P < 0.001$ ], mallards [ $F_{6, 1,339} = 12.019, P < 0.001$ ], northern pintails [ $F_{6, 1,339} = 13.692, P < 0.001$ ], northern shovelers [ $F_{6, 1,339} = 2.656, P = 0.015$ ], green-winged teal [ $F_{6, 1,339} = 4.657, P < 0.001$ ], American wigeon [ $F_{6, 1,339} = 13.415, P < 0.001$ ], gadwall [ $F_{6, 1,339} = 11.108, P < 0.001$ ]; Table 2). I estimated that salt marsh snails contributed an additional  $6,495 \pm \text{SE } 4,322$  kcal/ha to high marsh and  $2,614 \pm \text{SE } 1,501$  kcal/ha to low marsh for all focal species; thus, I added these values to soil core and nekton energy. Accounting for nekton and salt marsh snails, food energy density was highest in freshwater impoundments for black ducks (370,662 kcal/ha; Fig. 3), mallards (506,205 kcal/ha; Fig. 4), northern pintails (562,089 kcal/ha; Figure 5), American wigeon (217,710 kcal/ha; Fig. 8), and gadwall (294,938 kcal/ha; Fig. 9). By contrast, northern shoveler energy density was highest in quasi-tidal pools (300,342 kcal/ha; Fig. 6), and green-winged teal energy density

was highest in low marsh (244,268 kcal/ha; Fig. 7). Extrapolating to the landscape level and summing across all available habitat within a 16 km buffer from the coast, I estimated approximately  $9.70 \times 10^9$  kcal of food energy available to black ducks,  $1.14 \times 10^{10}$  kcal available to mallards,  $9.24 \times 10^9$  kcal available to northern pintails,  $7.60 \times 10^9$  kcal available to northern shovelers,  $7.86 \times 10^9$  kcal available to green-winged teal,  $2.38 \times 10^9$  kcal available to American wigeon, and  $5.47 \times 10^9$  kcal available to gadwall wintering on the Delaware Bayshore. Each of these values assumes no competition among species.

### *Behavior & Energy Demand*

I collected instantaneous scan samples ( $n_{black\ duck} = 1,725$  scans containing black ducks;  $n_{mallard} = 702$ ;  $n_{pintail} = 1,036$ ;  $n_{shoveler} = 1,433$ ;  $n_{green-winged\ teal} = 1,143$ ;  $n_{wigeon} = 371$ ;  $n_{gadwall} = 542$ ) over the 24-hr period to inform behavior and daily energy expenditure (*DEE*) for wintering dabblers. Across all observation periods and habitats, dabblers spent the greatest proportion of time feeding (range: 29.79–59.63%), typically followed by swimming (range: 20.02–25.93%), resting (range: 8.40–29.58%), and flying (range: 3.89–18.75%; Table 3). Other behaviors represented a negligible proportion of time and were thus excluded from analysis. Across all observation periods, Kruskal-Wallis tests ( $\alpha = 0.05$ ) indicated significant differences in behavioral proportions between habitats. Steel-Dwass post-hoc pairwise comparisons revealed significant pairwise comparisons. For most dabblers, feeding behavior tended to be higher on either freshwater or brackish impoundments than on salt marshes; exceptions include green-winged teal, which fed more on salt marshes than brackish impoundments, and American wigeon, for which feeding was not statistically different between habitats. Black ducks, northern pintails, and

gadwall tended to rest more on salt marshes than either freshwater or brackish impoundments; by contrast, green-winged teal rested more on freshwater and brackish impoundments than salt marshes. Mallards, northern shovelers, and American wigeon showed no significant differences in resting behavior between habitats. Black ducks swam more on freshwater impoundments and salt marshes than brackish impoundments. Northern pintails and green-winged teal swam more in freshwater or brackish impoundments than salt marshes. Mallards, northern shovelers, American wigeon, and gadwall showed no significant differences in swimming behavior between habitats. Flying behavior tended to be higher on salt marshes than either freshwater or brackish impoundments; exceptions include northern shovelers, which flew more on brackish impoundments than freshwater impoundments, but no significant difference was detected between impoundments and salt marshes, and American wigeon, for which I detected no significant differences in flying behavior (Table 3).

Across all observation periods, Kruskal-Wallis tests indicated significant differences in hourly energy expenditure (*HEE*) between habitats for all focal species except black ducks, American wigeon, and gadwall (black ducks [ $H_2 = 1.125, P = 0.570$ ], mallards [ $H_2 = 10.555, P = 0.005$ ], northern pintails [ $H_2 = 18.417, P < 0.001$ ], northern shovelers [ $H_2 = 6.909, P = 0.032$ ], green-winged teal [ $H_2 = 16.480, P < 0.001$ ], American wigeon [ $H_2 = 5.211, P = 0.074$ ], gadwall [ $H_2 = 2.906, P = 0.234$ ]). Mallard *HEE* was higher on salt marshes than brackish impoundments. Northern pintail *HEE* was higher on salt marshes than freshwater or brackish impoundments. Northern shoveler *HEE* was higher on brackish than freshwater impoundments. Green-winged teal *HEE* was higher on salt marshes and brackish impoundments than

freshwater impoundments (Tables 4–10). Scaled to the 24-hr day, black duck *DEE* over the winter period was  $338.92 \pm \text{SE } 15.61$  kcal/bird/day (95% CI: 308.18–369.66 kcal/bird/day; Table 11), mallard *DEE* was  $349.79 \pm \text{SE } 35.33$  kcal/bird/day (95% CI: 279.16–420.38 kcal/bird/day; Table 12), northern pintail *DEE* was  $258.58 \pm \text{SE } 9.86$  kcal/bird/day (95% CI: 238.93–278.20 kcal/bird/day; Table 13), northern shoveler *DEE* was  $192.69 \pm \text{SE } 5.51$  kcal/bird/day (95% CI: 181.84–203.56 kcal/bird/day; Table 14), green-winged teal *DEE* was  $111.84 \pm \text{SE } 4.22$  kcal/bird/day (95% CI: 103.30–120.42 kcal/bird/day; Table 15), American wigeon *DEE* was  $272.59 \pm \text{SE } 40.42$  kcal/bird/day (95% CI: 113.27–431.88 kcal/bird/day; Table 16), and gadwall *DEE* was  $232.99 \pm \text{SE } 18.96$  kcal/bird/day (95% CI: 194.13–271.83 kcal/bird/day; Table 17).

#### *Population Estimation*

I used aerial survey data from late December 2012, early January 2013, and late January 2013 to estimate the density of my focal species within 7 wetland habitats: Freshwater impoundment, brackish impoundment, high marsh, low marsh, mudflat, quasi-tidal pool, and subtidal. Density estimates based on aerial survey data showed that black duck densities were highest on subtidal habitats (0.28 individuals/ha), northern pintail and green-winged teal densities were highest on mudflats (0.33 and 0.44 individuals/ha, respectively), mallard densities were highest on freshwater impoundments (0.59 individuals/ha), and northern shoveler, American wigeon, and gadwall densities were highest on brackish impoundments (0.19, 0.03, and 0.32 individuals/ha, respectively; Table 18). Extrapolating to the state level, I estimated 6,457 black ducks, 8,366 mallards, 1,138 northern pintails, 1,313 northern shovelers, 2,386 green-winged teal, 302 American wigeon, and 2,226 gadwall were

present over the wintering period based on available habitat within a 16 km buffer of the Delaware Bayshore.

In addition to aerial surveys, I collected point-transect counts in freshwater impoundments, brackish impoundments, and salt marshes to estimate dabbling population density and abundance. In freshwater impoundments, dabbling density was best predicted using a half-normal key function and cosine series expansion, with observer as a covariate ( $P = 0.07$ , EDR = 118.75,  $D = 0.155$ ,  $P < 0.001$ ). In brackish impoundments, density was best predicted using a half-normal key function and cosine series expansion, with no included covariates ( $P = 0.05$ , EDR = 113.93 m,  $D = 0.120$ ,  $P < 0.001$ ). In salt marshes, density was best predicted using a half-normal key function and hermite polynomial series expansion, with no included covariates (covariates ( $P = 0.10$ , EDR = 158.41 m,  $D = 0.131$ ,  $P < 0.001$ ; Appendix D). After post-stratifying results by species, I found that mallard, northern pintail, and gadwall densities were highest on freshwater impoundments ( $D_{mallard} = 0.30 \pm 0.05$ ;  $D_{pintail} = 1.63 \pm 0.31$ ;  $D_{gadwall} = 0.38 \pm 0.12$  individuals/ha), northern shoveler, green-winged teal, and American wigeon densities were highest on brackish impoundments ( $D_{shoveler} = 0.96 \pm 0.14$ ;  $D_{green-winged\ teal} = 1.84 \pm 0.34$ ;  $D_{wigeon} = 1.40 \pm 0.52$  individuals/ha), and black duck densities were highest on salt marshes ( $D_{black\ duck} = 0.50 \pm 0.08$  individuals/ha). One-way ANOVAs revealed that black duck, mallard, northern shoveler, and green-winged teal densities differed significantly between habitats, and northern pintail, American wigeon, and gadwall densities did not differ significantly (black duck [ $F_{2, 2,125} = 5.276$ ,  $P = 0.005$ ], mallard [ $F_{2, 2,125} = 4.790$ ,  $P = 0.008$ ], northern pintail [ $F_{2, 2,125} = 2.326$ ,  $P = 0.098$ ], northern shoveler [ $F_{2, 2,125} = 10.321$ ,  $P < 0.001$ ], green-winged teal [ $F_{2, 2,125} = 8.574$ ,  $P < 0.001$ ], American wigeon [ $F_{2, 2,125} =$

2.844,  $P = 0.058$ ], gadwall [ $F_{2, 2,125} = 0.835$ ,  $P = 0.434$ ]). Tukey's HSD post-hoc test indicated that black duck density was significantly higher on salt marshes than brackish impoundments, mallard density was higher on freshwater impoundments and salt marshes than brackish impoundments, northern shoveler density was higher on freshwater and brackish impoundments than salt marshes, and green-winged teal density was higher on brackish impoundments than freshwater impoundments or salt marshes (Table 19). Extrapolating to the state-level, I estimated  $18,638 \pm 2,978$  black ducks,  $10,665 \pm 3,633$  mallards,  $36,376 \pm 15,146$  northern pintails,  $8,671 \pm 1,863$  northern shovelers,  $17,912 \pm 3,506$  green-winged teal,  $7,669 \pm 2,599$  American wigeon, and  $13,969 \pm 4,834$  gadwall in total over the wintering period based on available habitat within a 16 km buffer of the Delaware Bayshore.

#### *Bioenergetic Carrying Capacity & Sea Level Rise*

I estimated bioenergetic carrying capacity for dabbling species using Equation 1. Based on food energy and *DEE*, I estimated  $2.86 \times 10^7$  duck use-days (*DUD*) currently available to black ducks,  $3.26 \times 10^7$  *DUD* available to mallards,  $3.57 \times 10^7$  *DUD* available to northern pintails,  $3.95 \times 10^7$  *DUD* available to northern shovelers,  $7.06 \times 10^7$  *DUD* available to green-winged teal,  $8.73 \times 10^6$  *DUD* available to American wigeon, and  $2.35 \times 10^7$  *DUD* available to gadwall over the winter period. Assuming competition for preferred foods between focal species, carrying capacity estimates were reduced to  $1.23 \times 10^7$  *DUD* available to black ducks,  $1.67 \times 10^7$  *DUD* available to mallards,  $5.56 \times 10^6$  *DUD* available to northern pintails,  $2.26 \times 10^6$  *DUD* available to northern shovelers,  $4.26 \times 10^6$  *DUD* available to green-winged teal,  $1.52 \times 10^5$  *DUD* available to American wigeon, and  $3.18 \times 10^6$  *DUD* available to gadwall

over the winter period (Figure 10). Figures 11–17 spatially compare current carrying capacity (DUDs/ha) with population density estimated via aerial surveys for each habitat.

Generally, NOAA’s Sea Level Affecting Marshes Model (SLAMM) predicted that as SLR scenarios become more severe, an increasing amount of salt marsh habitat (corresponding largely with low marsh and high marsh) will likely be replaced with subtidal and mudflat habitats (Figures 18–21). Dabbling carrying capacity estimates tended to decrease with increasing sea level rise (SLR) over time. Black duck, mallard, and green-winged teal carrying capacity decreased under all SLR scenarios. Northern pintail, northern shoveler, and gadwall carrying capacity decreased under all SLR scenarios except the IPCC A1B Mean scenario. American wigeon presented a notable exception, with increasing carrying capacity under all SLR scenarios except the 1.5m by 2100 scenario (Figures 22–28). However, carrying capacity estimates for all focal species were higher in scenarios where impoundments were protected, compared with scenarios where impoundments were allowed to revert to unmanaged tidal marsh. Additionally, for scenarios with protected impoundments, the proportion of total available *DUD* contributed by impoundments within a 16 km buffer of the Delaware Bayshore increased with increasing SLR for all focal species.

## Chapter 5

### DISCUSSION

Though previous studies have investigated wintering waterfowl carrying capacities, few have sought to explicitly compare the value of managed and unmanaged habitats to these species. Additionally, few have taken a multi-species approach to addressing habitat quality from an energetic standpoint in present and future conditions. This study employed a variety of methods to assess the current and future status of dabbling duck habitat availability, use, and carrying capacity in Delaware. My results suggest that my focal species (American black duck, mallard, northern pintail, northern shoveler, green-winged teal, American wigeon, gadwall) utilize managed impoundments and unmanaged tidal marshes for a variety of purposes, and there is concern regarding their availability under future sea level rise scenarios.

#### *Behavior*

In a study quantifying behavior of black ducks wintering in southern New Jersey, Jones (2012) found that black ducks tended to spend more time feeding and resting on non-hunted impoundments than hunted tidal marshes during the hunting season, suggesting that black ducks utilize impoundments as refugia to escape from disturbance on hunted sites during the open hunting season. Additionally, Conroy et al. (1986) and Costanzo (1988) noted that black ducks tended to relocate to impoundments during the day, presumably to avoid hunting pressure. Turnbull and Baldassarre (1987) found that mallards and American wigeon in Alabama tended to feed more on managed impoundments, but rested more in river habitats. In contrast, Rave and Baldassare (1989) observed lower feeding and higher resting for green-

winged teal on coastal brackish impoundments compared with unimpounded brackish marshes in Louisiana. My results support the conclusion that dabbling ducks largely use impoundments more than unmanaged salt marshes for feeding (Table 3). It should be noted that, although sample sizes constraints precluded a thorough investigation of the influence of tidal stage on behavior, Jones (2012) found that foraging behavior in black ducks is affected by tidal stage, and black ducks tended to feed more at lower tides. I found that of all my focal species, only green-winged teal rested more on impoundments. Other dabblers rested significantly more on salt marshes (black ducks, northern pintails, gadwall) or displayed no significant difference in resting between habitats (mallards, northern shovelers, American wigeon). Despite this disparity, I found that several dabbler species spent less time flying on impoundments than salt marshes. Flight is a common response to disturbance (Morton 2002); as such, the lower rates of flying I observed on impoundments imply that impoundments may be valuable sites for disturbance avoidance refugia. Additionally, flight is the most energetically costly behavior (Morton et al. 1989, Gill et al. 2001, Cramer 2009). I found that energy expenditure on impoundments (particularly freshwater) was generally lower than salt marshes, largely due to the lower proportions of flight I observed on impoundments; thus, dabblers that utilize impoundments more frequently may expend less energy, which may in turn increase carrying capacity.

### *Food Energy*

My estimates of food energy availability by habitat type indicated that for most dabbler species, energy density was greater in impoundments than low marsh, high marsh, mudflat, subtidal, or quasi-tidal pool habitats (Table 2; Fig. 3–9). In particular, freshwater impoundments tended to have the greatest energy density due to a large

volume of seeds. For some species, quasi-tidal pools may actually contain greater energy density (i.e., northern shovelers, gadwall) than impoundments due to a high concentration of nekton energy. However, I estimated that pools comprise only 15 ha of the marshland in my study area, and thus contribute significantly less to carrying capacity than the estimated 3,858 ha of impoundments. It is perhaps unsurprising that impoundments emerge as the most energy dense wetland habitat available to wintering dabblers, given that they are often managed specifically to promote growth of waterfowl foods. Therefore, impoundments provide pockets of energy dense habitat that are regularly utilized by many dabbling duck species for feeding.

My results contrast with prior research on Atlantic Flyway black ducks (Plattner et al. 2010, Cramer et al. 2012), which has suggested that mudflat habitats contain the greatest energy density. However, Ringelman et al. (2015) found that energy estimates for mudflat habitats were influenced strongly by outliers associated with invertebrate food energy, resulting in an overestimation of mudflat energy density. My estimates of available black duck energy from soil cores for low marsh (283,064 kcal/ha) and freshwater impoundment (356,585 kcal/ha) generally agree with those of Cramer et al. (2012) for low marsh (268,513 kcal/ha) and freshwater marsh (371,057 kcal/ha) in southern New Jersey. However, my energy estimates for high marsh (201,545 kcal/ha) were somewhat higher than Cramer et al. (2012) (116,704 kcal/ha), and my mudflat and subtidal estimates (110,344 and 71,369 kcal/ha, respectively) were significantly lower than Cramer et al. (2012) (1,190,749 and 269,082 kcal/ha, respectively), likely due to the high variance associated with estimating energy in these habitats.

Ringelman et al. (2015) incorporated black duck energy estimates from Cramer et al. (2012) and Plattner et al. (2010) along with various unpublished estimates to estimate energy density by habitat across the mid-Atlantic region, and examined the effect of outliers on energy estimates. Ringelman et al. (2015) found lower energy estimates for low marsh (501,655 kcal/ha), high marsh (554,121 kcal/ha), mudflat (1,024,739 kcal/ha), and subtidal (129,603 kcal/ha) habitats and higher for freshwater (248,920 kcal/ha) when outliers were included. However, my estimates were higher than Ringelman et al. (2015) after they removed outliers for all habitats (low marsh [62,857 kcal/ha], high marsh [123,831 kcal/ha], mudflat [68,997 kcal/ha], subtidal [45,932 kcal/ha], freshwater [214,223 kcal/ha]).

Although considerable effort has been made to estimate energetic density of black duck foods in various habitat types in the Atlantic Flyway, no studies to my knowledge have sought to explicitly delineate energy density by habitat for other dabbler species in the mid-Atlantic region. However, several studies across the United States have examined the relative value of managed vs. unmanaged wetlands to waterfowl. I observed similar trends to Johnson (2007) and Stafford et al. (2011), who found that waterfowl food abundance was greater in managed than unmanaged habitats in Utah and Illinois, respectively. Similarly, Bowyer et al. (2005) found that managed moist-soil habitat in Illinois had a greater carrying capacity than estimates for waterfowl than other published estimates. However, my results contrast with those of Brasher (2010), who found that waterfowl carrying capacities in actively and passively managed wetlands during fall and spring were not statistically different.

Despite my attempts to refine estimates of energetic density for wetland habitats by sampling waterfowl foods via various methodologies, it should be noted

that there are inevitably limitations associated with these estimates (Williams et al. 2014). In particular, I elected not to include a foraging threshold in my modeling efforts. The foraging threshold is a basic tenet of optimal foraging theory (OFT; MacArthur and Pianka 1966, Charnov 1976) which suggests that at some point, foraging animals will deplete food resources in a patch to some “giving up density”, at which point it is no longer profitable to forage in that patch. Previous waterfowl researchers have used a foraging threshold of 50 kg/ha, developed for birds foraging in rice fields (Reinecke et al. 1989); however, few have investigated thresholds for non-agricultural foods (Naylor 2002, Cramer 2009), and there is little evidence to support the use of this threshold for natural foods. Recently, Hagy and Kaminski (2015) found that dabbling ducks reduced natural food densities to 170 kg/ha, but cautioned that their results may be specific to their system in the Mississippi Alluvial Valley (MAV). This foraging threshold is liberal compared with other estimates, and applying it to my system would have drastically reduced available food estimates. Additionally, no threshold has been published for invertebrate foods, which are known to be a significant food source particularly in mid-Atlantic salt marsh systems (Cramer 2009). Further, Plattner et al. (2010), Cramer et al. (2012), and Ringelman et al. (2015) found that seasonal depletion of food energy largely did not occur in mid-Atlantic wetlands. If wintering waterfowl populations do not noticeably deplete food supplies in the mid-Atlantic coastal salt marsh, then applying a foraging threshold model at the landscape scale may be an unnecessary consideration. Ultimately, I felt more comfortable omitting a foraging threshold, rather than incorporating thresholds that I do not believe are applicable to my study system. However, I recommend that future researchers attempt to determine a realistic foraging threshold that is applicable to mid-Atlantic

salt marsh systems, and refine my estimates of food energy density using this threshold.

### *Energy Expenditure*

In recent years, significant effort has been devoted towards estimating daily energy expenditure (*DEE*) for wintering waterfowl using various methodologies (Miller and Eadie 2006, Cramer et al. 2012, Heise 2012, Jones et al. 2014). Allometric estimation, based on body mass, has become a popular technique for estimating waterfowl *DEE* because it requires little effort compared to other methods (Heitmeyer 1989, Cramer 2009). Typically, investigators estimate *DEE* to be three times the resting metabolic rate (*RMR*; Purol 1975, Prince 1979). Miller and Eadie (2006) facilitated the estimation of *DEE* for dabbling ducks by regressing historical *RMR* values estimated in prior respirometry studies against body mass (Hartung 1967, Berger et al. 1970, Prange and Schmidt-Nielsen 1970, Smith and Prince 1973, Wooley and Owen 1977, Prinzing and Hänsler 1980, Gavrilov and Dol'nik 1985, Bennett and Harvey 1987), allowing researchers to effectively estimate *DEE* for many dabbling species using only body mass data as an input. However, this method does not account for behavioral and environmental changes that may influence *DEE* over the wintering period; for example, variable cost of thermoregulation (*CT*; Albright et al. 1983, Morton et al. 1989, Jones 2012). Time-energy budgets offer a more detailed (albeit significantly more resource-intensive) method of estimating *DEE*.

Cramer (2009) estimated *DEE* of wintering black ducks in southern New Jersey to be 283.7 kcal/bird/day based on time-energy budgets constructed from diurnal instantaneous scan samples and a fixed *CT*. Jones et al. (2014) refined this estimate by incorporating nocturnal behavioral observations in addition to diurnal and

crepuscular observations, and incorporating a simple variable *CT* model based on the difference between ambient temperature and a species-specific lower critical temperature (LCT), resulting in an increased *DEE* of 294.3 kcal/bird/day. My *DEE* estimates represent a further refinement of the time-energy budget methodology employed in these studies by incorporating a more detailed *CT* model based on temperature, wind speed, and heat loss from various anatomical regions (McKinney and McWilliams 2005). Jones (2012) noted that his black duck *DEE* estimate was likely higher than previously reported estimates because he 1) recorded a higher proportion of flight behavior than other studies, 2) collected behavioral observations over the 24-hr period, and so captured more temporal variation, and 3) used a higher *RMR* value based on Miller and Eadie's (2006) predictive equation for dabbling ducks. Although I recorded a lower proportion of flight behavior than Jones et al. (2014), my *DEE* estimate for black ducks was significantly higher ( $338.92 \pm \text{SE } 15.61$  kcal/bird/day). This is primarily due to using a more detailed *CT* model, which resulted in drastically (>400%) higher *CT* estimates.

Though efforts have been made to estimate *DEE* for black ducks (i.e., Jones et al. 2014, Wooley and Owen 1978), few studies have addressed *DEE* in other waterfowl species using behavioral sampling methods (e.g. Atlantic brant; Ladin 2010, Heise 2012), likely due to logistical constraints; thus, there is little context within which to compare my *DEE* estimates for other focal species. *DEE* for these species is likely often estimated via the allometric model, based solely on *RMR*. Jones (2012) found that using the allometric method with dabbling specific *RMR* estimates obtained from Miller and Eadie (2006) resulted in a significantly higher *DEE* value (369.1 kcal/bird/day) for black ducks than using time-energy budgets. Interestingly, my *DEE*

estimate is closer to this value than to previously reported estimates based on time-energy budgets. In fact, *DEE* values for all focal species constructed from time-energy budgets deviated relatively little from allometric estimates (12.96% lower on average; range 0.57– 22.88%). These results suggest that simply multiplying the dabbler specific *RMR* value by 3 (the mean of all activity multipliers; Wooley and Owen 1977) may be an appropriate substitution in lieu of collecting detailed behavioral and environmental data, especially if further refinements to time-energy budget methodology continue to result in increasing *DEE* estimates.

#### *Population Estimation*

My point count estimates suggest that generally, dabbler densities are higher on either freshwater or brackish impoundments than on unmanaged salt marshes. Although post-hoc comparisons indicated that only mallard, northern shoveler, and green-winged teal densities were statistically higher on impoundments than salt marshes, all focal species except black ducks showed higher densities on impoundments. Thus, my point count estimates suggest that in general, dabblers tend to concentrate on impoundments, implying that dabblers preferentially select impoundments over salt marshes. This preference may be a result of several factors, including selecting impoundments for disturbance avoidance (Jones 2012), higher food energy densities, or other physiological requirements that may be provided by freshwater or brackish impoundments. However, it should also be noted that for black ducks, a species of particular conservation concern to this system, densities were highest on salt marshes. Black duck densities were significantly higher on salt marshes than brackish impoundments; perhaps an unsurprising result, considering that black ducks are well known as a salt marsh obligate species, requiring habitats with

significant emergent vegetation in addition to open spaces such as impoundments when possible (Baldassarre 2014). Furthermore, although black duck densities were higher on salt marshes than freshwater impoundments, the difference was not statistically significant. My results agree with Gordon et al. (2010), who found that dabblers were present in greater numbers on impoundments than tidal marshes in South Carolina, with the exception of black ducks. Generally, density estimates produced by point counts tended to be higher than aerial survey estimates for freshwater and brackish impoundments (Tables 18 & 19). Although my aerial survey density estimates were delineated between specific salt marsh habitat types, I found that most dabblers had higher densities on freshwater or brackish impoundments than on most unmanaged salt marsh habitat types. Exceptions included black ducks, which were densest on subtidal habitats, and northern pintails and green-winged teal, which were densest on mudflats. Extrapolating to the state level, point counts generally produced much higher abundance estimates than aerial surveys. Aerial survey abundance estimates were similar to 10-yr MWS mean estimates for Delaware.

Although both aerial survey and point count density estimates are useful, there are biases associated with each methodology. My aerial survey estimates are likely biased low, particularly for unmanaged salt marsh habitats, because these areas tend to be heavily vegetated in comparison with the open pools typically associated with impoundments. Because aerial surveys are less likely to detect uncommon or rare species, especially when present among larger flocks or hiding in vegetation (e.g., black ducks), they likely underestimate true density. Additionally, though I used GPS points associated with aerial survey counts to estimate density in various habitats, because GPS points were taken by an observer in an aircraft, these points only exist

along the survey transect. In some cases birds were located off to the side of the transect, potentially occupying a different habitat type than that associated with the recorded GPS point and thus introducing a further source of bias into aerial survey estimates. By contrast, my point-transect counts more likely overestimated density, because counts were typically conducted on flocks of birds in relatively open habitats for ease of visibility, which likely leads to upward bias in density estimates. Since many waterfowl species tend to congregate on open water, and may therefore have higher densities in these areas compared with vegetated habitats, my point-transect density and abundance estimates may be biased high.

Historically, breeding waterfowl surveys in the United States account for biases in aerial survey abundance estimates by applying a visibility correction factor (VCF) developed using ground-based point-transect surveys conducted simultaneously, usually resulting in an upward adjustment of aerial estimates (Smith 1995). However, accomplishing such a feat requires a significant coordinated effort, and was beyond the means of this project. I therefore did not attempt to determine a VCF to correct aerial survey estimates, but rather present aerial survey and point count abundance estimates separately. These estimates provide utility as a range of possible density and abundance values, which may allow managers to plan for a multiple scenarios. The Atlantic Coast Joint Venture (ACJV) stepped down continental population objectives set by the North American Waterfowl Management Plan (USFWS 2012) to the state-level, resulting in population goals of 36,749 black ducks, 41,291 mallards, 30,362 green-winged teal, 13,445 northern pintails, 11,143 northern shovelers, 6,023 gadwall, and 4,112 wigeon for Delaware (ACJV 2005). My point count estimates suggest that for several of my focal species, these goals are near to

being met, and in some cases may have been exceeded (i.e., wigeon). However, maintenance of critical wetland habitats will be required if these goals are to be met in the future.

### *Carrying Capacity and Sea Level Rise*

I estimated more DUDs (including competition between dabblers) available to black ducks and mallards than are required to sustain current population sizes predicted by point counts, aerial surveys, or 10-yr MWS data by a significant margin (Fig. 10). Although aerial survey and MWS abundance estimates for northern pintails, northern shovelers, green-winged teal, and gadwall suggest that these species are also well below carrying capacity, point count estimates were very similar to carrying capacity values. Indeed, if point counts approximate true population sizes, northern shovelers, green-winged teal, and gadwall may be near to their respective carrying capacities, and northern pintails may be at or above carrying capacity. Of all focal species, only American wigeon appear to be at or above carrying capacity regardless of the methodology used for population estimation; however, because American wigeon rely upon submerged aquatic vegetation (SAV) such as wigeongrass (*Ruppia maritima*) as a food source, and I did not sample for SAV, I likely underestimated wigeon carrying capacity. Future researchers seeking to improve carrying capacity estimates for wigeon and other aquatic grazers should consider the energy provided by SAV in various habitats. Carrying capacities for black ducks and mallards were reduced by approximately half when accounting for competition, but nonetheless were significantly higher than other dabblers because I rationed available food between species proportionately based on 10-yr MWS population estimates in an attempt to account for the effects of competition; thus, more food (and therefore energy) was

allocated to species with comparatively high population abundances (i.e., black ducks, mallards), resulting in higher carrying capacity estimates for these species.

Although my estimates suggest that most dabblers in Delaware are not currently at carrying capacity, my modeling efforts may have overestimated carrying capacity due to multiple factors. First, although I attempted to account for the effects of competition between dabbler species by dividing shared food resources among the species known to consume them, I did not attempt to account for external competition for food by non-focal waterfowl species or other wildlife (i.e., fish). Thus, because some non-focal species likely compete for the same food resources as my focal species, the true effect of competition may be greater than my estimates indicate, which in turn decreases carrying capacity. Second, because I elected not to include a foraging threshold in my food energy density models, energy availability may be overestimated. Depending on the foraging threshold of the mid-Atlantic salt marsh system (if applicable), incorporating a threshold could significantly reduce food energy and carrying capacity estimates. Thus, true carrying capacity values may be lower than predicted. Additionally, though it was beyond the scope of this project, it may be prudent for future researchers to consider the significance of other non-marsh habitats (i.e. mallards may forage in agricultural fields, wigeon forage in SAV beds, etc.) and sample those habitats appropriately.

Although dabblers in Delaware have likely not yet reached carrying capacity, carrying capacity is likely to decrease in the future as a result of SLR for most species. I predicted that under the most conservative SLR scenario considered (IPCC A1B Mean, 39 cm rise by 2100), mallard and green-winged teal carrying capacities will likely decrease slightly, black duck and northern shoveler carrying capacities will

remain relatively constant, and northern pintail, American wigeon, and gadwall carrying capacities may increase slightly due to changes in marsh habitat composition. Under all other SLR scenarios (IPCC A1B Max [69 cm rise by 2100], 1m by 2100, 1.5m by 2100), I predicted carrying capacity to decrease between 2025 and 2100 for all species (American wigeon presented an exception, as I predicted carrying capacity to increase under both the IPCC A1B Mean and Max scenarios; Fig. 27).

Changes in future dabbling carrying capacity result from variation in the amount and composition of available salt marsh and impoundment habitat. Such changes are effected largely by SLR, and thus the severity of future SLR plays an important role in dabbling carrying capacity. My energy density estimates, along with changes in habitat availability as predicted by the Sea Level Affecting Marshes Model (SLAMM), suggest that energetically dense habitats (such as low marsh and high marsh) will gradually be replaced by habitats with lower food energy densities (such as subtidal and mudflat), resulting in decreased carrying capacities. Indeed, if SLR over the next century is more severe than the conservative IPCC A1B Mean scenario, carrying capacity will likely decrease for most dabbling species (Fig. 22–28). Although Fig. 22–28 depict scenarios in which impoundments are both protected and unprotected from SLR, it should be noted that because I was only able to obtain SLR data at 4 time steps (2025, 2050, 2075, 2100), I was unable to determine the precise “tipping point” at which each impoundment becomes susceptible to SLR. Further, this “tipping point” may vary based on the effort invested in impoundment upkeep, as well as unpredictable events such as major storms, which may cause premature breaches (i.e., Prime Hook Unit II in years 2009 and 2012 following a nor’easter and Hurricane Sandy, respectively). Thus, managers should consider that in reality, carrying capacity

estimates for unprotected scenarios gradually depart from those for protected scenarios as these “tipping points” are reached.

To illustrate the potential impact of SLR, I estimated the difference in available DUDs to black ducks in 2100 between the most conservative (IPCC A1B Mean) and liberal (1.5m by 2100) scenarios. I found that the 1.5m by 2100 scenario predicted ~18.4 million fewer DUDs than were estimated under the IPCC A1B Mean scenario (where black duck carrying capacity remained relatively constant; Fig. 10). This equates to ~102,000 fewer black ducks supported over a 180-day wintering period, not accounting for interspecific competition. Given that my estimates of black duck carrying capacity suggest that the landscape can currently support ~159,000 black ducks over the wintering period (sans competition), a decrease in carrying capacity of such magnitude could hold important implications for future black duck populations. I acknowledge that there is a disparity in my present day carrying capacity estimates and those predicted by SLR models; namely, the SLAMM model predicts a baseline carrying capacity that is significantly higher than my estimates. This disparity is likely due to differences in the land cover data set used by SLAMM and the State Wetlands Mapping Project (SWMP) land cover data I used to estimate carrying capacity. However, because SLAMM is a regional project and its data set spans much of the Chesapeake Bay area, and SWMP data is more refined and specific to Delaware, I believe my carrying capacity estimates are more accurate than those produced by SLAMM. Although SLAMM may overestimate carrying capacity, the trends predicted by the model over time are valuable nonetheless, and likely reflect future trends in carrying capacity as salt marsh habitat is increasingly lost.

## Chapter 6

### MANAGEMENT IMPLICATIONS

My results suggest that both freshwater and brackish managed impoundments are important habitats for dabbling ducks wintering on the Delaware Bayshore for a variety of reasons. From a behavioral standpoint, impoundments serve as important sites where most dabblers exhibit increased feeding behavior and decreased flying behavior compared with unmanaged salt marsh sites. Managers should consider the implications of these behavioral differences, particularly in hunted areas, where dabblers may depend upon adjacent impoundments as refugia to escape from hunting pressure and other disturbance. Additionally, given that impoundments in Delaware contain more available food energy for nearly all dabblers compared with unmanaged salt marshes, and that most dabbler species were denser on impoundments than unmanaged marshes and therefore experienced greater use, impoundments serve as important pockets of high-density food energy where dabblers congregate to feed and avoid disturbance. However, although trends between species were relatively consistent, managers should base their strategies on their particular species of interest, and the life history characteristics of said species. For example, managers interested in increasing black duck habitat should note that although impoundments provide a variety of services, black ducks remain salt marsh obligate species and thus require available tidal marsh habitat, where they typically exist in higher densities. Although impoundments contain more energy per unit area than salt marshes, at the state-level salt marshes provide significantly more energy than impoundments because they comprise a much larger area overall. My “hot-spot” maps of energetic and population density (Fig. 11–17) may assist managers in identifying key areas where habitat

modification or restoration will be most effective; for example, managers may wish to target areas that contain low food energy density and experience high use by dabbling species of interest for management action.

In the long term, managers should consider the implications of sea level rise (SLR) on future dabbling duck populations. As sea level rises, carrying capacity will likely decrease for most dabbling species, depending on severity. Currently, impoundments represent < 10% of available wetland habitat in a 16 km buffer from the Delaware Bayshore. However, they represent nearly 15% of available duck use-days (DUDs). If managers continue to maintain impoundments in the face of SLR, and food availability within impoundments does not change, impoundments will represent an increasingly greater proportion of available DUDs as overall carrying capacity decreases due to loss of natural salt marsh habitat. Based on changes in marsh habitat area and composition projected by the Sea Level Affecting Marshes Model (SLAMM) and the 1.5m by 2100 SLR scenario, the proportion of DUDs provided by impoundments could increase by as much as ~7%, suggesting that if SLR is severe enough, >20% of the total DUDs available in Delaware could be provided by managed impoundments. However, my results suggest that although impoundments are important habitats for wintering dabblers, unmanaged salt marshes nonetheless fulfill important life history aspects for many of these species. Thus, managers should strive to maintain diverse wetland complexes that include both impoundment and salt marsh habitat to meet the needs of dabblers and other wintering or migrating waterfowl species. In developing long-term management strategies, managers should weigh the benefits of maintaining such complexes for future dabbling duck populations against the cost of impoundment maintenance. Additionally, managers

may also wish consider the benefit of creating new impoundments in upland areas if impoundment maintenance is not possible, although this represents a significant expenditure and should therefore be weighed carefully.

Table 1 Mean biomass (kg/ha) of seed and animal foods, separated by season and year, obtained from soil core samples collected in managed impoundments and unmanaged salt marshes along the Delaware Bayshore, October–April, 2011–2013. Biomass estimates are not separated by food preferences of specific waterfowl species, and all seed or animal foods were included.

Food	Freshwater impoundment		Brackish impoundment		High marsh		Low marsh		Mudflat		Quasi-tidal pool		Subtidal		
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	
F11	Seed	346.63	71.05	219.09	38.08	181.94	75.10	75.69	30.85	110.58	51.57	128.66	38.98	104.82	46.24
	Animal	38.12	8.76	37.08	5.99	89.06	31.97	308.15	170.54	84.50	22.89	78.49	38.16	140.84	45.46
W12	Seed	292.83	73.34	242.00	52.68	114.49	39.08	122.42	30.31	64.90	23.90	170.70	73.41	84.60	48.75
	Animal	17.15	3.75	78.07	21.49	70.10	15.47	90.76	31.57	90.26	27.00	152.55	67.31	85.91	16.61
S12	Seed	303.76	61.05	185.90	29.14	144.68	61.05	95.24	40.08	34.25	14.13	644.47	566.54	33.83	9.85
	Animal	24.83	5.40	106.22	41.88	101.04	63.71	160.99	43.74	333.31	270.50	111.44	81.48	126.60	27.42
F12	Seed	227.37	33.15	202.80	28.20	145.56	44.65	112.58	25.26	53.33	25.80	68.92	36.40	61.22	22.54
	Animal	14.31	3.34	33.25	8.07	132.26	73.23	184.96	55.77	95.10	32.11	387.17	327.39	134.98	81.85
W13	Seed	450.05	83.31	254.11	37.55	83.54	28.31	158.81	33.47	142.27	47.26	64.49	40.35	71.48	22.67
	Animal	70.72	26.86	44.78	7.81	580.57	365.65	122.47	32.68	70.81	15.32	182.29	146.34	85.46	28.47
S13	Seed	604.60	185.22	224.69	26.56	264.08	83.78	182.32	45.16	99.27	30.93	26.04	14.22	175.36	87.96
	Animal	14.22	3.42	63.03	13.18	157.16	36.80	933.21	863.57	80.52	28.53	31.57	10.38	73.60	31.76
Mean	Seed	372.09	40.34	221.46	14.82	157.56	24.42	124.51	14.30	83.36	14.69	183.10	94.05	81.50	16.30
	Animal	30.03	5.07	60.31	8.41	206.57	74.55	300.09	146.73	128.73	48.88	159.55	64.99	111.32	18.55

Table 2 Mean food energy availability (kcal/ha) from soil core samples in 7 habitats for dabbling duck species wintering on the Delaware Bayshore, October-April, 2011–2013. Values with the same letter in the same row were not significantly different. ABDU = American black duck, MALL = mallard, NOPI = northern pintail, NSHO = northern shoveler, AGWT = green-winged teal, AMWI = American wigeon, GADW = gadwall.

Species		Habitat						
		Freshwater impoundment	Brackish impoundment	High marsh	Low marsh	Quasi-tidal pool	Mudflat	Subtidal
ABDU	$\bar{x}$	356,585 <sub>a</sub>	290,881 <sub>ab</sub>	201,545 <sub>abc</sub>	283,064 <sub>ab</sub>	136,605 <sub>abc</sub>	110,344 <sub>c</sub>	71,369 <sub>bc</sub>
	SE	80,151	77,270	61,875	117,330	50,474	27,265	11,616
MALL	$\bar{x}$	492,128 <sub>a</sub>	259,530 <sub>b</sub>	265,577 <sub>bc</sub>	332,036 <sub>ab</sub>	187,192 <sub>bcd</sub>	137,473 <sub>d</sub>	81,883 <sub>cd</sub>
	SE	82,926	23,425	65,501	117,751	60,904	30,606	12,475
NOPI	$\bar{x}$	548,622 <sub>a</sub>	222,120 <sub>b</sub>	236,175 <sub>bc</sub>	233,233 <sub>ab</sub>	128,131 <sub>bc</sub>	129,617 <sub>c</sub>	105,331 <sub>c</sub>
	SE	84,974	20,882	63,519	110,041	39,844	33,207	24,657
NSHO	$\bar{x}$	240,143 <sub>a</sub>	171,175 <sub>ab</sub>	196,607 <sub>ab</sub>	204,552 <sub>ab</sub>	136,342 <sub>ab</sub>	96,346 <sub>b</sub>	70,791 <sub>ab</sub>
	SE	27,103	19,129	59,773	109,857	55,491	27,492	12,927
AGWT	$\bar{x}$	183,335 <sub>ab</sub>	165,054 <sub>ab</sub>	208,809 <sub>a</sub>	241,654 <sub>a</sub>	121,750 <sub>abc</sub>	96,223 <sub>c</sub>	55,679 <sub>bc</sub>
	SE	19,985	18,002	59,936	109,869	39,046	26,533	8,786
AMWI	$\bar{x}$	217,696 <sub>a</sub>	107,809 <sub>b</sub>	69,526 <sub>bc</sub>	36,863 <sub>c</sub>	40,814 <sub>bc</sub>	50,745 <sub>c</sub>	51,395 <sub>bc</sub>
	SE	26,089	11,658	18,357	53,885	10,670	12,375	12,273
GADW	$\bar{x}$	281,487 <sub>a</sub>	190,137 <sub>a</sub>	138,693 <sub>a</sub>	118,199 <sub>a</sub>	124,914 <sub>ab</sub>	74,547 <sub>c</sub>	77,442 <sub>bc</sub>
	SE	28,921	19,263	24,732	15,850	38,984	13,346	17,758

Table 3 Percent time ( $\bar{x} \pm SE$ ), Kruskal-Wallis test results, and connecting letters report by habitat for dabbling ducks engaged in various behaviors while wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh		Kruskal-Wallis results		
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	<i>H</i>	df	P
American black duck									
Feeding	31.52 <sub>b</sub>	2.29	43.15 <sub>a</sub>	1.57	33.15 <sub>b</sub>	1.52	26.318	2	< 0.001
Resting	28.51 <sub>ab</sub>	4.15	19.31 <sub>b</sub>	2.22	26.21 <sub>a</sub>	2.38	22.380	2	< 0.001
Swimming	35.05 <sub>a</sub>	2.34	22.51 <sub>b</sub>	1.33	24.94 <sub>a</sub>	1.42	12.900	2	0.002
Flying	3.99 <sub>b</sub>	0.97	13.78 <sub>a</sub>	1.17	13.65 <sub>a</sub>	1.20	47.206	2	< 0.001
Mallard									
Feeding	33.07 <sub>a</sub>	2.26	36.88 <sub>a</sub>	3.20	18.97 <sub>b</sub>	2.11	11.307	2	0.004
Resting	26.60	3.76	30.61	5.40	33.35	4.26	4.741	2	0.093
Swimming	25.65	2.09	17.45	2.45	13.38	1.82	5.769	2	0.044
Flying	13.48 <sub>b</sub>	1.75	13.39 <sub>b</sub>	2.47	31.26 <sub>a</sub>	2.99	63.006	2	< 0.001
Northern pintail									
Feeding	51.07 <sub>b</sub>	2.00	58.69 <sub>a</sub>	1.80	42.11 <sub>c</sub>	3.18	22.748	2	< 0.001
Resting	11.65 <sub>b</sub>	1.88	12.18 <sub>b</sub>	1.75	15.88 <sub>a</sub>	3.54	9.959	2	0.007
Swimming	29.15 <sub>a</sub>	1.80	19.00 <sub>b</sub>	1.38	17.24 <sub>b</sub>	2.15	22.709	2	< 0.001
Flying	7.56 <sub>b</sub>	1.11	9.00 <sub>b</sub>	1.16	23.33 <sub>a</sub>	3.16	47.848	2	< 0.001

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh		Kruskal-Wallis results		
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	<i>H</i>	df	P
Northern shoveler									
Feeding	60.55 <sub>a</sub>	1.88	61.32 <sub>a</sub>	1.31	51.13 <sub>b</sub>	2.82	9.766	2	0.008
Resting	7.17	1.62	8.54	1.28	10.49	2.73	3.626	2	0.163
Swimming	25.63	1.73	18.83	1.02	22.25	2.30	1.861	2	0.394
Flying	6.23 <sub>b</sub>	0.92	10.69 <sub>a</sub>	0.92	15.35 <sub>ab</sub>	2.37	17.385	2	< 0.001
Green-winged teal									
Feeding	50.61 <sub>ab</sub>	2.82	46.54 <sub>b</sub>	1.62	52.49 <sub>a</sub>	2.02	6.381	2	0.041
Resting	19.23 <sub>a</sub>	3.45	15.24 <sub>a</sub>	1.75	11.05 <sub>b</sub>	2.02	19.473	2	< 0.001
Swimming	21.17 <sub>ab</sub>	2.13	22.87 <sub>a</sub>	1.29	17.45 <sub>b</sub>	1.48	13.456	2	0.001
Flying	7.70 <sub>b</sub>	1.53	14.57 <sub>ab</sub>	1.30	17.24 <sub>a</sub>	1.71	11.806	2	0.003
American wigeon									
Feeding	40.44 <sub>b</sub>	5.18	57.24 <sub>a</sub>	2.86	49.51 <sub>ab</sub>	3.24	10.163	2	0.006
Resting	24.70	7.37	16.51	3.68	19.36	3.74	3.921	2	0.141
Swimming	28.24	4.87	22.92	2.38	23.07	2.59	1.555	2	0.460
Flying	4.75	2.28	1.98	0.79	6.33	1.93	3.978	2	0.137
Gadwall									
Feeding	66.34 <sub>a</sub>	3.02	50.29 <sub>b</sub>	2.69	57.53 <sub>b</sub>	2.44	12.835	2	0.002
Resting	8.85 <sub>b</sub>	2.21	14.37 <sub>b</sub>	3.03	17.62 <sub>a</sub>	2.82	26.063	2	< 0.001
Swimming	22.70	2.65	25.67	2.28	15.69	1.62	0.446	2	0.800
Flying	1.84 <sub>b</sub>	0.88	9.62 <sub>b</sub>	1.81	7.43 <sub>a</sub>	1.63	20.886	2	< 0.001

Table 4 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in three habitats for American black ducks wintering on the Delaware Bayshore, November-March, 2011–2013.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	4.08	0.35	4.29	0.18	2.97	0.14
Loafing	0.75	0.11	0.47	0.05	0.78	0.06
Sleeping	1.26	0.21	0.44	0.07	0.49	0.07
Comfort	0.75	0.15	0.72	0.09	0.89	0.11
Swimming	5.10	0.38	2.72	0.17	3.08	0.19
Flying	2.57	0.62	8.90	0.76	8.80	0.78
Walking	0.01	0.01	0.00	0.00	0.11	0.02
Agonistic	0.00	0.00	0.01	0.00	0.01	0.01
Courtship	0.00	0.00	0.01	0.00	0.02	0.02
Alert	0.09	0.05	0.16	0.04	0.05	0.02
Total	14.61	0.59	17.70	0.65	17.21	0.67
<i>n</i>	343	–	728	–	654	–

Table 5 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in three habitats for mallards wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	3.15	0.24	3.23	0.28	1.66	0.19
Loafing	0.82	0.10	1.02	0.15	1.44	0.14
Sleeping	0.45	0.08	0.48	0.12	0.36	0.08
Comfort	0.65	0.10	0.68	0.13	0.46	0.09
Swimming	2.96	0.25	1.98	0.28	1.52	0.21
Flying	8.84	1.15	8.63	1.59	20.27	1.94
Walking	0.06	0.03	0.09	0.06	0.18	0.07
Agonistic	0.00	0.00	0.01	0.01	0.02	0.01
Courtship	0.02	0.01	0.00	0.00	0.00	0.00
Alert	0.04	0.02	0.07	0.04	0.09	0.06
Total	16.99 <sub>ab</sub>	1.00	16.19 <sub>b</sub>	1.38	26.00 <sub>a</sub>	1.70
<i>n</i>	324	–	169	–	209	–

Table 6 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in three habitats for northern pintails wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	4.44	0.22	4.46	0.15	3.12	0.24
Loafing	0.35	0.05	0.37	0.06	0.39	0.08
Sleeping	0.08	0.02	0.12	0.02	0.12	0.04
Comfort	0.35	0.05	0.49	0.06	0.55	0.11
Swimming	3.13	0.22	1.89	0.14	1.65	0.21
Flying	4.13	0.61	4.98	0.64	12.71	1.72
Walking	0.00	0.00	0.00	0.00	0.02	0.01
Agonistic	0.00	0.00	0.00	0.00	0.08	0.07
Courtship	0.00	0.00	0.00	0.00	0.00	0.00
Alert	0.05	0.02	0.10	0.04	0.04	0.01
Total	12.53 <sub>b</sub>	0.53	12.42 <sub>b</sub>	0.56	18.68 <sub>a</sub>	1.47
<i>n</i>	405	–	477	–	154	–

Table 7 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in three habitats for northern shovelers wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	3.64	0.13	3.69	0.10	2.86	0.16
Loafing	0.13	0.04	0.16	0.03	0.14	0.04
Sleeping	0.11	0.04	0.05	0.01	0.11	0.04
Comfort	0.17	0.03	0.32	0.05	0.28	0.06
Swimming	2.01	0.15	1.42	0.08	1.61	0.17
Flying	2.61	0.39	4.47	0.38	6.32	0.97
Walking	0.00	0.00	0.00	0.00	0.01	0.01
Agonistic	0.00	0.00	0.01	0.00	0.00	0.00
Courtship	0.00	0.00	0.00	0.00	0.00	0.00
Alert	0.03	0.02	0.05	0.02	0.04	0.04
Total	8.70 <sub>b</sub>	0.34	10.16 <sub>a</sub>	0.33	11.39 <sub>ab</sub>	0.83
<i>n</i>	436	–	792	–	205	–

Table 8 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in three habitats for green-winged teal wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	1.72	0.11	1.62	0.07	1.78	0.08
Loafing	0.18	0.03	0.24	0.03	0.11	0.02
Sleeping	0.13	0.03	0.09	0.02	0.16	0.06
Comfort	0.28	0.04	0.23	0.04	0.23	0.05
Swimming	0.91	0.09	1.14	0.08	0.92	0.10
Flying	1.84	0.36	3.45	0.31	4.03	0.40
Walking	0.01	0.00	0.00	0.00	0.04	0.01
Agonistic	0.01	0.00	0.01	0.00	0.01	0.00
Courtship	0.00	0.00	0.01	0.00	0.00	0.00
Alert	0.03	0.02	0.01	0.00	0.01	0.00
Total	5.10 <sub>b</sub>	0.33	6.80 <sub>a</sub>	0.27	7.29 <sub>a</sub>	0.34
<i>n</i>	196	–	571	–	376	–

Table 9 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in three habitats for American wigeon wintering on the Delaware Bayshore, November-March, 2011–2013.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	3.37	0.57	4.39	0.29	3.90	0.34
Loafing	0.85	0.22	0.15	0.04	0.82	0.21
Sleeping	0.11	0.08	0.23	0.07	0.01	0.01
Comfort	0.59	0.18	0.63	0.10	0.63	0.11
Swimming	2.66	0.51	1.94	0.20	2.31	0.31
Flying	2.26	1.09	0.98	0.41	3.01	0.92
Walking	0.00	0.00	0.04	0.03	0.08	0.05
Agonistic	0.00	0.00	0.01	0.00	0.01	0.01
Courtship	0.00	0.00	0.00	0.00	0.00	0.00
Alert	0.15	0.15	0.05	0.05	0.03	0.01
Total	10.00	0.98	8.43	0.39	10.80	0.81
<i>n</i>	56	–	187	–	128	–

Table 10 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in three habitats for gadwall wintering on the Delaware Bayshore, November-March, 2011–2013.

Behavior	Freshwater impoundment		Brackish impoundment		Salt marsh	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	4.85	0.24	4.05	0.26	4.10	0.17
Loafing	0.26	0.06	0.44	0.08	0.54	0.08
Sleeping	0.00	0.00	0.08	0.04	0.17	0.05
Comfort	0.32	0.08	0.40	0.08	0.32	0.04
Swimming	2.51	0.37	2.72	0.27	1.45	0.15
Flying	0.97	0.46	5.06	0.95	3.90	0.85
Walking	0.00	0.00	0.00	0.00	0.05	0.03
Agonistic	0.03	0.02	0.00	0.00	0.02	0.01
Courtship	0.00	0.00	0.00	0.00	0.00	0.00
Alert	0.00	0.00	0.00	0.00	0.08	0.06
Total	8.94	0.46	12.76	0.82	10.62	0.74
<i>n</i>	135	–	239	–	168	–

Table 11 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in four observation periods and scaled to the 24-hr day for American black ducks wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Morning crepuscular		Diurnal		Evening crepuscular		Nocturnal		24-hr	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	3.70	0.25	4.35	0.17	3.23	0.25	1.50	0.21	66.74	4.72
Loafing	0.59	0.08	0.58	0.05	0.72	0.08	0.97	0.16	19.00	2.59
Sleeping	0.24	0.08	0.43	0.06	0.63	0.13	2.35	0.38	34.58	5.59
Comfort	0.43	0.09	0.91	0.10	0.86	0.14	0.74	0.22	19.17	3.96
Swimming	3.68	0.31	3.09	0.18	3.01	0.27	4.54	0.47	92.87	8.11
Flying	9.76	1.11	6.99	0.62	10.56	1.21	1.43	0.71	103.98	17.08
Walking	0.05	0.03	0.05	0.01	0.06	0.02	0.00	0.00	0.56	0.16
Agonistic	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.09	0.05
Courtship	0.04	0.04	0.00	0.00	0.00	0.00	0.02	0.01	0.30	0.24
Alert	0.10	0.05	0.15	0.04	0.04	0.01	0.01	0.01	1.66	0.52
Total	18.61 <sub>a</sub>	0.95	16.55 <sub>b</sub>	0.53	19.10 <sub>a</sub>	1.04	11.56 <sub>c</sub>	0.69	338.92	15.61
<i>n</i>	332	–	917	–	305	–	171	–	1,725	–

Table 12 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in four observation periods and scaled to the 24-hr day for mallards wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Morning crepuscular		Diurnal		Evening crepuscular		Nocturnal		24-hr	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	2.55	0.35	3.23	0.21	1.88	0.24	2.22	0.41	62.74	7.70
Loafing	1.17	0.17	0.84	0.09	1.12	0.16	2.15	0.30	37.25	4.92
Sleeping	0.22	0.08	0.56	0.08	0.33	0.10	0.46	0.19	11.59	3.29
Comfort	0.34	0.11	0.62	0.08	0.78	0.17	0.63	0.21	14.87	3.68
Swimming	2.92	0.37	2.08	0.20	2.19	0.30	2.41	0.57	55.04	9.67
Flying	13.29	2.07	10.36	1.17	18.08	2.17	2.86	2.00	164.84	40.42
Walking	0.15	0.08	0.13	0.05	0.00	0.00	0.10	0.10	2.60	1.74
Agonistic	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.10	0.06
Courtship	0.03	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.07
Alert	0.14	0.08	0.05	0.02	0.03	0.02	0.00	0.00	0.64	0.31
Total	20.81 <sub>a</sub>	1.79	17.89 <sub>a</sub>	1.01	24.44 <sub>a</sub>	1.88	10.82 <sub>b</sub>	1.76	349.79	35.33
<i>n</i>	142	–	359	–	156	–	45	–	702	–

Table 13 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in four observation periods and scaled to the 24-hr day for northern pintails wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Morning crepuscular		Diurnal		Evening crepuscular		Nocturnal		24-hr	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	4.14	0.27	4.62	0.16	3.67	0.20	1.47	0.46	69.75	7.80
Loafing	0.39	0.07	0.31	0.05	0.47	0.09	0.62	0.26	11.59	3.86
Sleeping	0.03	0.02	0.15	0.02	0.06	0.02	0.00	0.00	1.50	0.26
Comfort	0.42	0.09	0.40	0.05	0.60	0.11	0.40	0.20	9.90	3.15
Swimming	2.28	0.22	2.19	0.16	2.32	0.24	6.12	0.76	102.31	11.51
Flying	8.91	1.20	5.14	0.59	5.11	1.01	0.00	0.00	62.34	7.73
Walking	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.12	0.05
Agonistic	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.21	0.16
Courtship	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
Alert	0.05	0.03	0.07	0.03	0.10	0.06	0.00	0.00	0.80	0.33
Total	16.24 <sub>a</sub>	1.03	12.92 <sub>b</sub>	0.51	12.33 <sub>b</sub>	0.87	8.62	0.25	258.58	9.86
<i>n</i>	219	–	595	–	194	–	28	–	1,036	–

Table 14 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in four observation periods and scaled to the 24-hr day for northern shovelers wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Morning crepuscular		Diurnal		Evening crepuscular		Nocturnal		24-hr	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	3.45	0.15	3.76	0.10	3.32	0.14	2.02	0.28	67.59	4.79
Loafing	0.09	0.03	0.19	0.03	0.08	0.02	0.09	0.04	3.07	0.85
Sleeping	0.04	0.02	0.11	0.02	0.00	0.00	0.15	0.09	3.05	1.36
Comfort	0.27	0.06	0.27	0.04	0.26	0.06	0.27	0.12	6.42	2.04
Swimming	1.70	0.15	1.47	0.09	1.62	0.14	3.91	0.40	66.39	6.13
Flying	4.84	0.66	3.72	0.36	5.61	0.73	0.01	0.01	45.57	4.93
Walking	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02
Agonistic	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.07	0.04
Courtship	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
Alert	0.04	0.03	0.05	0.02	0.00	0.00	0.00	0.00	0.55	0.25
Total	10.44 <sub>a</sub>	0.56	9.58 <sub>b</sub>	0.31	10.90 <sub>a</sub>	0.62	6.45 <sub>ab</sub>	0.11	192.69	5.51
<i>n</i>	274	–	832	–	276	–	51	–	1,433	–

Table 15 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in four observation periods and scaled to the 24-hr day for green-winged teal wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different.

Behavior	Morning crepuscular		Diurnal		Evening crepuscular		Nocturnal		24-hr	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	1.47	0.09	1.86	0.07	1.39	0.09	1.37	0.33	37.60	4.99
Loafing	0.19	0.03	0.19	0.03	0.15	0.03	0.48	0.16	8.16	2.33
Sleeping	0.01	0.00	0.18	0.04	0.05	0.02	0.00	0.00	1.75	0.38
Comfort	0.13	0.02	0.27	0.03	0.29	0.07	0.02	0.01	3.15	0.59
Swimming	1.19	0.13	1.03	0.07	0.81	0.10	1.44	0.35	29.88	5.32
Flying	5.41	0.56	2.14	0.22	5.27	0.61	0.00	0.00	30.79	3.23
Walking	0.02	0.00	0.01	0.00	0.03	0.02	0.00	0.00	0.18	0.07
Agonistic	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.11	0.03
Courtship	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01
Alert	0.01	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.17	0.07
Total	8.46 <sub>a</sub>	0.48	5.71 <sub>b</sub>	0.20	7.99 <sub>a</sub>	0.52	3.31	0.11	111.84	4.22
<i>n</i>	236	–	681	–	211	–	15	–	1,143	–

Table 16 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in four observation periods and scaled to the 24-hr day for American wigeon wintering on the Delaware Bayshore, November-March, 2011–2013.

Behavior	Morning crepuscular		Diurnal		Evening crepuscular		Nocturnal		24-hr	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	3.27	0.39	4.48	0.27	3.03	0.36	11.36	4.38	191.58	58.58
Loafing	0.49	0.16	0.44	0.10	0.67	0.28	0.00	0.00	5.29	1.33
Sleeping	0.24	0.12	0.15	0.05	0.01	0.01	0.00	0.00	1.62	0.55
Comfort	0.26	0.07	0.64	0.09	0.97	0.16	0.00	0.00	7.25	1.11
Swimming	2.55	0.37	1.83	0.20	3.07	0.46	1.67	1.67	43.91	23.82
Flying	2.28	1.07	1.87	0.53	1.58	0.81	0.00	0.00	21.41	6.86
Walking	0.04	0.03	0.06	0.04	0.01	0.01	0.00	0.00	0.66	0.39
Agonistic	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.04
Courtship	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alert	0.02	0.01	0.07	0.05	0.04	0.03	0.00	0.00	0.73	0.51
Total	9.18	0.93	9.55	0.49	9.39	0.74	13.03	2.71	272.59	40.42
<i>n</i>	67	–	236	–	65	–	3	–	371	–

Table 17 Mean  $\pm$  SE hourly energy expenditure (*HEE*, kcal/bird/hr) per behavior in four observation periods and scaled to the 24-hr day for gadwall wintering on the Delaware Bayshore, November-March, 2011–2013.

Behavior	Morning crepuscular		Diurnal		Evening crepuscular		Nocturnal		24-hr	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Feeding	3.69	0.36	4.49	0.18	4.12	0.34	3.82	0.52	98.17	8.89
Loafing	0.68	0.15	0.38	0.05	0.35	0.09	0.54	0.16	11.33	2.69
Sleeping	0.02	0.06	0.09	0.03	0.14	0.05	0.09	0.05	2.15	1.04
Comfort	0.29	0.07	0.37	0.06	0.40	0.08	0.20	0.07	6.63	1.55
Swimming	2.12	0.39	2.23	0.20	2.20	0.32	3.97	1.41	75.31	20.36
Flying	7.44	1.83	2.74	0.53	4.35	1.38	0.00	0.00	37.48	8.21
Walking	0.00	0.00	0.02	0.02	0.00	0.00	0.05	0.04	0.83	0.64
Agonistic	0.00	0.00	0.02	0.01	0.00	0.00	0.04	0.03	0.69	0.45
Courtship	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alert	0.00	0.00	0.03	0.03	0.01	0.01	0.00	0.00	0.33	0.28
Total	14.24	1.57	10.37	0.48	11.58	1.18	8.71	0.93	232.99	18.96
<i>n</i>	87	–	337	–	98	–	20	–	542	–

Table 18 Density (individuals/ha, average over the winter period) of 7 dabbling duck species wintering in various managed and unmanaged habitats on the Delaware Bayshore. Estimates are based on aerial surveys conducted by the Delaware Department of Natural Resources and Environmental Control Division of Fish and Wildlife in December-January, 2012–2013. ABDU = American black duck, MALL = mallard, NOPI = northern pintail, NSHO = northern shoveler, AGWT = green-winged teal, AMWI = American wigeon, GADW = gadwall.

Species	Habitat						
	Freshwater impoundment	Brackish impoundment	High marsh	Low marsh	Mudflat	Quasi-tidal pool	Subtidal
ABDU	0.25	0.26	0.11	0.15	0.14	0.00	0.28
MALL	0.59	0.04	0.07	0.27	0.12	0.00	0.41
NOPI	0.06	0.02	0.03	0.01	0.33	0.00	0.08
NSHO	0.01	0.19	0.02	0.01	0.02	0.00	0.06
AGWT	0.07	0.07	0.01	0.04	0.44	0.00	0.19
AMWI	0.00	0.03	0.00	0.00	0.00	0.00	0.02
GADW	0.01	0.32	0.05	0.02	0.03	0.00	0.05
Area (ha)	293	3,330	5,876	12,395	279	13	4,513

Table 19 Mean density ( $D$ ) and summary statistics based on point-transect counts of dabbling ducks wintering on the Delaware Bayshore, November-March, 2011–2013. Values with the same letter in the same row were not significantly different. ABDU = American black duck, MALL = mallard, NOPI = northern pintail, NSHO = northern shoveler, AGWT = green-winged teal, AMWI = American wigeon, GADW = gadwall.

Species	Freshwater impoundment				Brackish impoundment				Salt marsh			
	$D$	SE	95% C.I.	$N$	$D$	SE	95% C.I.	$N$	$D$	SE	95% C.I.	$N$
ABDU	0.29 <sub>b</sub>	0.05	0.21–0.40	108	0.26 <sub>b</sub>	0.04	0.20–0.36	250	0.50 <sub>a</sub>	0.08	0.37–0.68	199
MALL	0.30 <sub>a</sub>	0.05	0.21–0.42	116	0.09 <sub>b</sub>	0.02	0.05–0.14	74	0.29 <sub>a</sub>	0.10	0.15–0.57	68
NOPI	1.63	0.31	1.13–2.35	128	0.74	0.16	0.48–1.14	147	0.95	0.41	0.42–2.15	39
NSHO	0.82 <sub>a</sub>	0.14	0.59–1.15	129	0.96 <sub>a</sub>	0.14	0.72–1.28	250	0.16 <sub>b</sub>	0.04	0.09–0.26	66
AGWT	0.49 <sub>b</sub>	0.12	0.30–0.80	56	1.84 <sub>a</sub>	0.34	1.28–2.64	161	0.35 <sub>b</sub>	0.07	0.23–0.52	120
AMWI	0.23	0.11	0.09–0.56	15	1.40	0.52	0.68–2.86	61	0.10	0.03	0.06–0.17	46
GADW	0.38	0.12	0.12–0.70	45	0.24	0.06	0.15–0.38	89	0.37	0.13	0.19–0.74	56

Figure 1 Seven managed impoundments (blue = freshwater, green = brackish) and three unmanaged tidal salt marshes (red) in Kent and Sussex Counties, Delaware, USA, sampled for dabbling duck food and behavior over the winter period, 2011–2012 and 2012–2013.

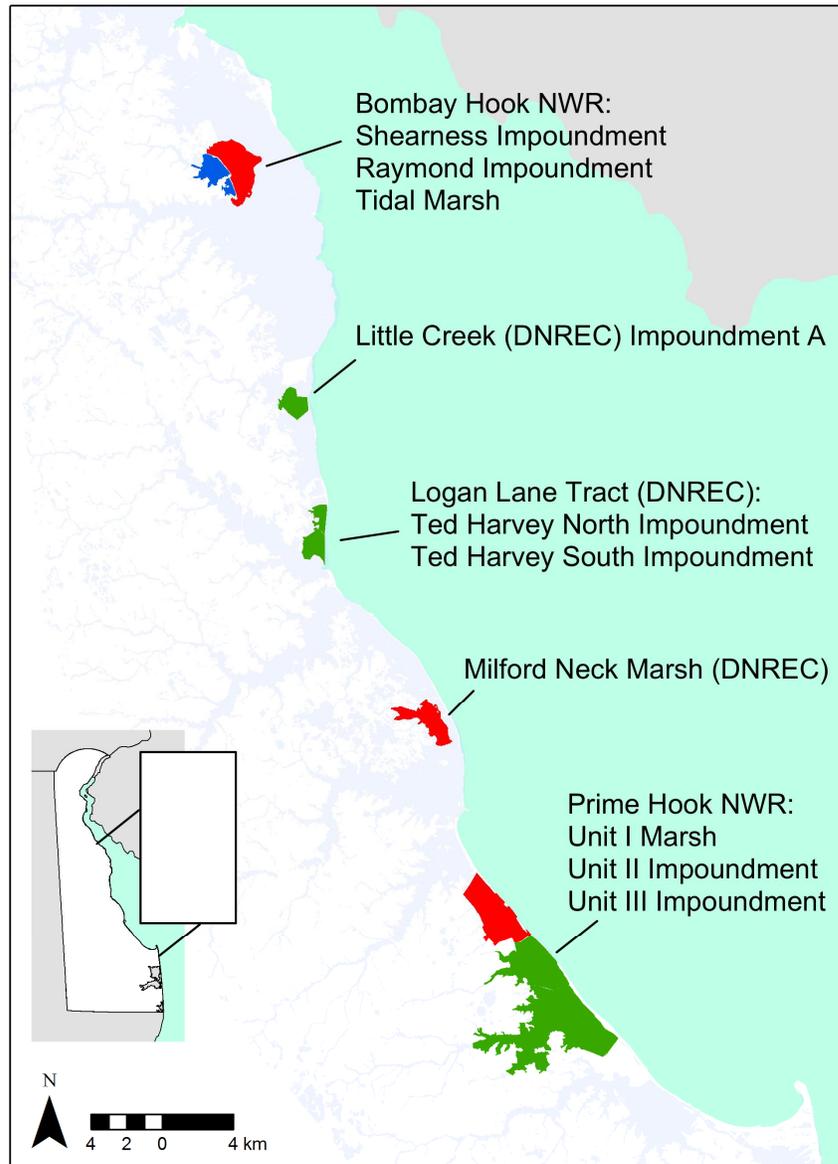


Figure 2 Behavioral scan and point count schedule for PM scanning period (left) and AM scanning period (right) of wintering dabbling ducks along the Delaware Bayshore, November–March, 2011–2013. Each block represents one 10 min scan period. Yellow denotes diurnal blocks, pink denotes crepuscular blocks, and purple denotes nocturnal blocks. Gray shaded blocks denote breaks where no behavioral scans were taken. “P” denotes blocks in which a point count was taken in addition to a scan.

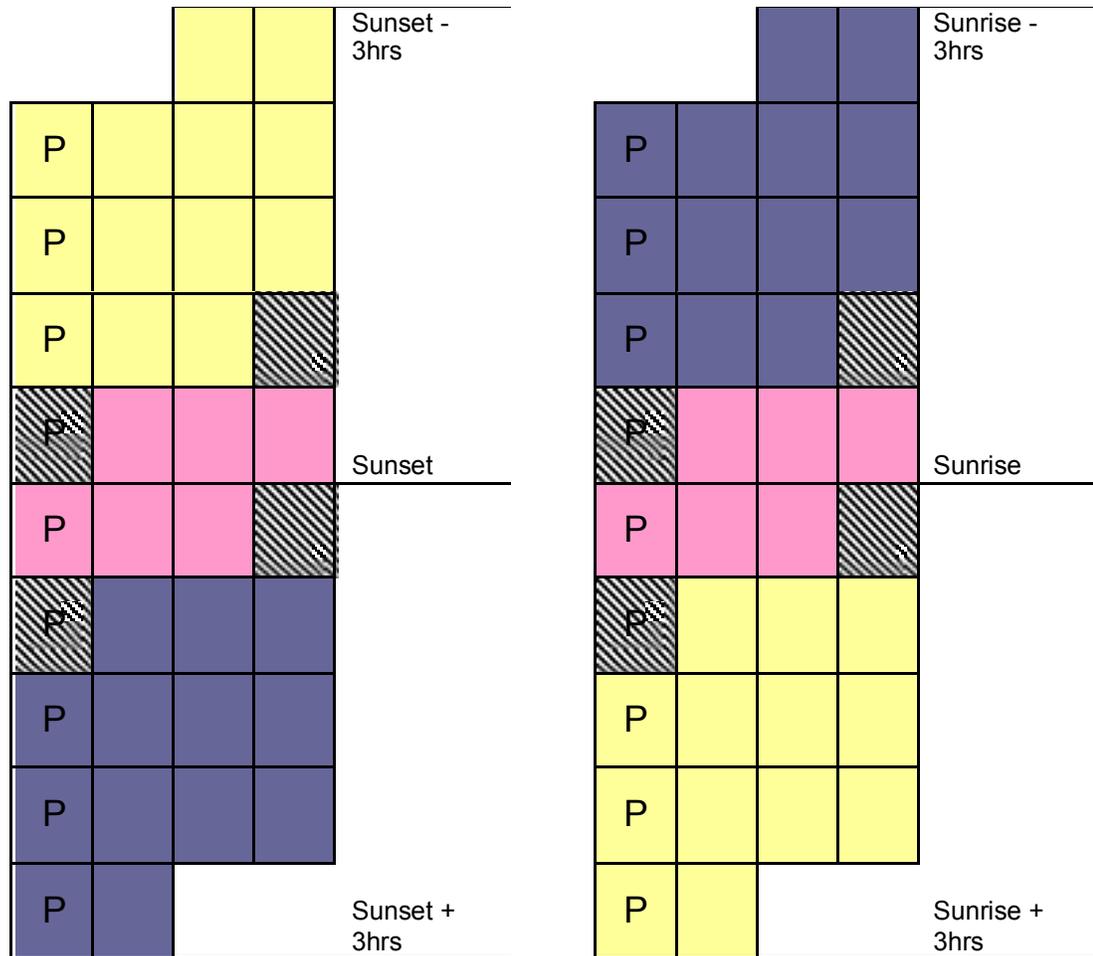


Figure 3 Mean energy density (kcal/ha)  $\pm$  SE from soil core, nekton, and salt marsh snail (*Melampus* spp.) samples in 7 wetland habitats for American black ducks wintering on the Delaware Bayshore, October-March, 2011–2013.

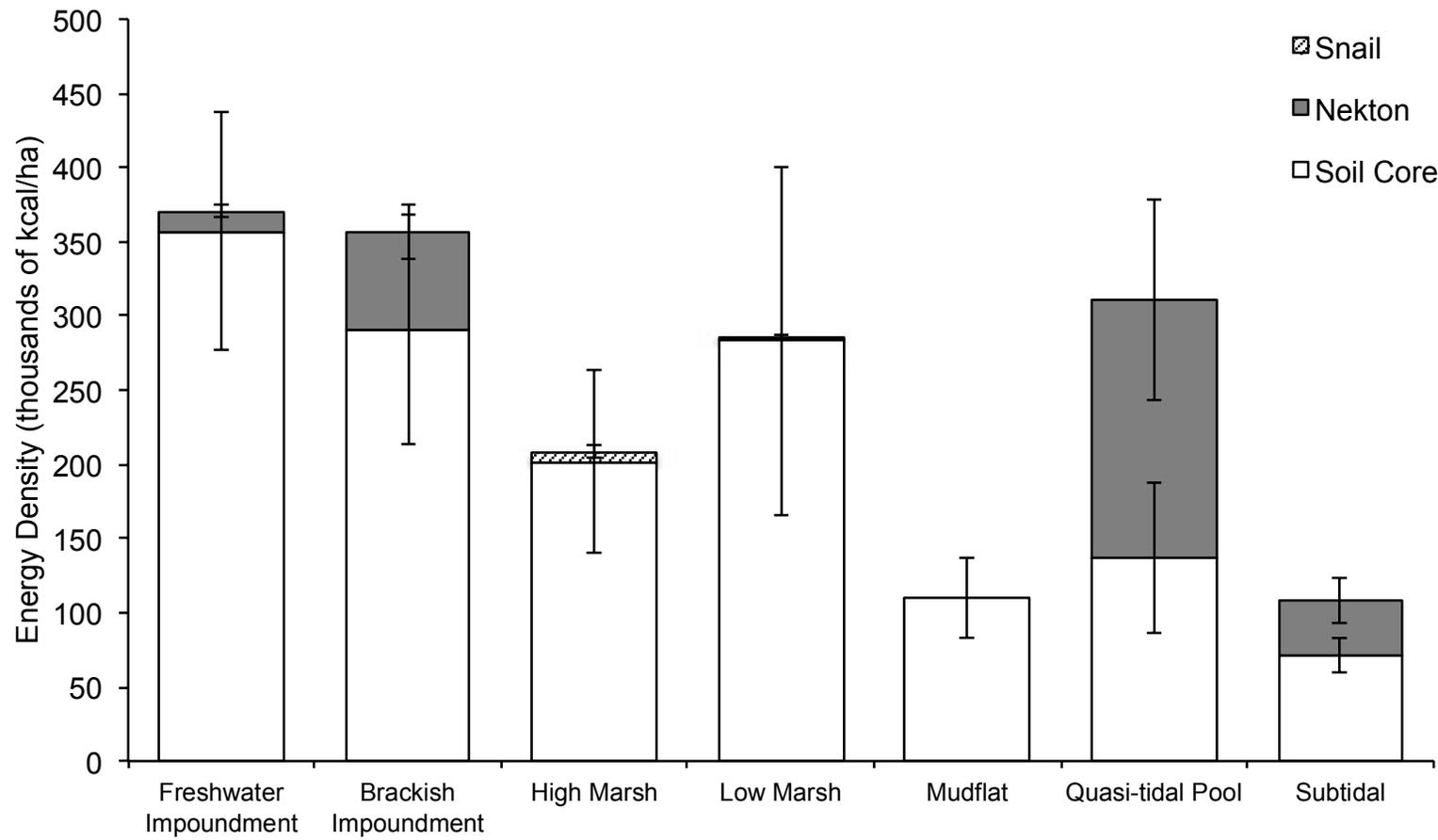


Figure 4 Mean energy density (kcal/ha)  $\pm$  SE from soil core, nekton, and salt marsh snail (*Melampus* spp.) samples in 7 wetland habitats for mallards wintering on the Delaware Bayshore, October-March, 2011–2013.

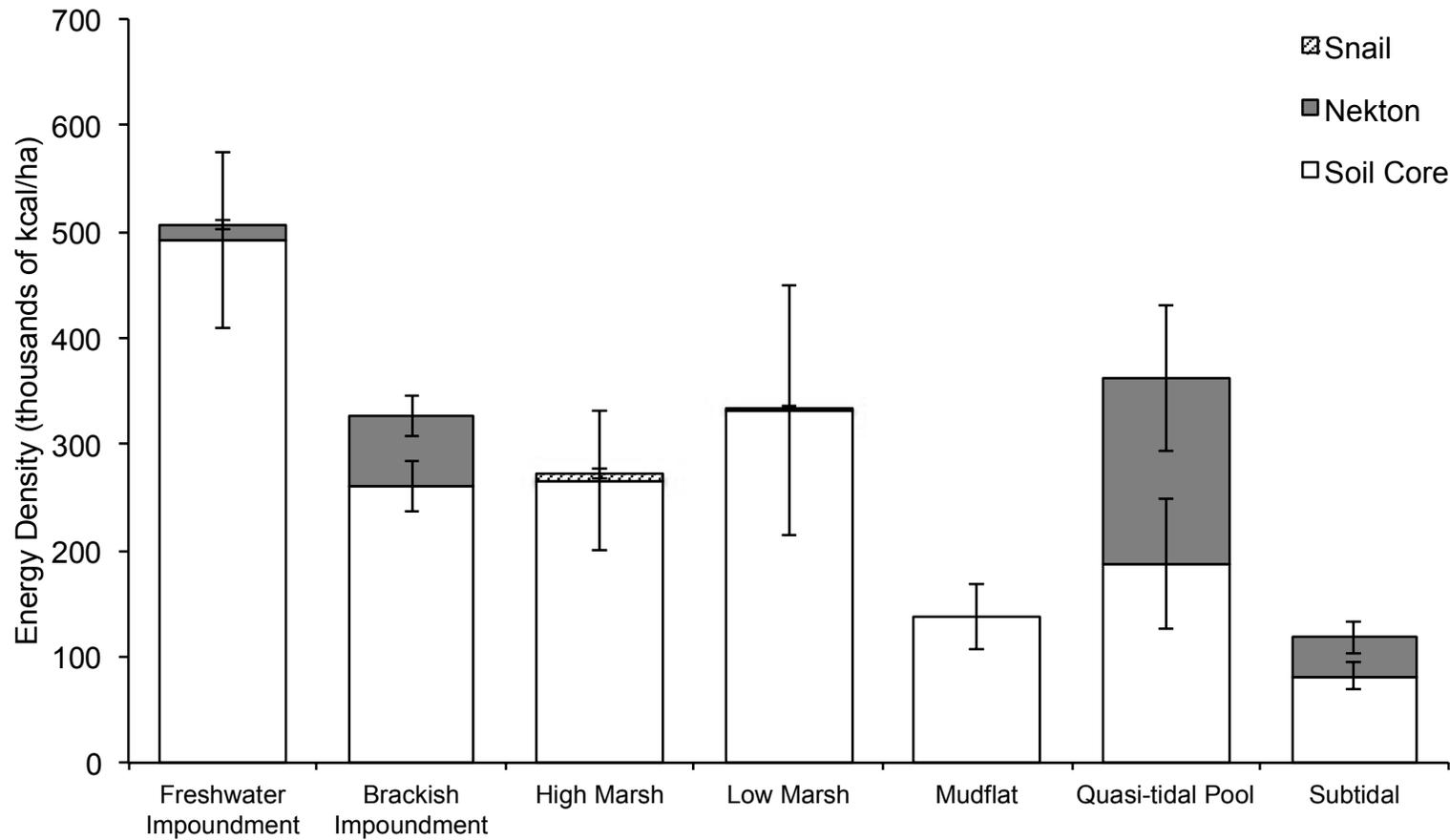


Figure 5 Mean energy density (kcal/ha)  $\pm$  SE from soil core, nekton, and salt marsh snail (*Melampus* spp.) samples in 7 wetland habitats for northern pintails wintering on the Delaware Bayshore, October-March, 2011–2013.

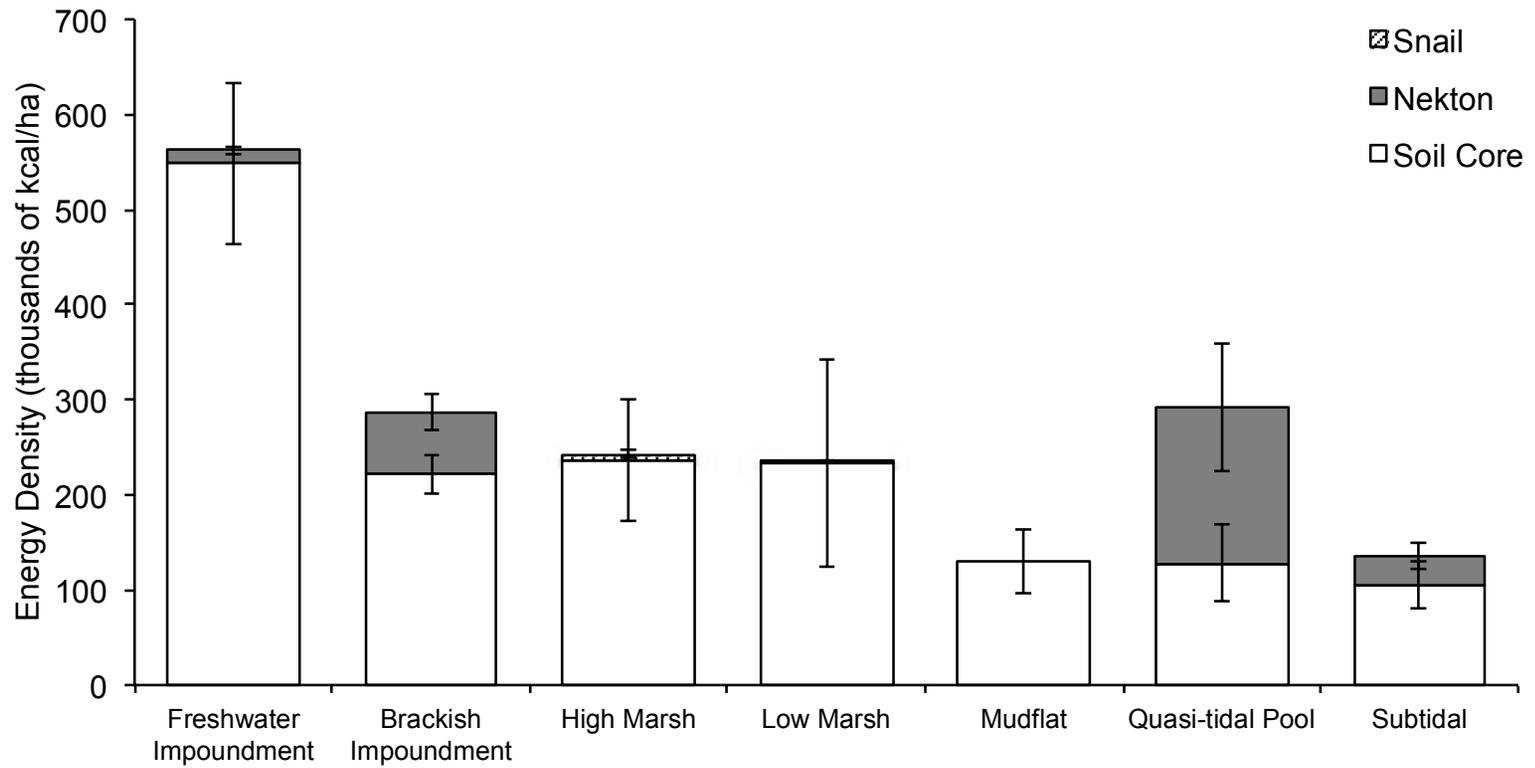


Figure 6 Mean energy density (kcal/ha)  $\pm$  SE from soil core, nekton, and salt marsh snail (*Melampus* spp.) samples in 7 wetland habitats for northern shovelers wintering on the Delaware Bayshore, October-March, 2011–2013.

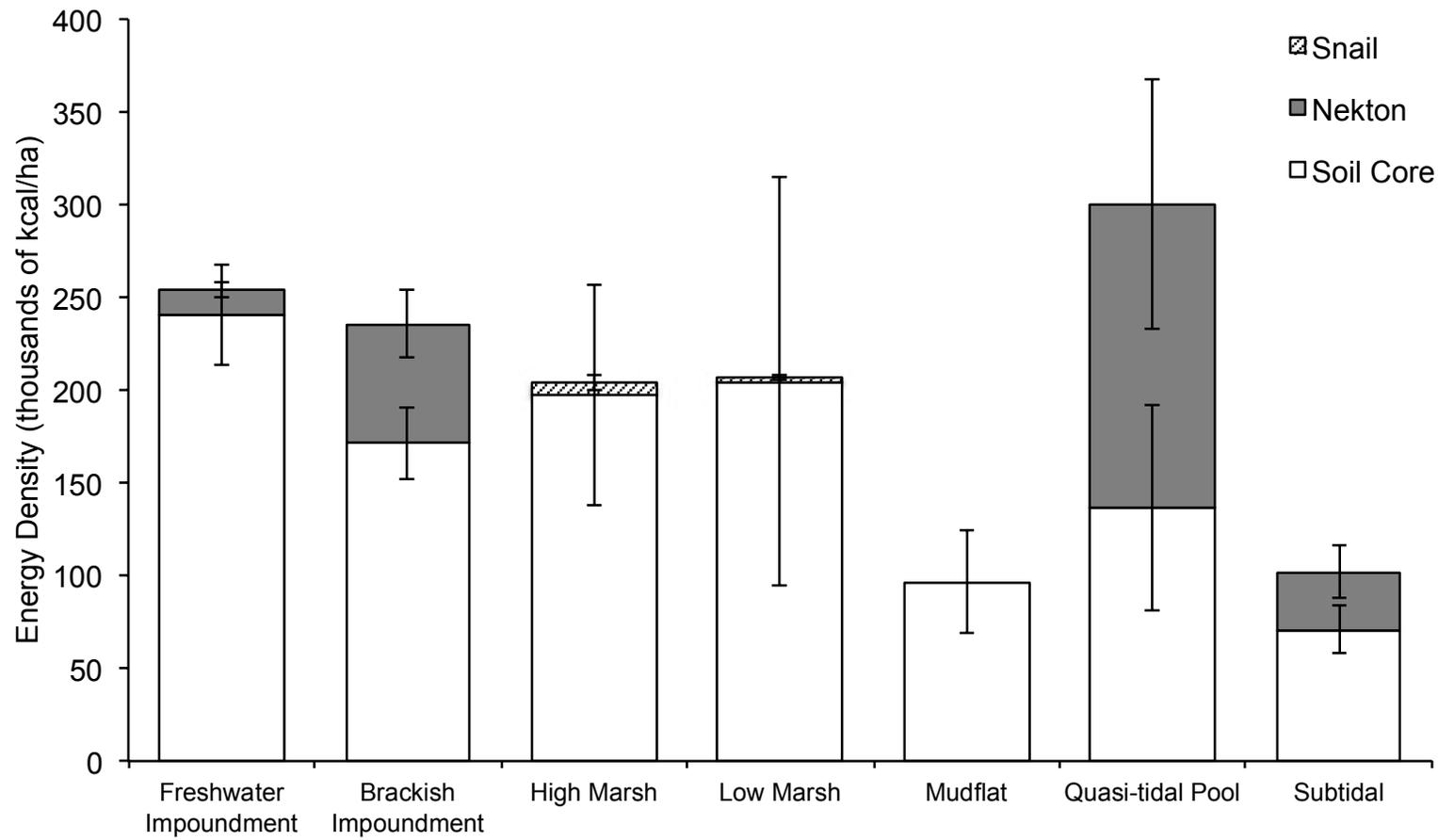


Figure 7 Mean energy density (kcal/ha)  $\pm$  SE from soil core, nekton, and salt marsh snail (*Melampus* spp.) samples in 7 wetland habitats for green-winged teal wintering on the Delaware Bayshore, October-March, 2011–2013.

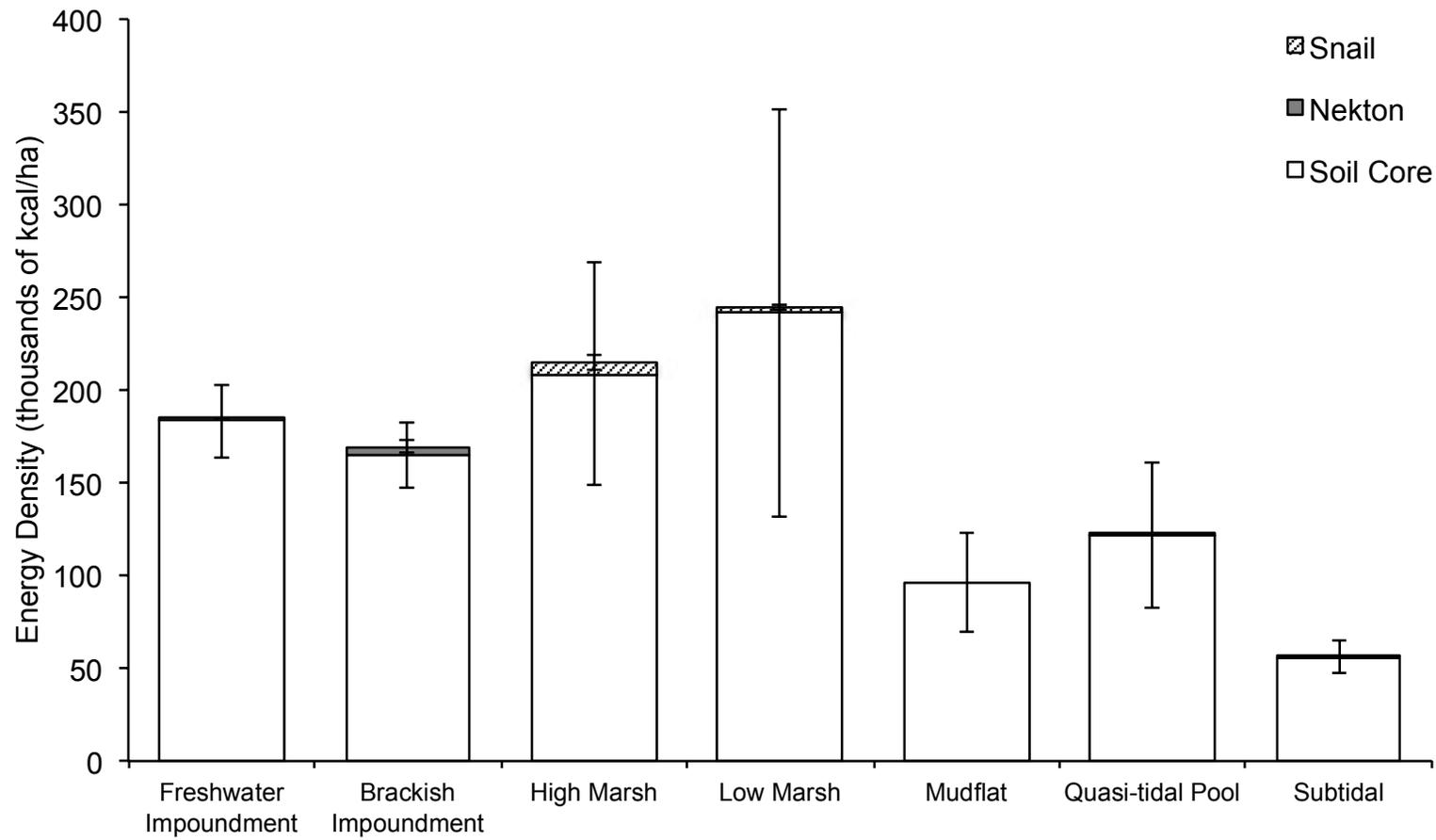


Figure 8 Mean energy density (kcal/ha)  $\pm$  SE from soil core, nekton, and salt marsh snail (*Melampus* spp.) samples in 7 wetland habitats for American wigeon wintering on the Delaware Bayshore, October-March, 2011–2013.

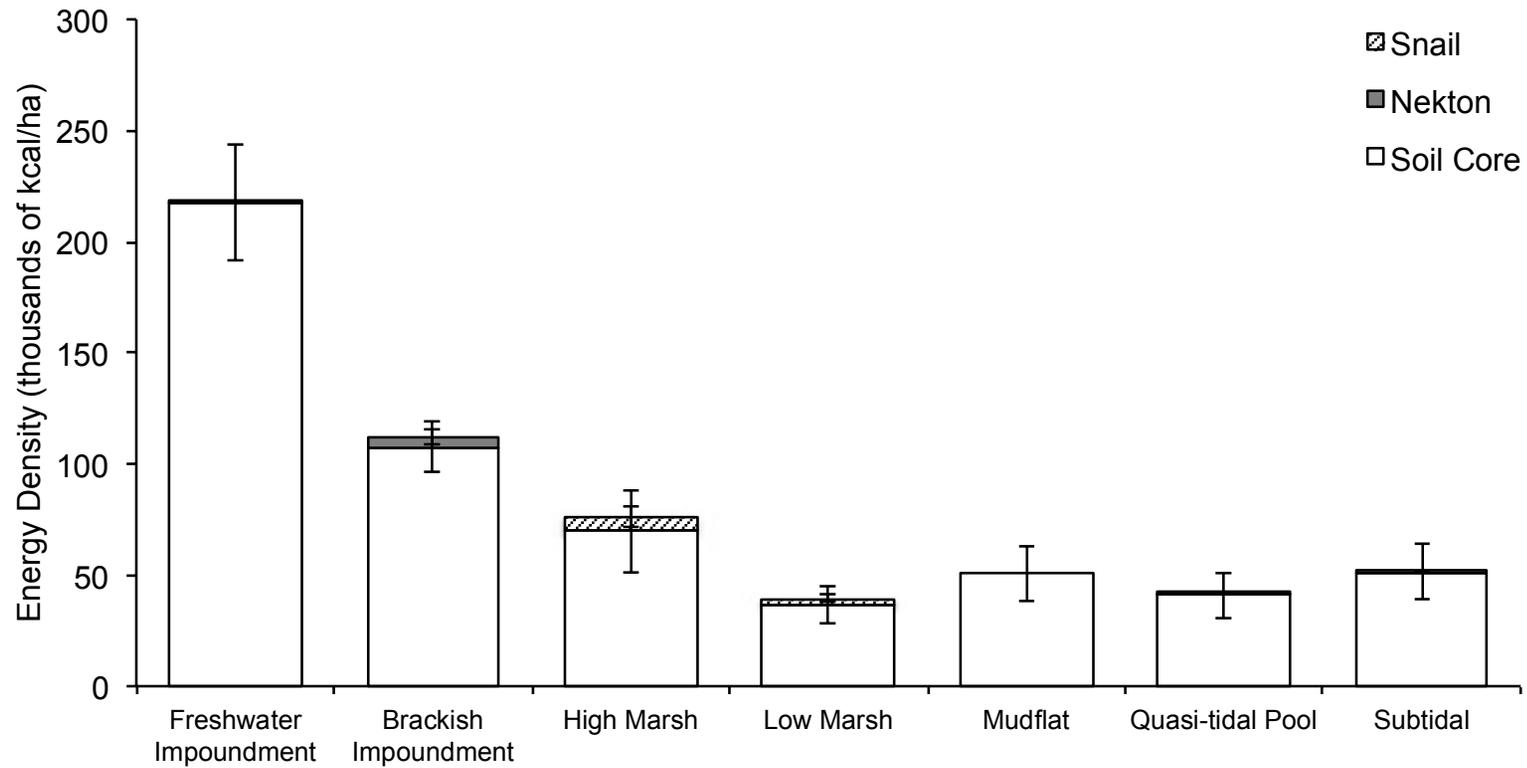


Figure 9 Mean energy density (kcal/ha)  $\pm$  SE from soil core, nekton, and salt marsh snail (*Melampus* spp.) samples in 7 wetland habitats for gadwall wintering on the Delaware Bayshore, October-March, 2011–2013.

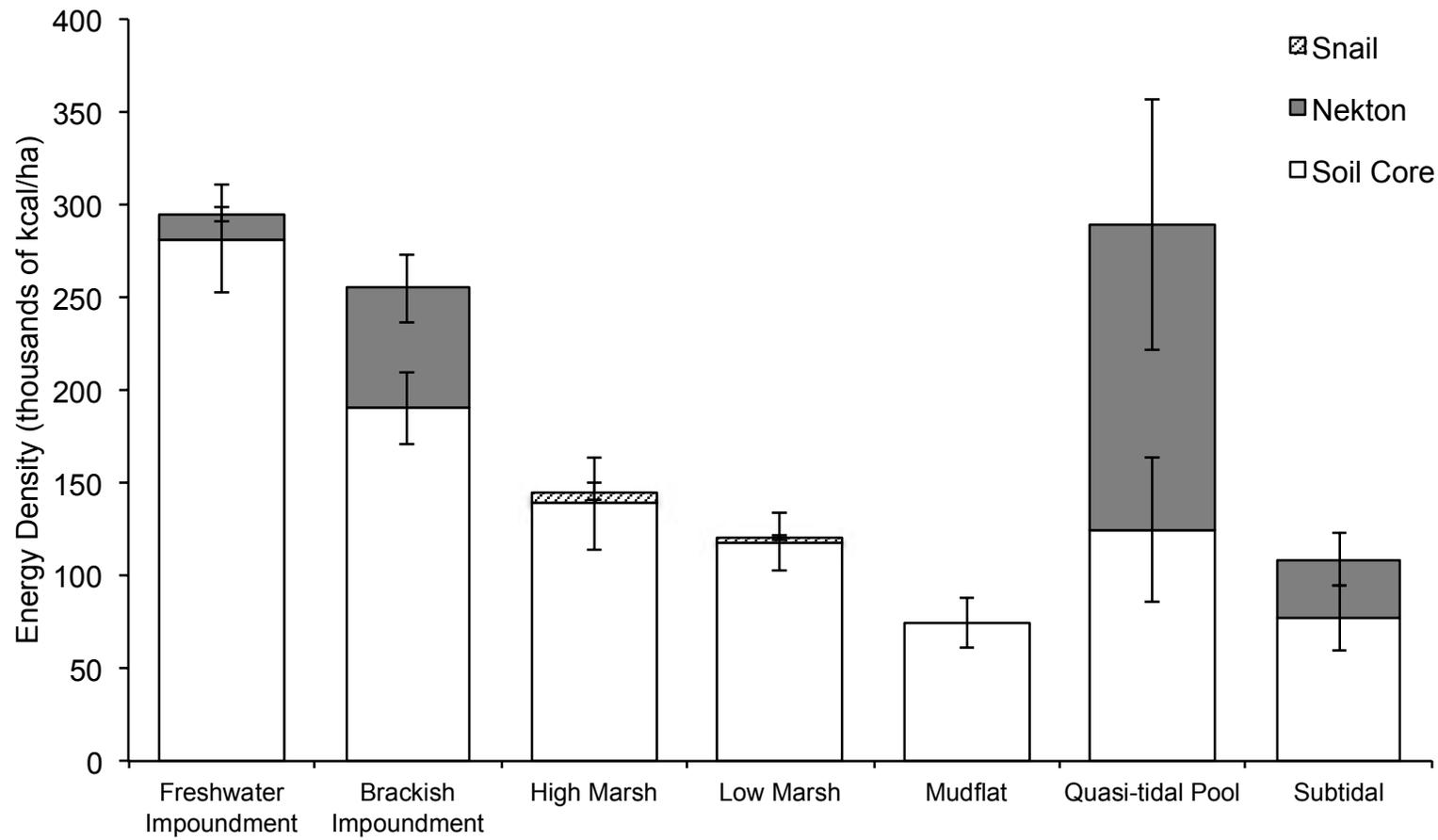


Figure 10 Carrying capacity (including estimated competition for food resources between dabblers), point count  $\pm$  SE, aerial survey, and 10-yr Mid-Winter Survey (MWS, USFWS 2004–2014) abundance estimates for 7 species of dabbling ducks on the Delaware Bayshore over a 180-day wintering period (October-March).

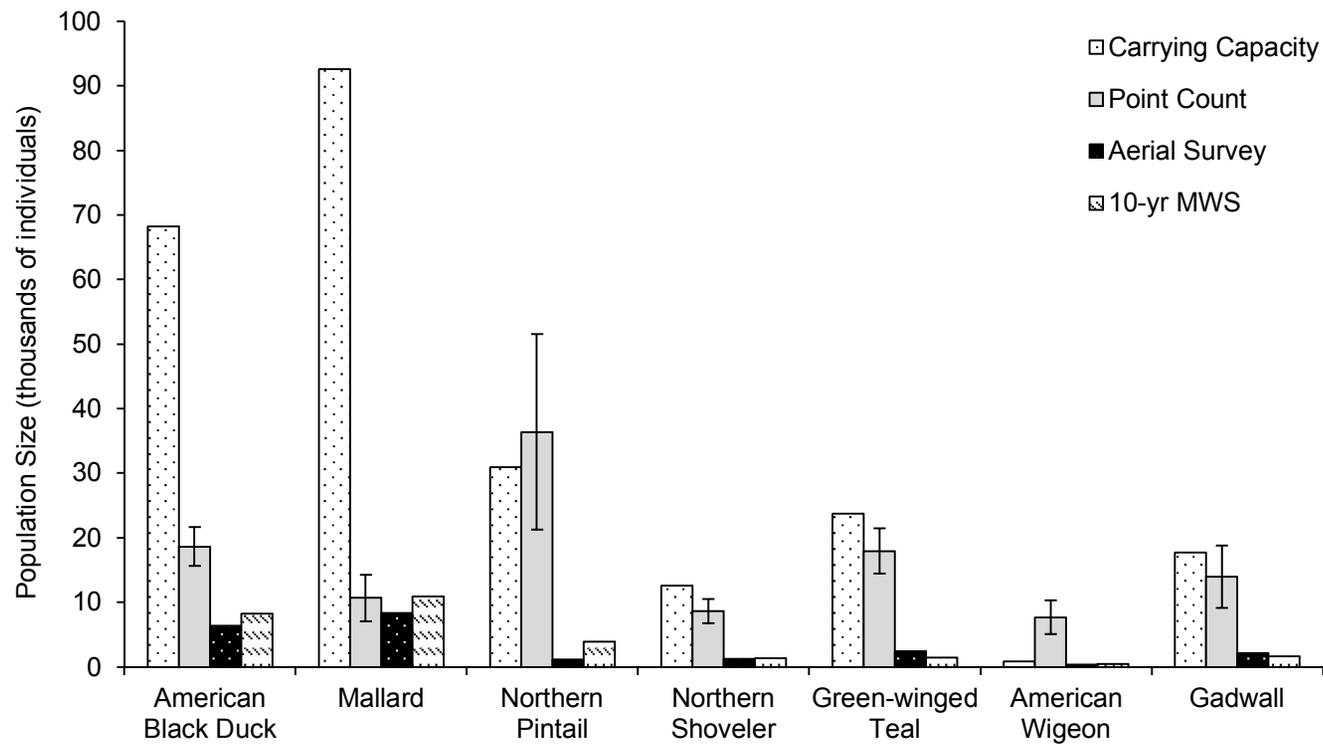


Figure 11 “Hot-spot” map depicting density of currently available duck use-days (DUDs/ha; “A”) and population density (individuals/ha; “B”) based on aerial surveys for American black ducks wintering on the Delaware Bayshore.

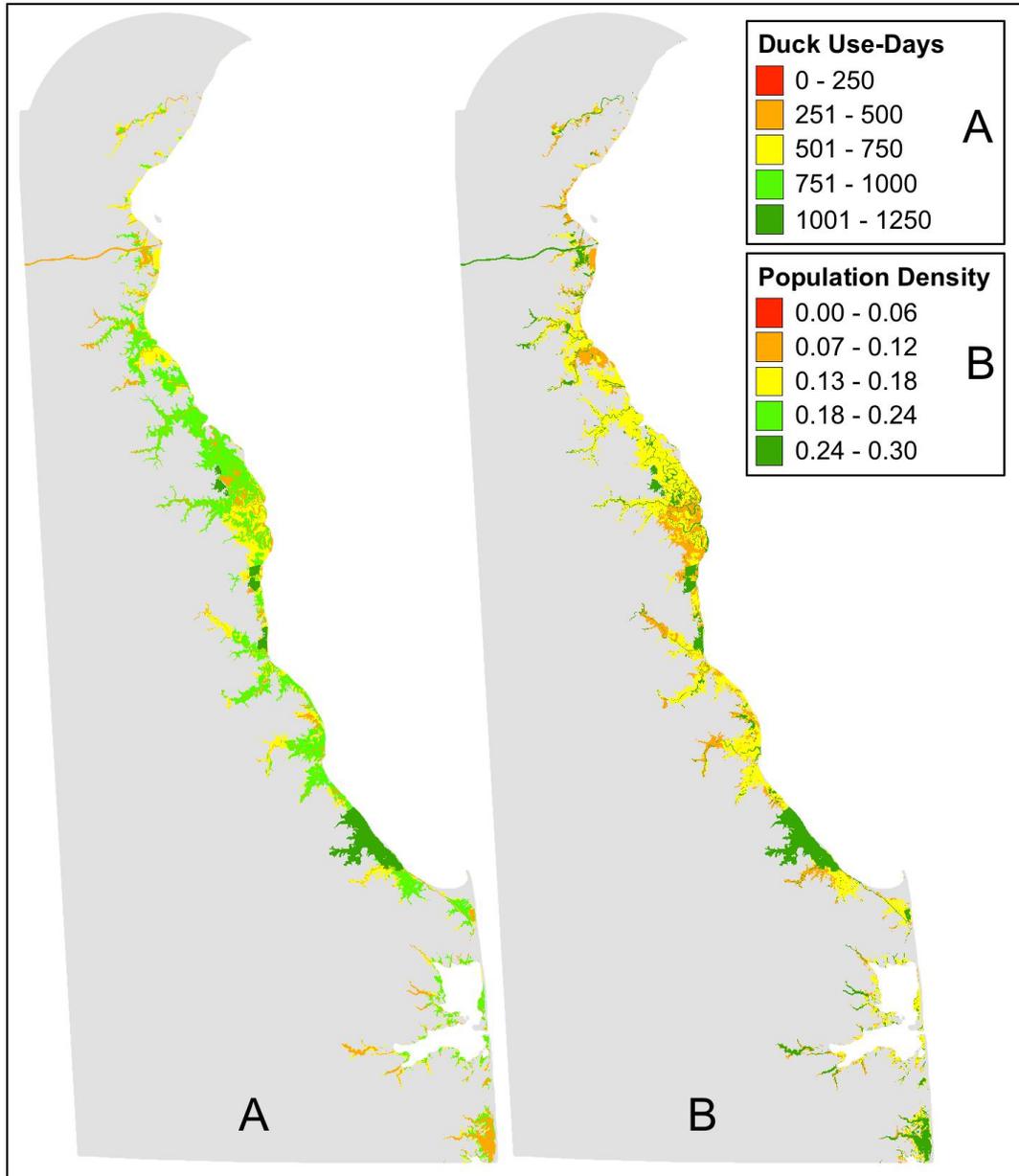


Figure 12 “Hot-spot” map depicting density of currently available duck use-days (DUDs/ha; “A”) and population density (individuals/ha; “B”) based on aerial surveys for mallards wintering on the Delaware Bayshore.

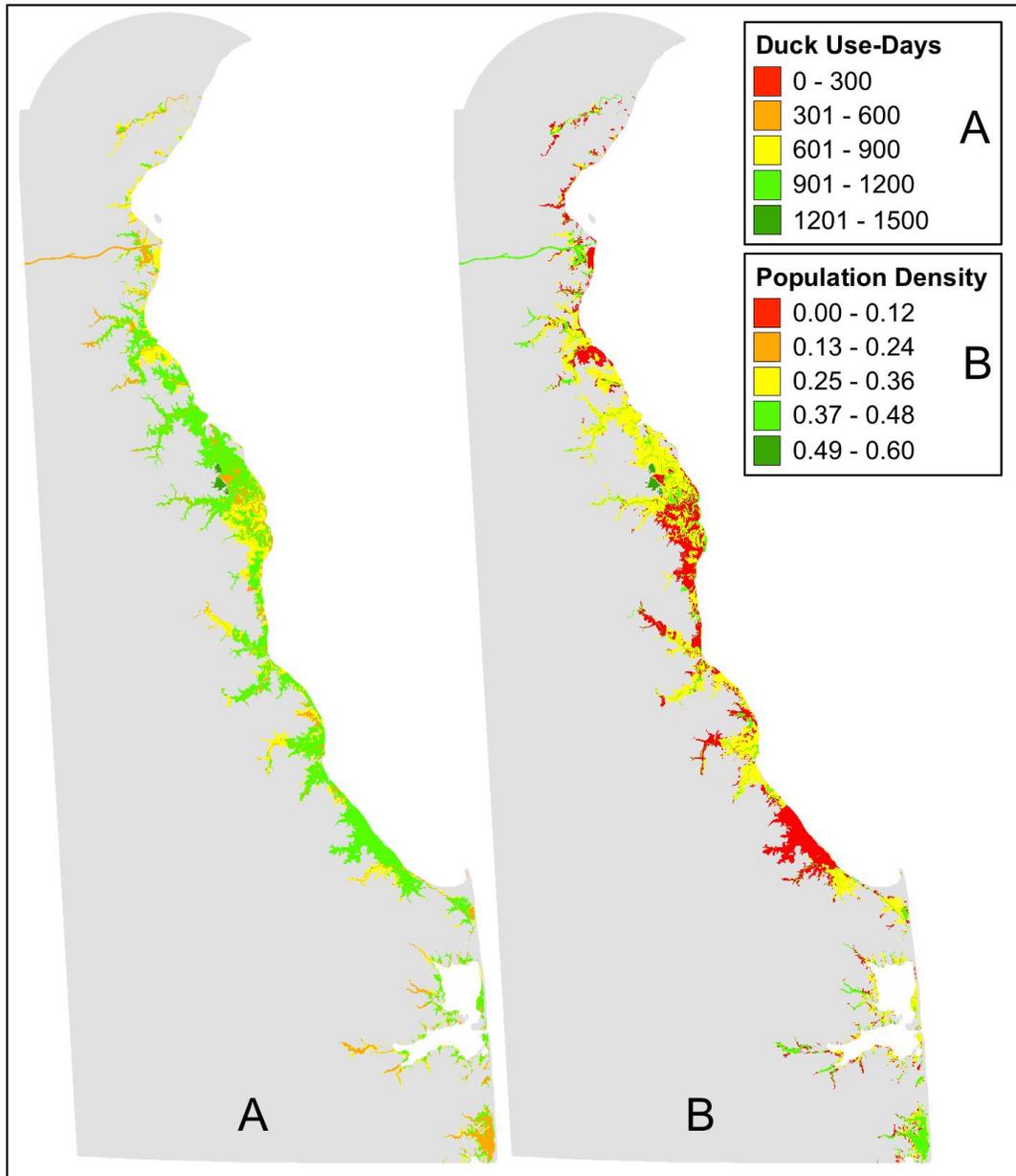


Figure 13 “Hot-spot” map depicting density of currently available duck use-days (DUDs/ha; “A”) and population density (individuals/ha; “B”) based on aerial surveys for northern pintails wintering on the Delaware Bayshore.

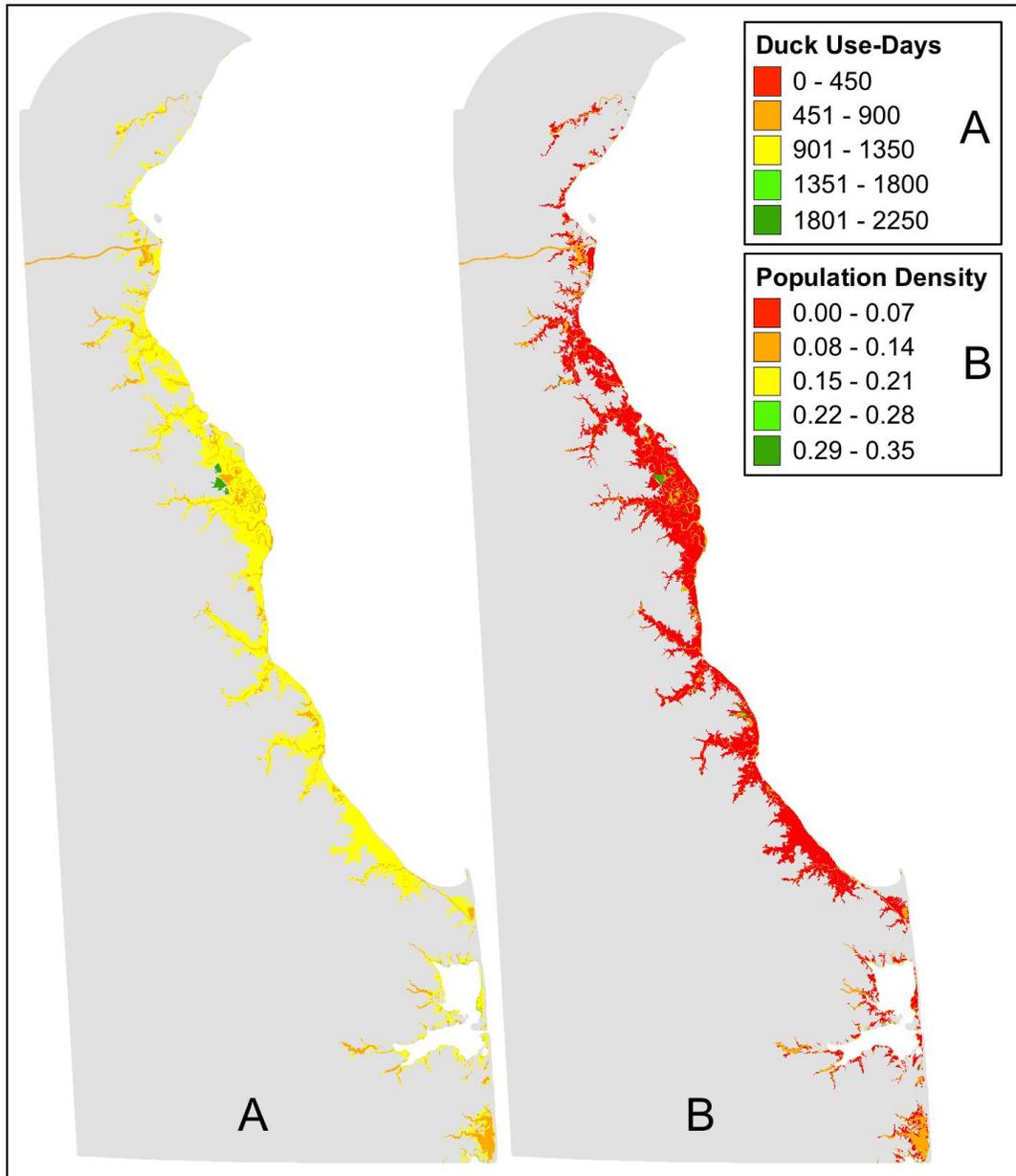


Figure 14 “Hot-spot” map depicting density of currently available duck use-days (DUDs/ha; “A”) and population density (individuals/ha; “B”) based on aerial surveys for northern shovelers wintering on the Delaware Bayshore.

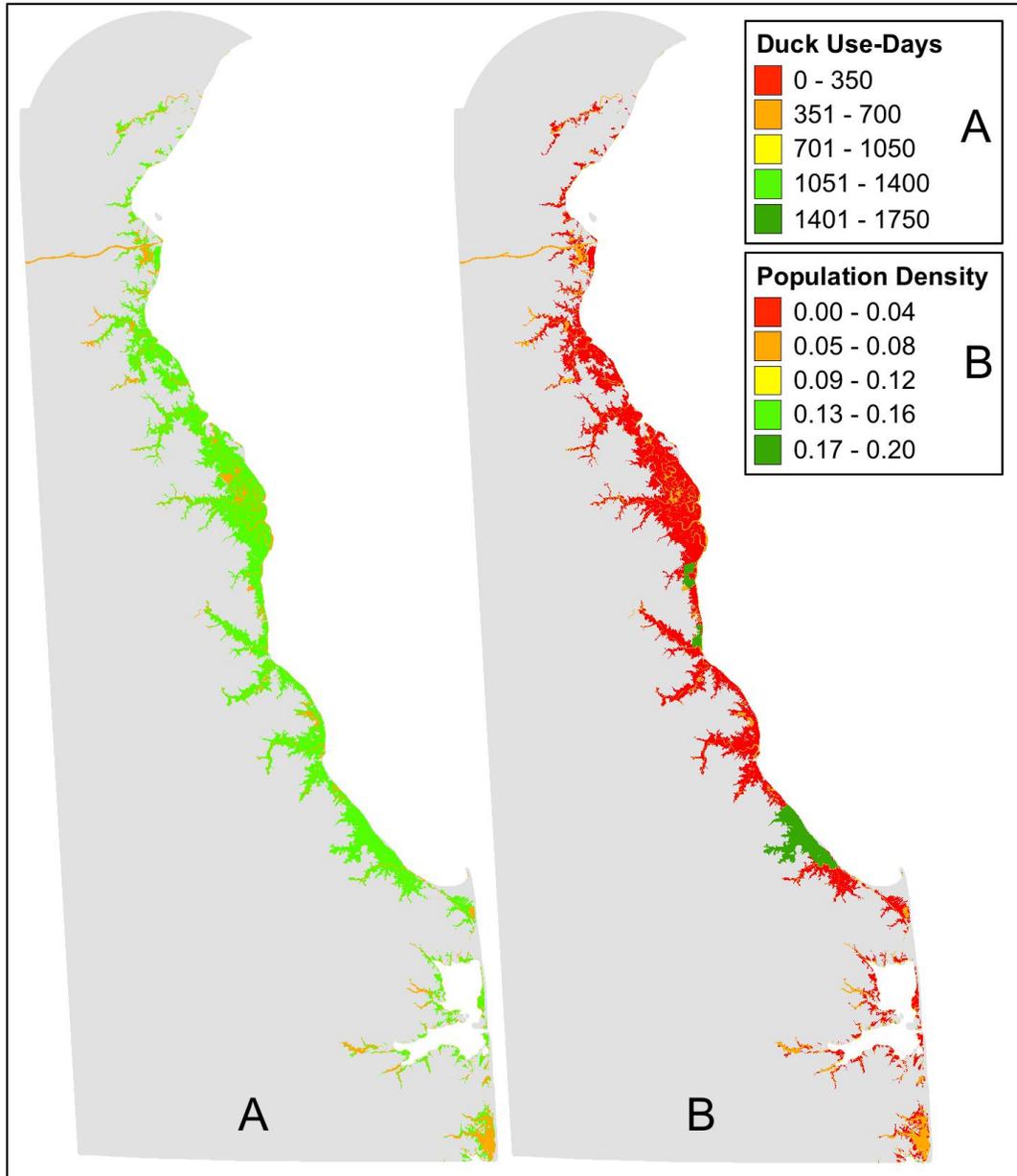


Figure 15 “Hot-spot” map depicting density of currently available duck use-days (DUDs/ha; “A”) and population density (individuals/ha; “B”) based on aerial surveys for green-winged teal wintering on the Delaware Bayshore.

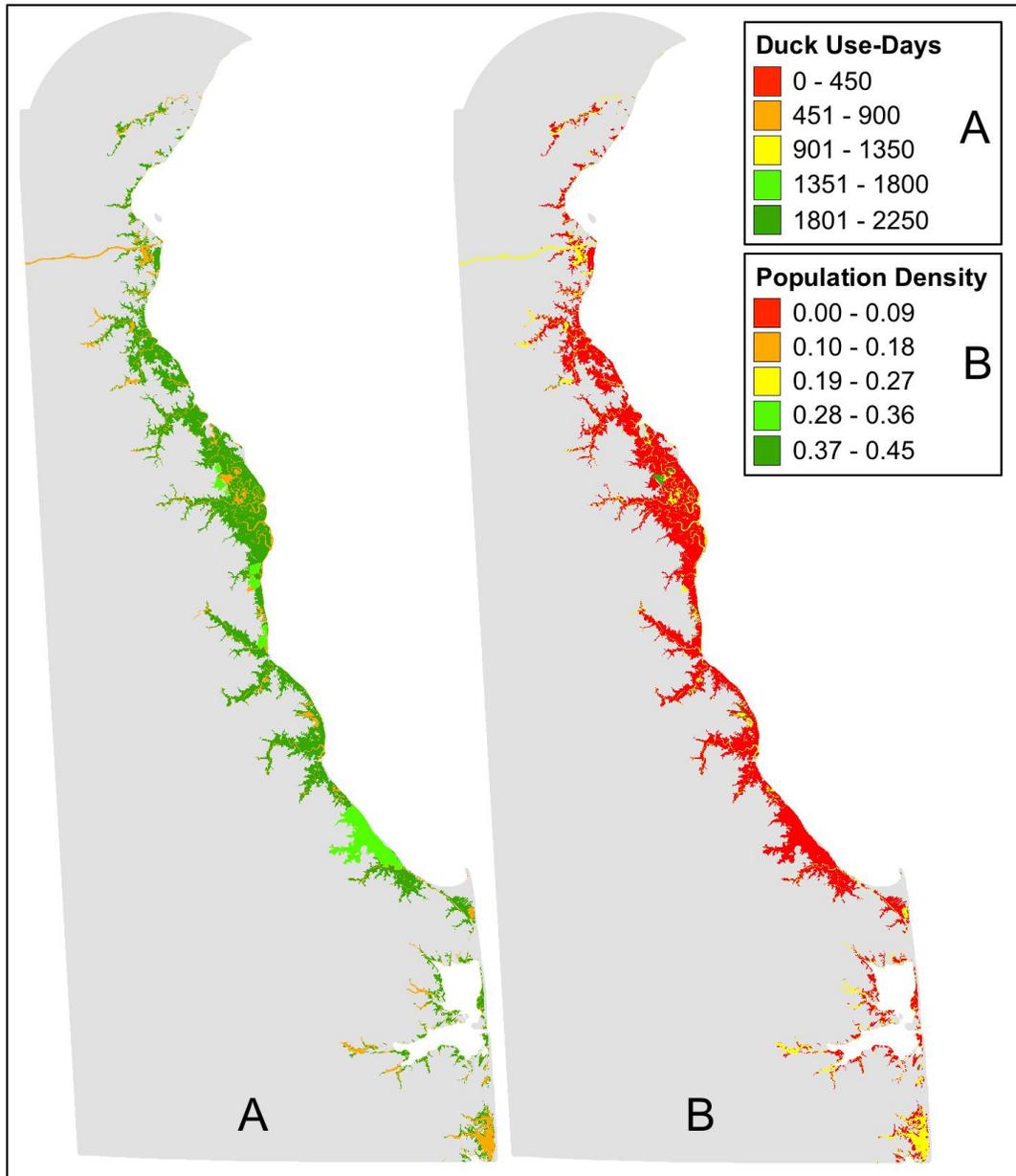


Figure 16 “Hot-spot” map depicting density of currently available duck use-days (DUDs/ha; “A”) and population density (individuals/ha; “B”) based on aerial surveys for American wigeon wintering on the Delaware Bayshore.

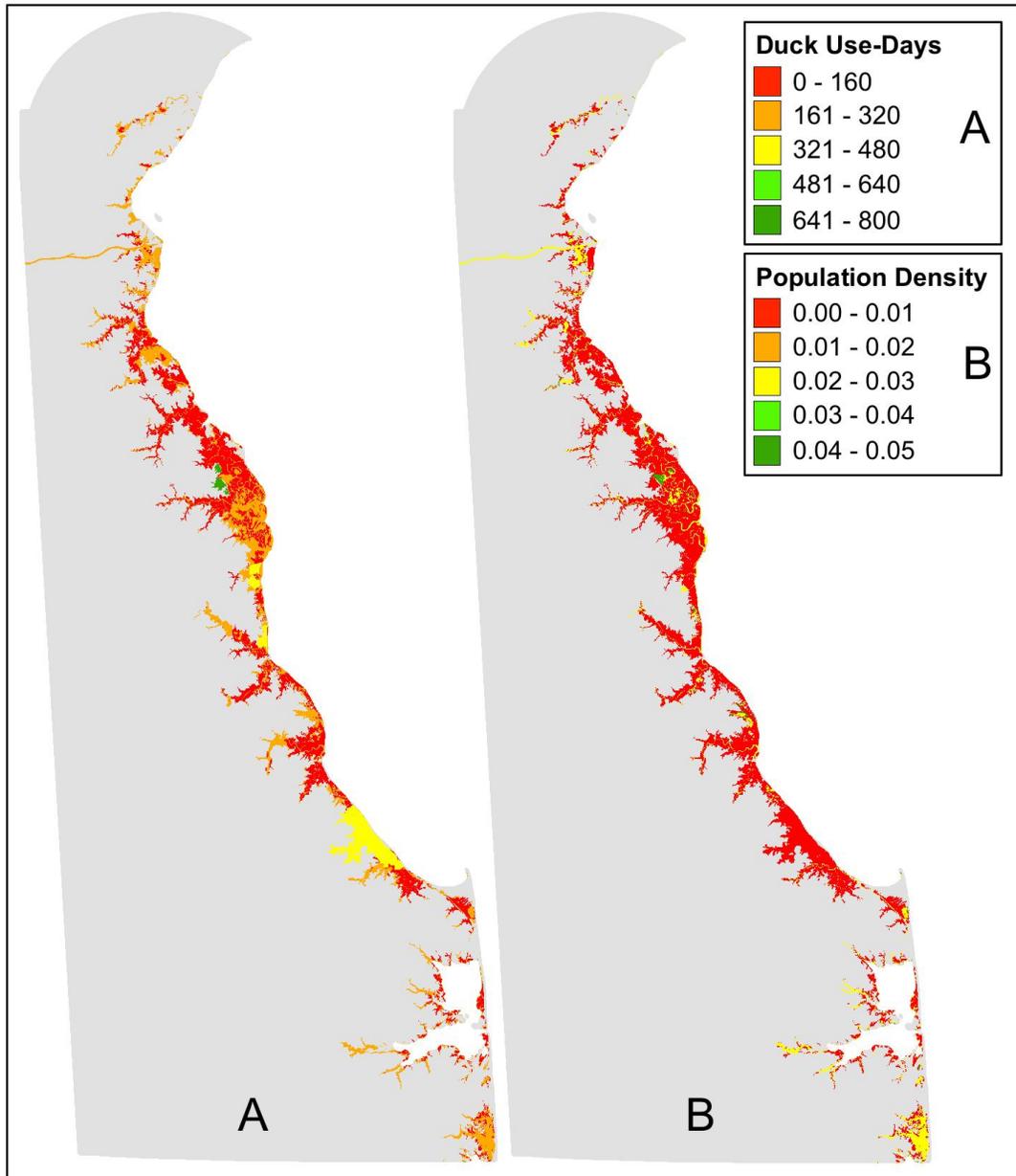


Figure 17 “Hot-spot” map depicting density of currently available duck use-days (DUDs/ha; “A”) and population density (individuals/ha; “B”) based on aerial surveys for gadwall wintering on the Delaware Bayshore.

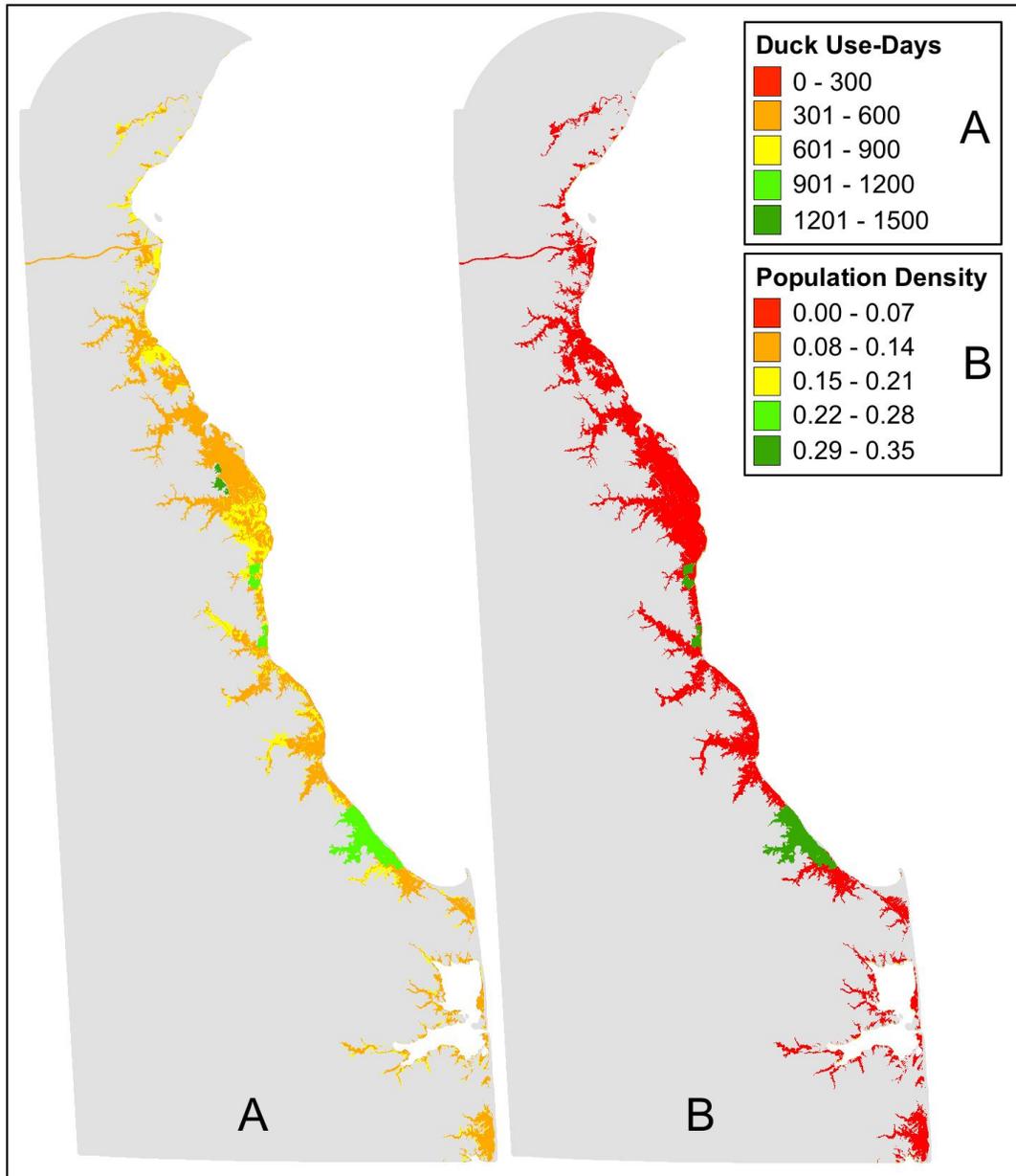


Figure 18 Future wetland habitat composition along the Delaware Bayshore in four time steps based on the Sea Level Affecting Marshes Model (SLAMM, NOAA 2012) under the IPCC A1B Mean scenario (39 cm rise by 2100).

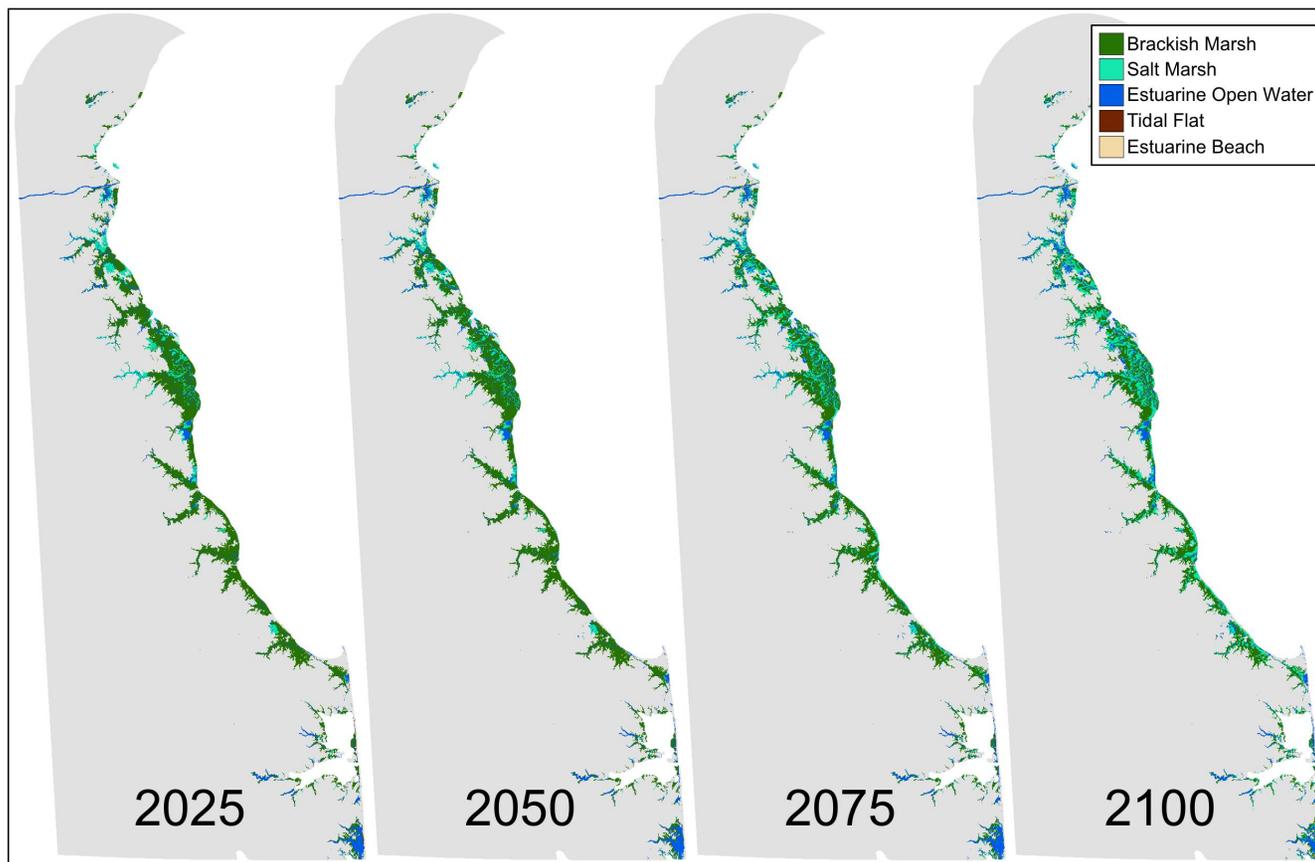


Figure 19 Future wetland habitat composition along the Delaware Bayshore in four time steps based on the Sea Level Affecting Marshes Model (SLAMM, NOAA 2012) under the IPCC A1B Max scenario (69 cm rise by 2100).

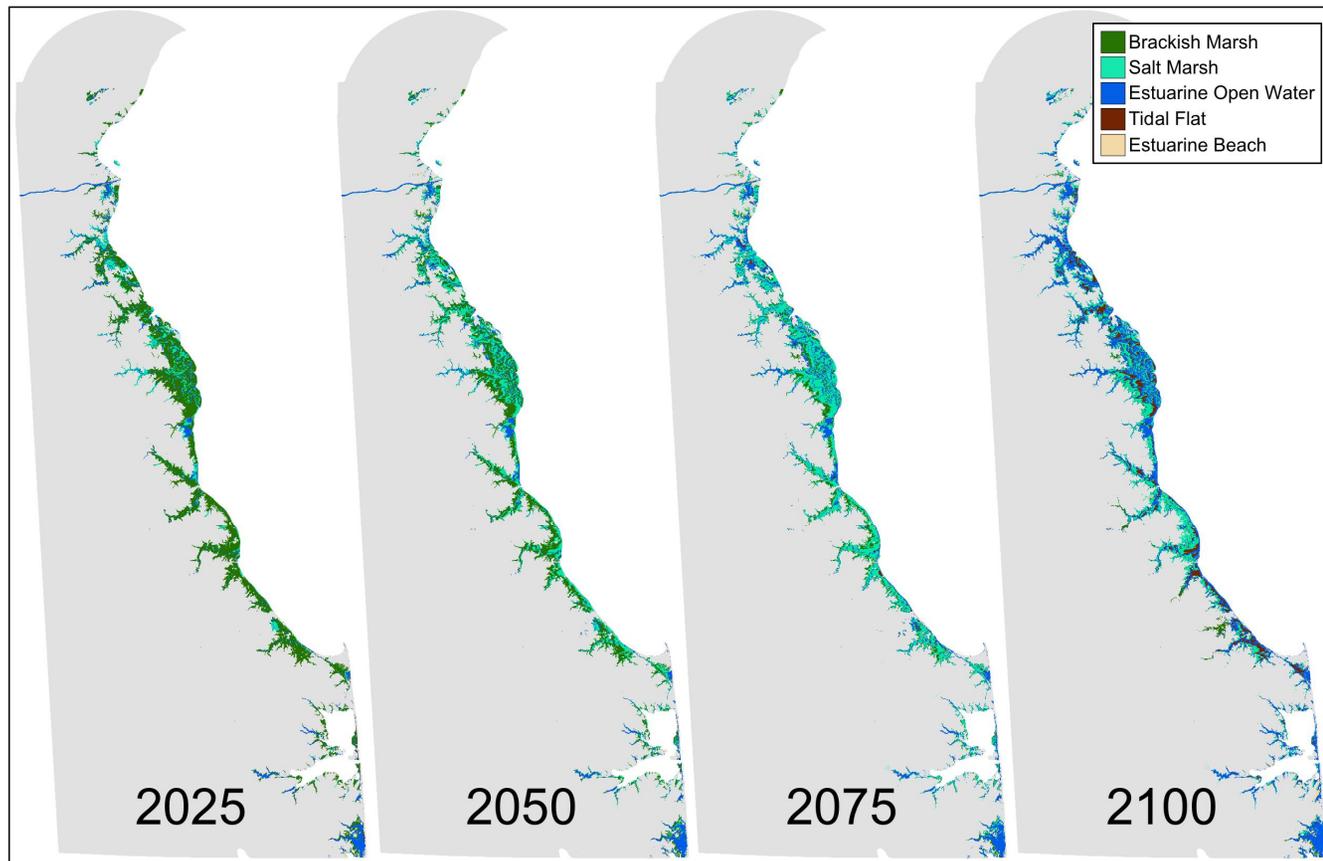


Figure 20 Future wetland habitat composition along the Delaware Bayshore in four time steps based on the Sea Level Affecting Marshes Model (SLAMM, NOAA 2012) under the 1 m rise by 2100 scenario.

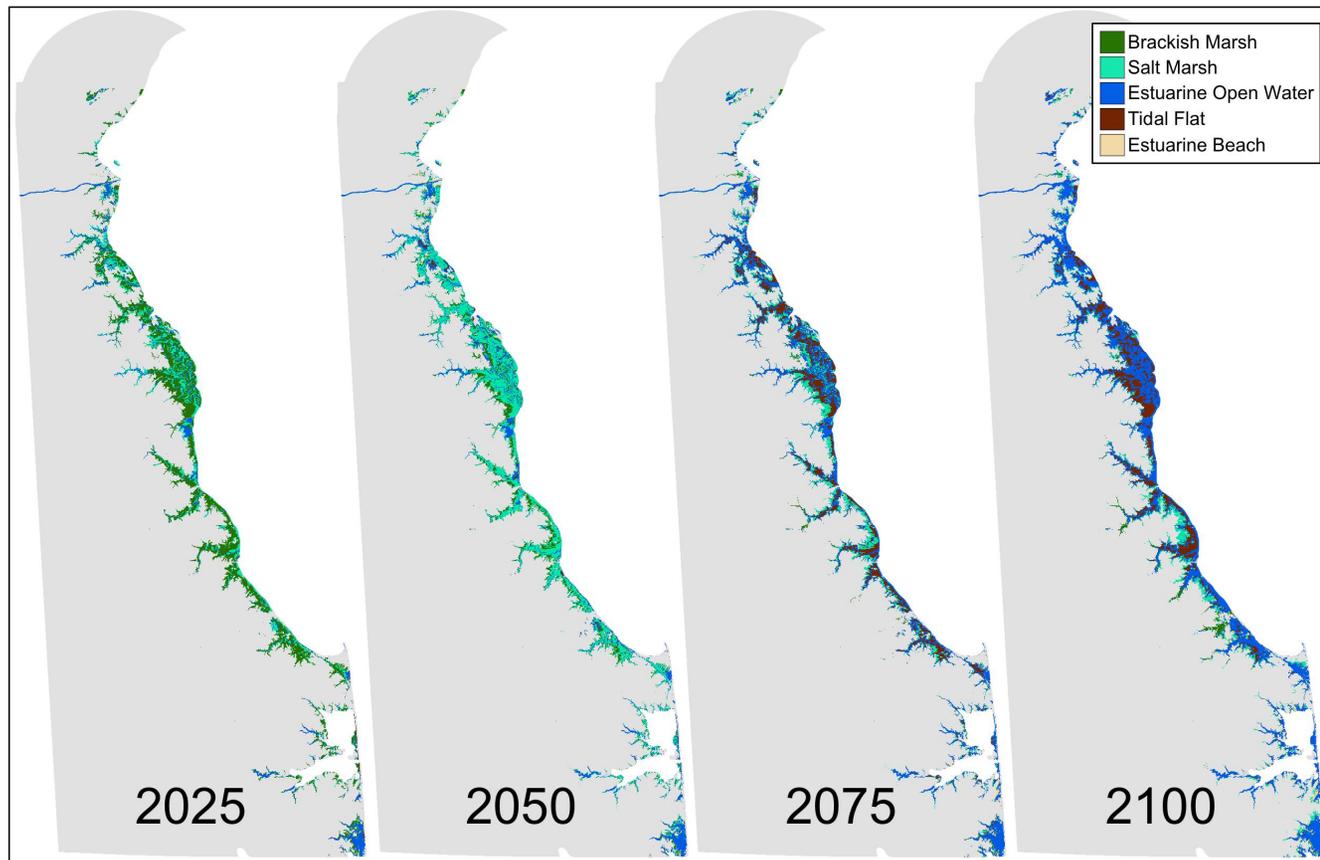


Figure 21 Future wetland habitat composition along the Delaware Bayshore in four time steps based on the Sea Level Affecting Marshes Model (SLAMM, NOAA 2012) under the 1.5 m rise by 2100 scenario.

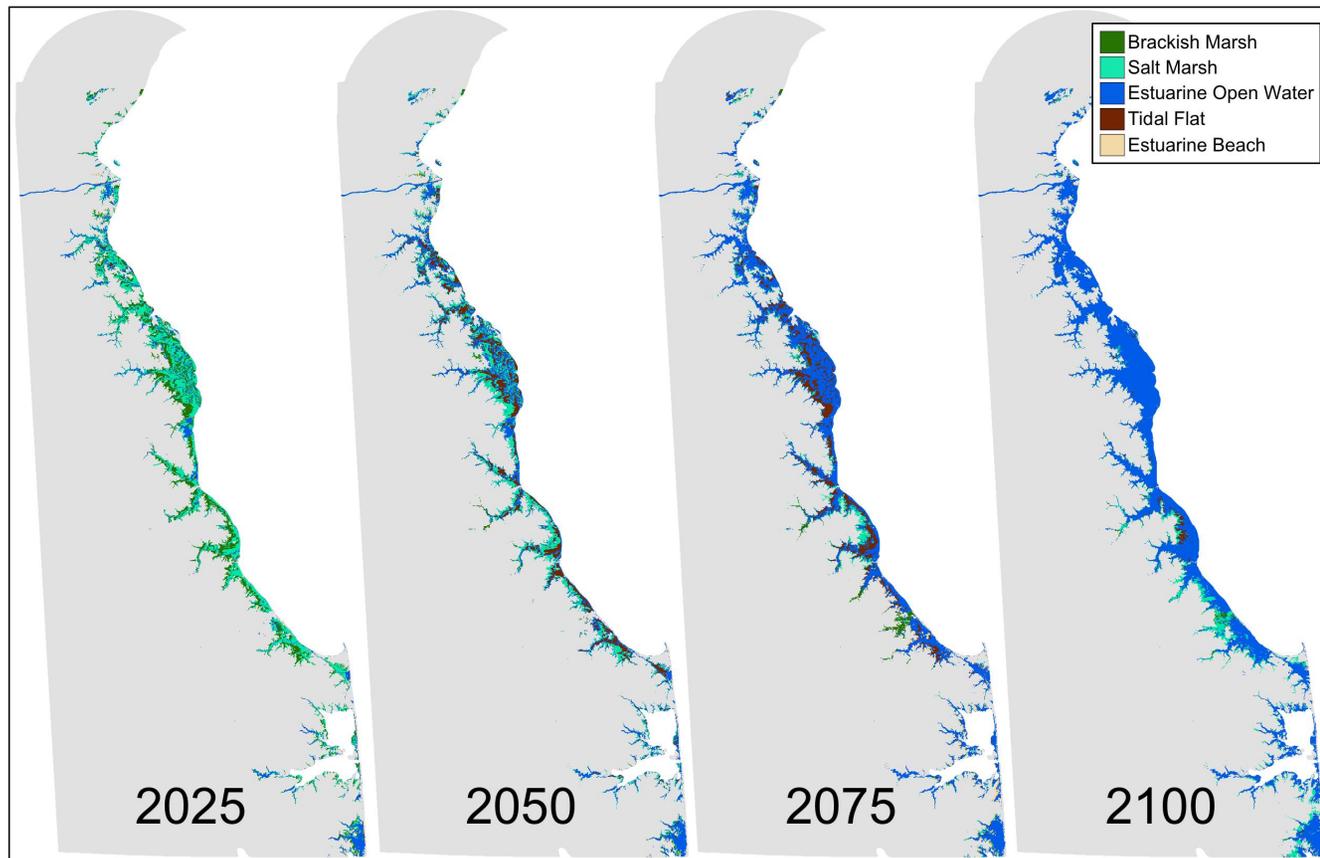


Figure 22 Future carrying capacity estimates for American black ducks within a 16 km buffer from the Delaware Bayshore based on several SLR scenarios. “P” denotes scenarios in which impoundments were protected from SLR.

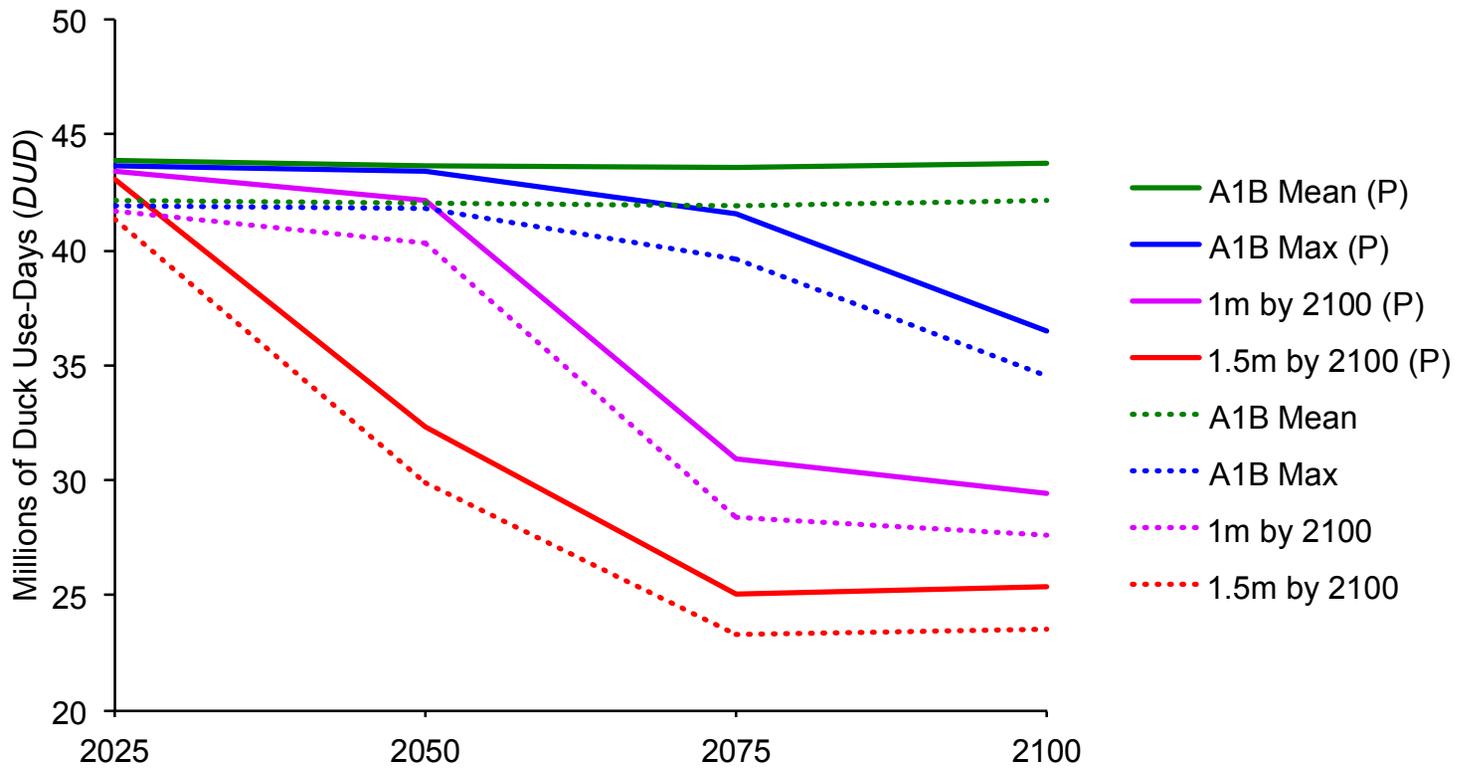


Figure 23 Future carrying capacity estimates for mallards within a 16 km buffer from the Delaware Bayshore based on several SLR scenarios. “P” denotes scenarios in which impoundments were protected from SLR.

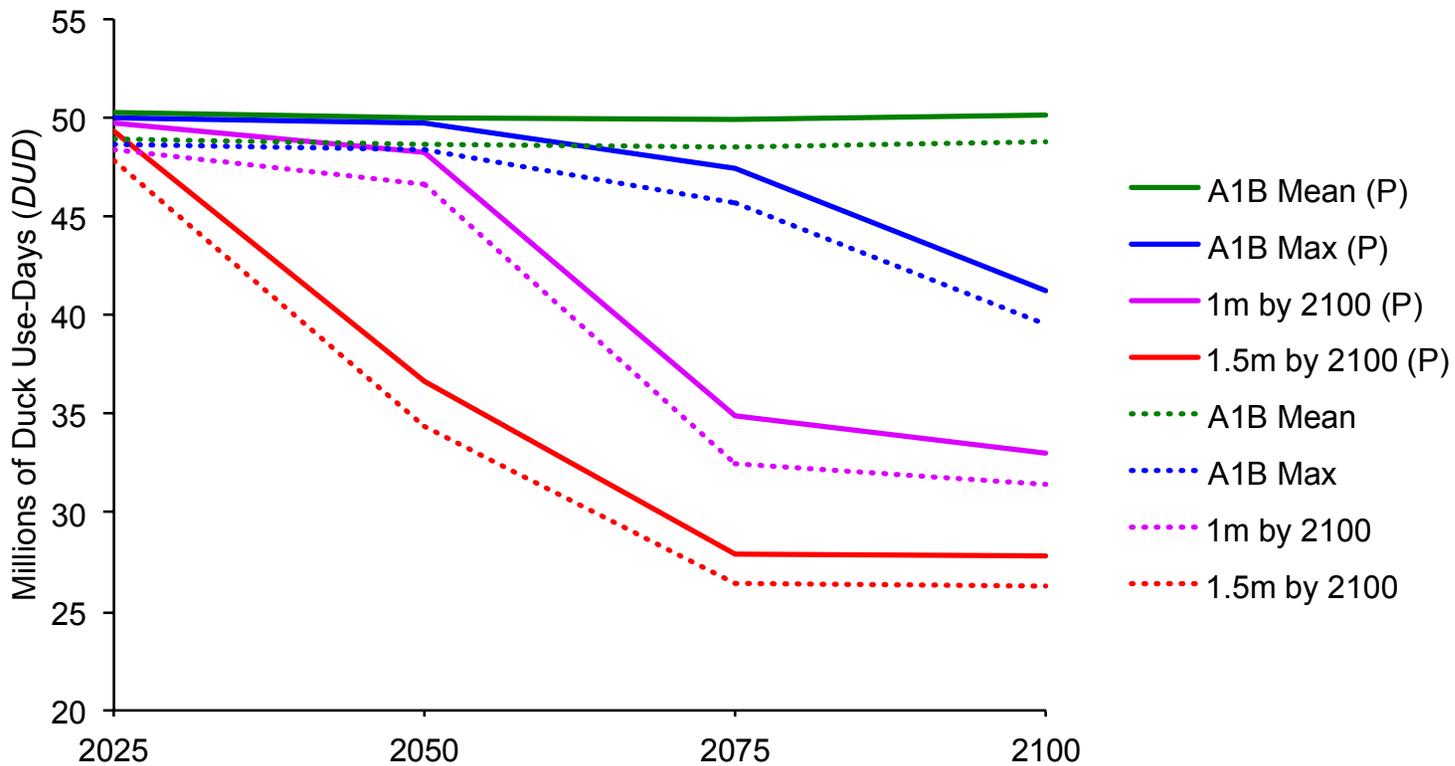


Figure 24 Future carrying capacity estimates for northern pintails within a 16 km buffer from the Delaware Bayshore based on several SLR scenarios. “P” denotes scenarios in which impoundments were protected from SLR.

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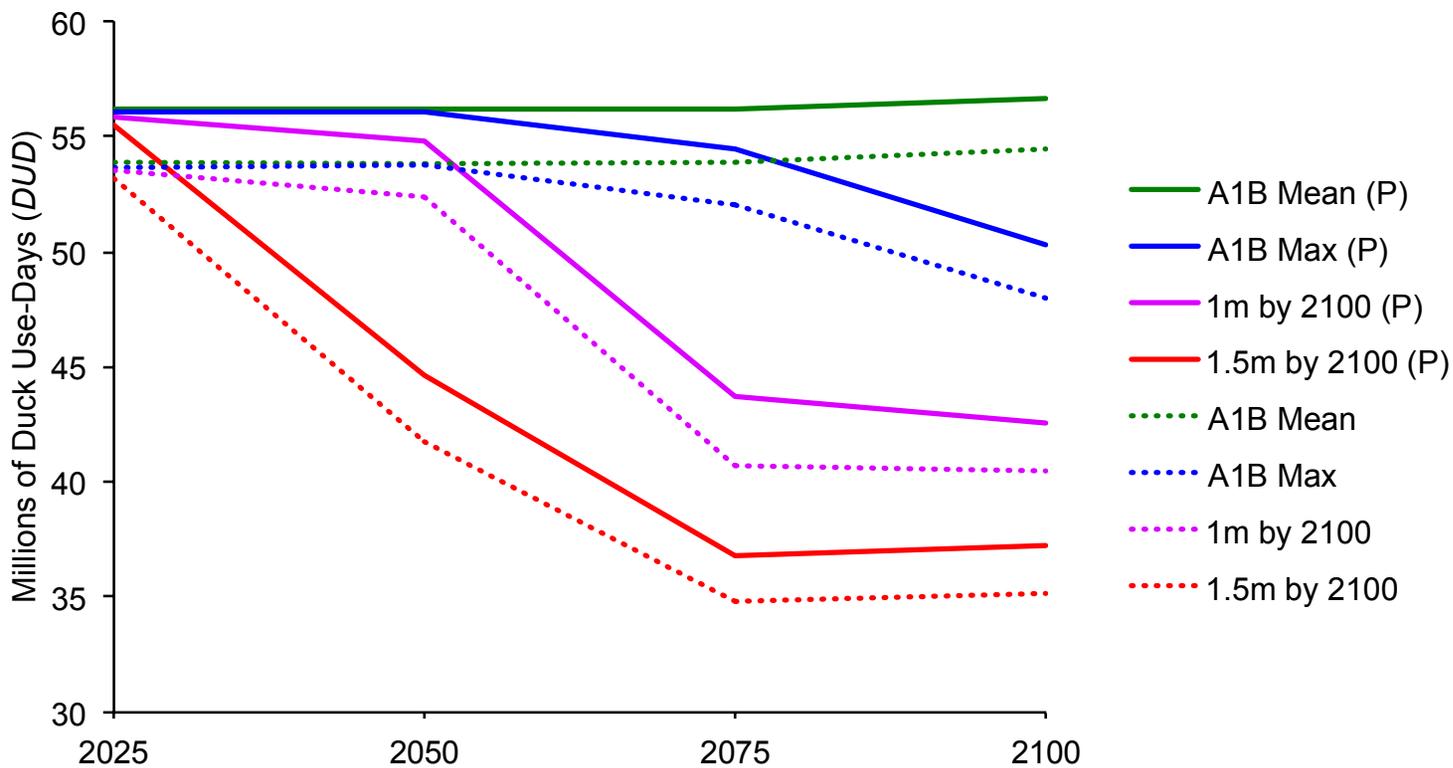


Figure 25 Future carrying capacity estimates for northern shovelers within a 16 km buffer from the Delaware Bayshore based on several SLR scenarios. “P” denotes scenarios in which impoundments were protected from SLR.

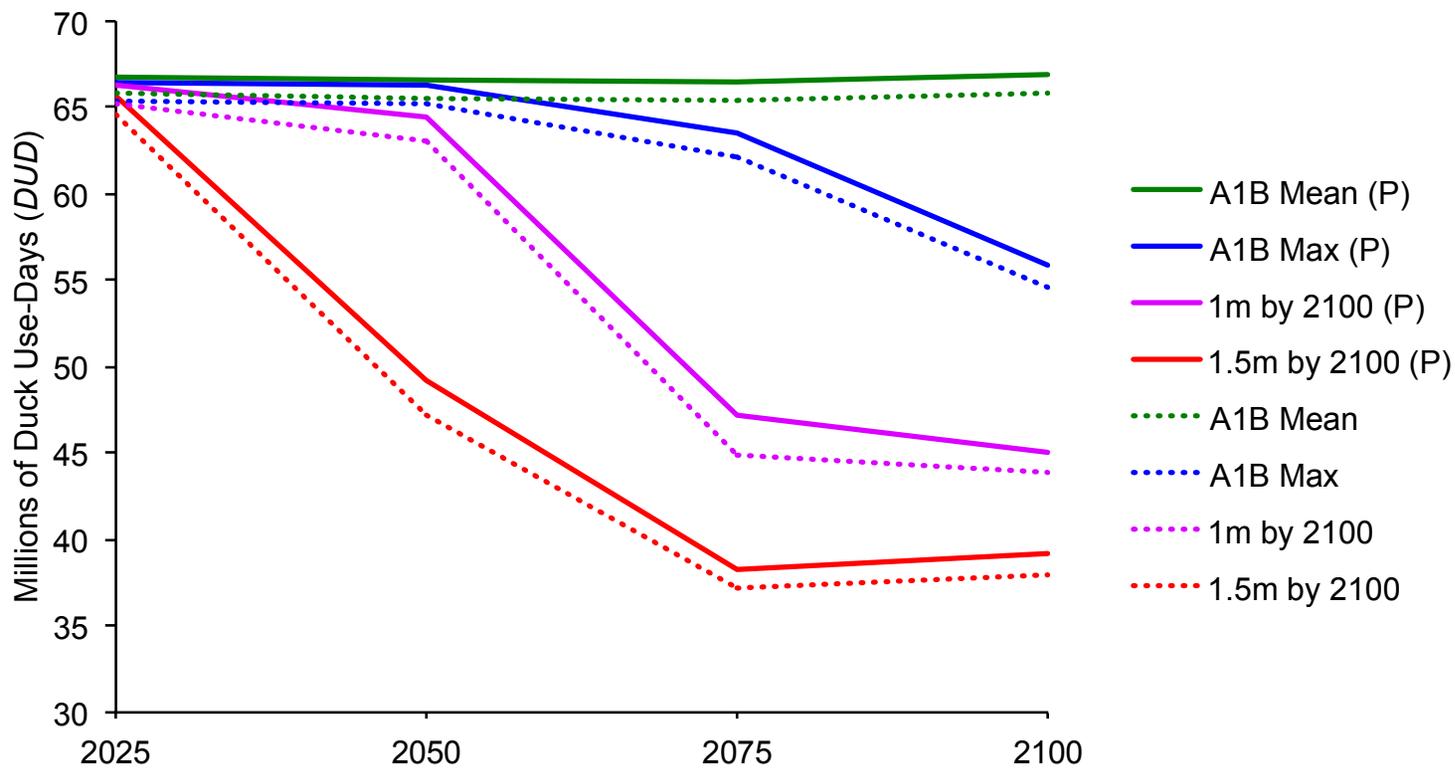


Figure 26 Future carrying capacity estimates for green-winged teal within a 16 km buffer from the Delaware Bayshore based on several SLR scenarios. “P” denotes scenarios in which impoundments were protected from SLR.

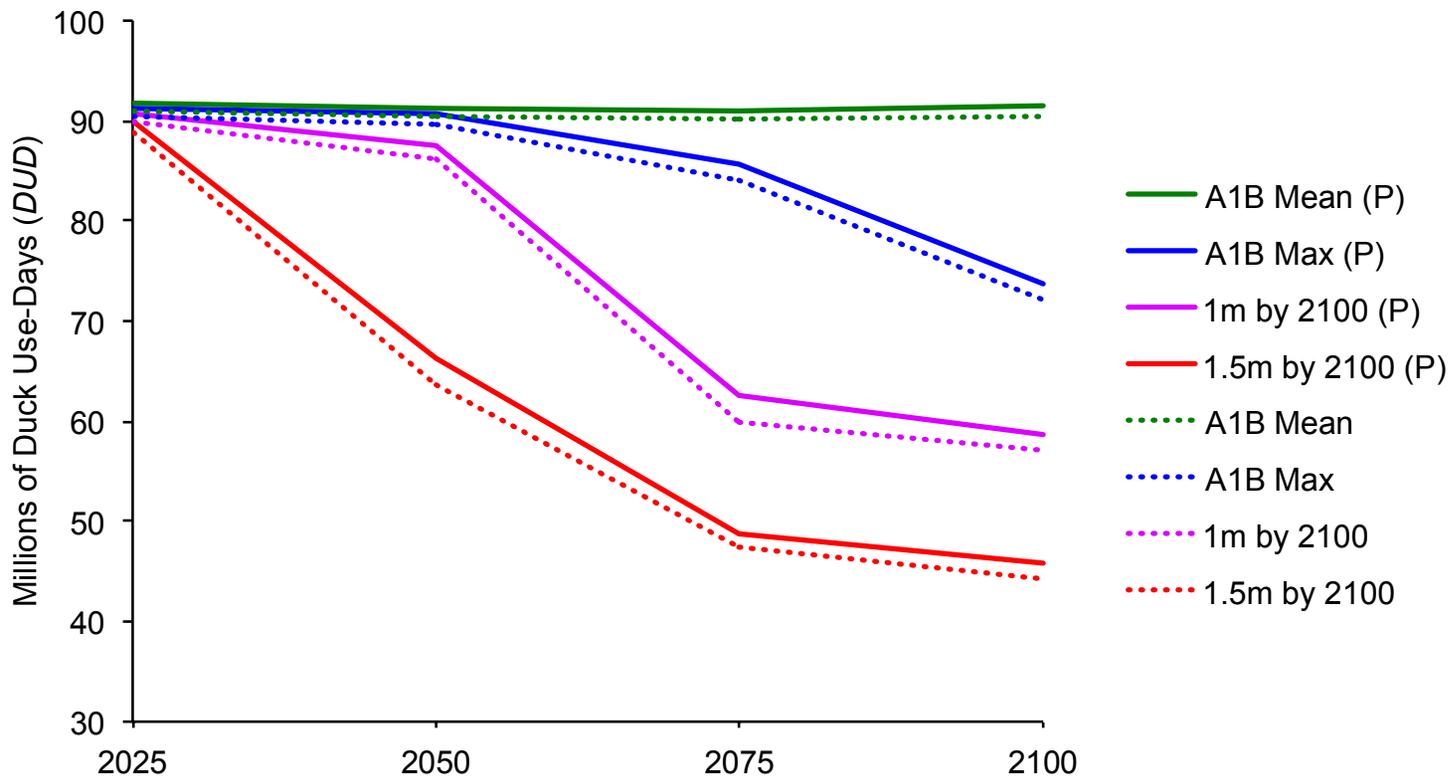


Figure 27 Future carrying capacity estimates for American wigeon within a 16 km buffer from the Delaware Bayshore based on several SLR scenarios. “P” denotes scenarios in which impoundments were protected from SLR.

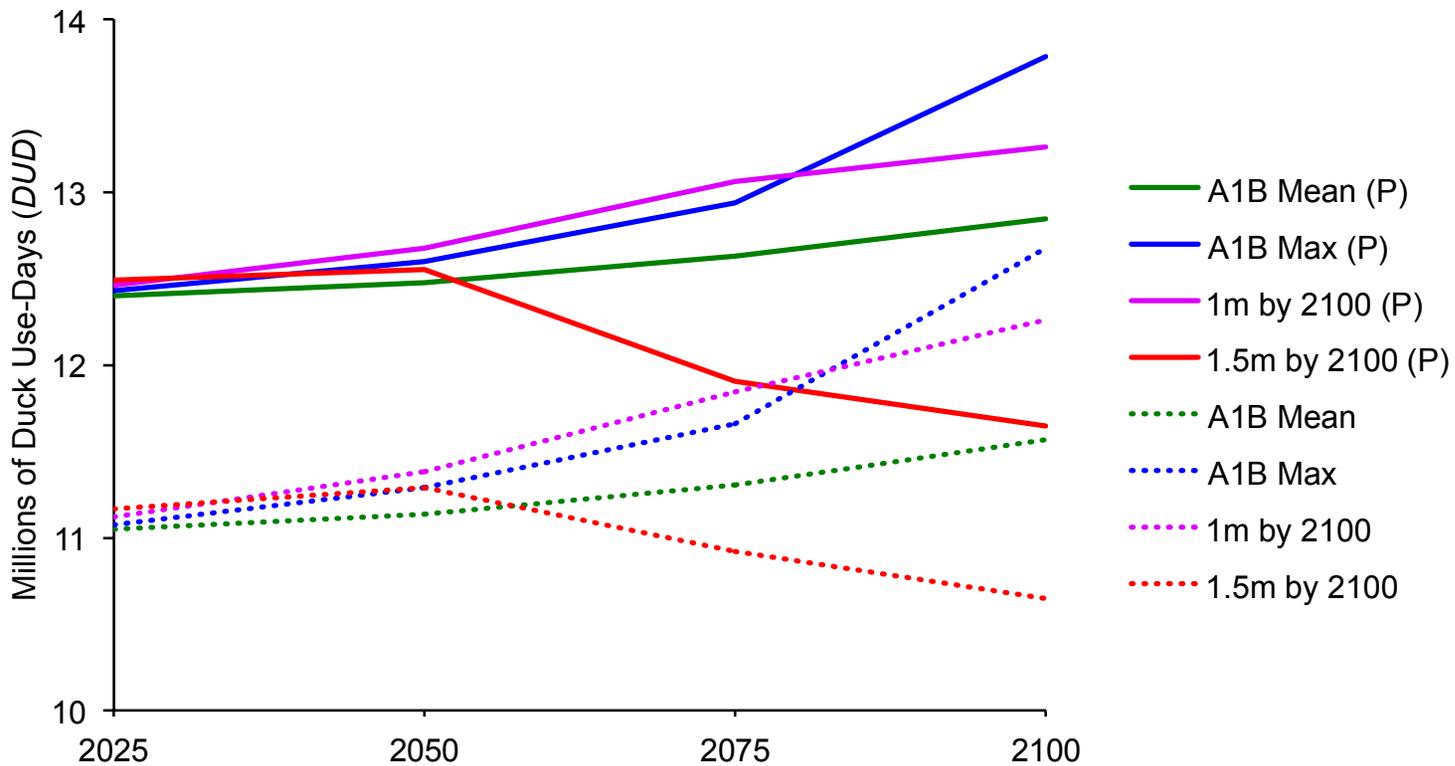
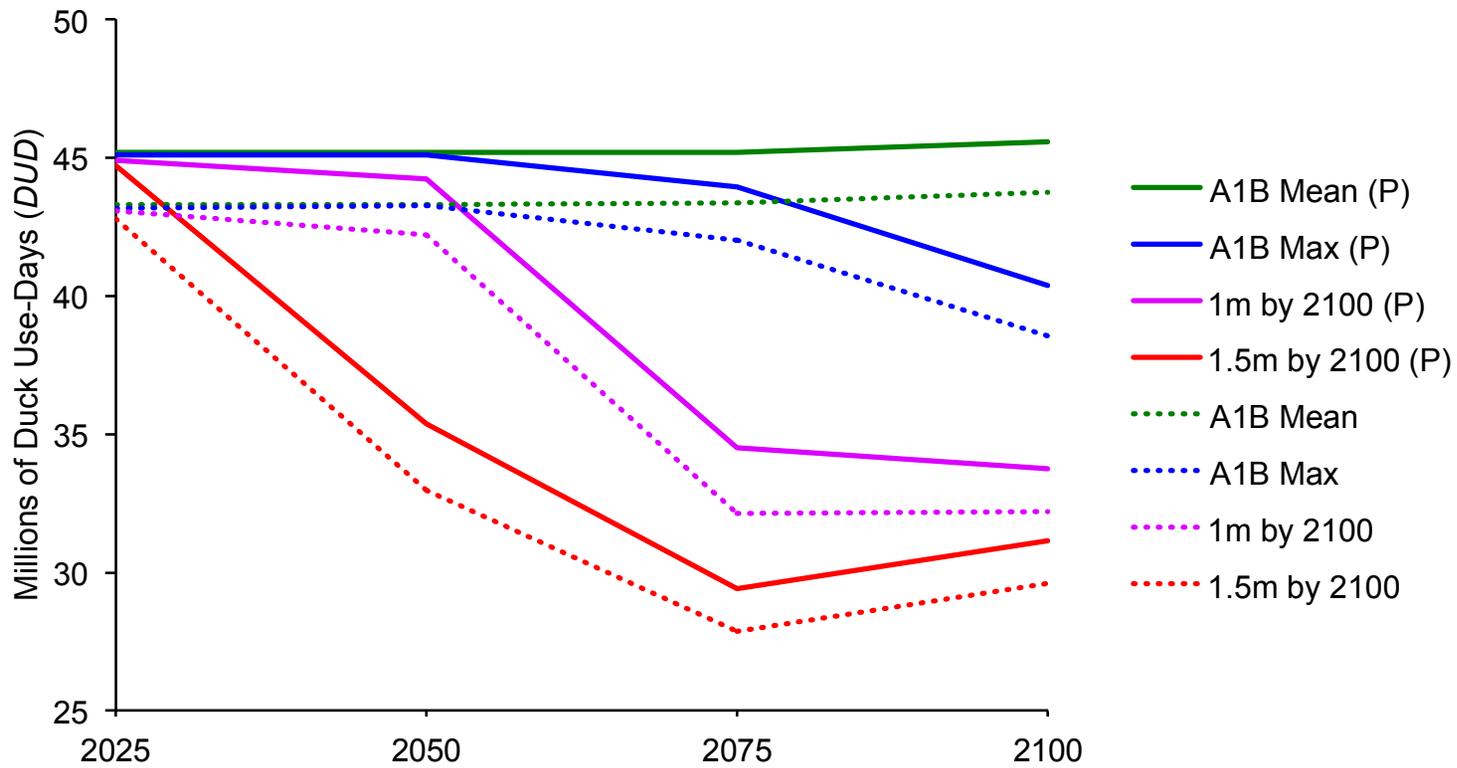


Figure 28 Future carrying capacity estimates for gadwall within a 16 km buffer from the Delaware Bayshore based on several SLR scenarios. “P” denotes scenarios in which impoundments were protected from SLR.



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## Appendix A

### TRUE METABOLIZABLE ENERGY (TME) VALUES AND JUSTIFICATIONS FOR PREFERRED FOODS OF DABBLING DUCKS WINTERING ON THE DELAWARE BAYSHORE, OCTOBER–APRIL, 2011–2013.

Note: If a dashed line occurs for a food item for a waterfowl species, this indicates the food was not preferred and not included in waterfowl species carrying capacity estimates.

Food Item	MALL	ABDU	AGWT	NSHO	AMWI	NOPI	GADW
<i>Animal Foods</i>							
Actinopterygii: <i>Cyprinodon</i> spp.	3.66 <sup>1</sup>	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	3.66 <sup>1</sup>
Actinopterygii: <i>Fundulus</i> spp.	3.66 <sup>1</sup>	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	3.66 <sup>1</sup>
Actinopterygii: <i>Gambusia affinis</i>	3.66 <sup>1</sup>	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	3.66 <sup>1</sup>
Actinopterygii: <i>Lucania parva</i>	3.66 <sup>1</sup>	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	3.66 <sup>1</sup>
Actinopterygii: <i>Menidia</i> spp.	3.66 <sup>1</sup>	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	3.66 <sup>1</sup>
Arachnida	–	–	–	–	–	–	0.91 <sup>2</sup>
Arachnida: Araneae	–	–	–	–	–	0.91 <sup>2</sup>	0.91 <sup>2</sup>
Bivalvia: <i>Gemma gemma</i>	0 <sup>3</sup>	0 <sup>3</sup>	0 <sup>3</sup>	0 <sup>3</sup>	–	0 <sup>3</sup>	–
Bivalvia: <i>Modiolus demissus</i>	0.76 <sup>4</sup>	0.76 <sup>4</sup>	0.76 <sup>4</sup>	0.76 <sup>4</sup>	–	0.76 <sup>4</sup>	–
Bivalvia: <i>Mya arenaria</i>	0.52 <sup>5</sup>	0.52 <sup>5</sup>	0.52 <sup>5</sup>	0.52 <sup>5</sup>	–	0.52 <sup>5</sup>	–
Gastropoda	0.6 <sup>6</sup>	–	-0.09 <sup>7</sup>	0.51 <sup>8</sup>	0.51 <sup>8</sup>	0.6 <sup>6</sup>	0.51 <sup>8</sup>

Gastropoda: <i>Hydrobia</i> spp.	0.77 <sup>9</sup>						
Gastropoda: <i>Littoraria irrorata</i>	0.39 <sup>10</sup>	–	0.39 <sup>10</sup>				
Gastropoda: <i>Melampus bidentatus</i>	0.77 <sup>9</sup>						
Insecta: Coleoptera	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	–	–	–	–
Insecta: Coleoptera: Carabidae	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	0.38 <sup>11</sup>	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–
Insecta: Coleoptera: Chrysomelidae	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	–	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–
Insecta: Coleoptera: Dytiscidae	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	0.38 <sup>11</sup>	0.38 <sup>11</sup>	0.38 <sup>11</sup>	0.38 <sup>11</sup>
Insecta: Coleoptera: Haliplidae	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	–	–	0.38 <sup>11</sup>	–
Insecta: Coleoptera: Hydrophilidae	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	–	–	0.38 <sup>11</sup>	0.38 <sup>11</sup>
Insecta: Coleoptera: Scirtidae	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	–	–	–	–
Insecta: Coleoptera: Staphylinidae	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–	0.38 <sup>11</sup>	–	0.38 <sup>11</sup>	–
Insecta: Diptera	–	0.27 <sup>12</sup>	0.27 <sup>12</sup>	–	–	–	0.27 <sup>12</sup>
Insecta: Diptera: Chironomidae	0.27 <sup>12</sup>						
Insecta: Diptera: Culicidae	–	0.27 <sup>12</sup>	0.27 <sup>12</sup>	–	–	–	0.27 <sup>12</sup>
Insecta: Diptera: Ephydriidae	0.27 <sup>12</sup>	0.27 <sup>12</sup>	0.27 <sup>12</sup>	–	–	–	0.27 <sup>12</sup>
Insecta: Diptera: Stratiomyidae	–	0.27 <sup>12</sup>	0.27 <sup>12</sup>	–	–	–	0.27 <sup>12</sup>
Insecta: Diptera: Tabanidae	0.27 <sup>12</sup>	0.27 <sup>12</sup>	0.27 <sup>12</sup>	–	–	–	0.27 <sup>12</sup>
Insecta: Hemiptera: Corixidae	0.48 <sup>13</sup>	–	–	0.48 <sup>13</sup>	0.48 <sup>13</sup>	0.48 <sup>13</sup>	0.48 <sup>13</sup>
Insecta: Hemiptera: Notonectidae	0.48 <sup>13</sup>	–	–	–	–	–	–
Insecta: Hymenoptera: Formicidae	0.38 <sup>11</sup>	–	–	–	–	0.38 <sup>11</sup>	–
Insecta: Lepidoptera: Noctuidae	0.38 <sup>11</sup>	–	–	–	–	–	0.38 <sup>11</sup>

Insecta: Odonata: Libellulidae	0.38 <sup>11</sup>	–	–	–	0.38 <sup>11</sup>	0.38 <sup>11</sup>	–
Insecta: Trichoptera	0.38 <sup>11</sup>	–	–	0.38 <sup>11</sup>	0.38 <sup>11</sup>	0.38 <sup>11</sup>	0.38 <sup>11</sup>
Malacostraca: <i>Gammarus</i> spp.	2.21 <sup>14</sup>	2.21 <sup>14</sup>	1.66 <sup>15</sup>	1.99 <sup>16</sup>	–	–	–
Malacostraca: <i>Palaemonetes</i> spp.	2.02 <sup>17</sup>	2.02 <sup>17</sup>	–	–	–	–	–
Malacostraca: <i>Uca</i> spp.	1.57 <sup>18</sup>	1.57 <sup>18</sup>	–	–	–	–	–
Osteichthyes	3.66 <sup>1</sup>	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	–	3.66 <sup>1</sup>	3.66 <sup>1</sup>
Ostracoda	2.04 <sup>19</sup>	–	0.91 <sup>2</sup>	1.09 <sup>20</sup>	–	1.09 <sup>20</sup>	1.09 <sup>20</sup>

*Plant Foods*

Amaranthaceae: <i>Salicornia</i> spp.	–	2.97 <sup>21</sup>	–	–	–	–	–
Asteraceae: <i>Ambrosia artemisiifolia</i>	0.55 <sup>22</sup>	–	–	–	–	–	–
Asteraceae: <i>Aster</i> spp.	–	0.55 <sup>22</sup>	–	–	–	–	–
Asteraceae: <i>Bidens comosa</i>	0.55 <sup>22</sup>	–	–	–	–	–	–
Asteraceae: <i>Iva</i> spp.	0.55 <sup>22</sup>	–	–	–	–	–	–
Brassicaceae: <i>Brassica</i> spp.	–	1.31 <sup>23</sup>	–	–	–	–	–
Cannabaceae: <i>Humulus japonicus</i>	–	1.74 <sup>24</sup>	–	–	–	–	–
Convolvulaceae: <i>Ipomoea</i> spp.	–	1.74 <sup>24</sup>	–	–	–	–	–
Cornaceae: <i>Nyssa sylvatica</i>	1.74 <sup>24</sup>	–	–	–	–	1.74 <sup>24</sup>	–
Cyperaceae: <i>Carex</i> spp.	1 <sup>25</sup>	1 <sup>25</sup>	0.71 <sup>26</sup>	–	–	–	–
Cyperaceae: <i>Cladium jamaicense</i>	1 <sup>25</sup>	–	–	–	1.04 <sup>29</sup>	1.41 <sup>30</sup>	1.04 <sup>29</sup>
Cyperaceae: <i>Cyperus</i> spp.	1.69 <sup>27</sup>	–	1.96 <sup>28</sup>	1.69 <sup>27</sup>	–	1.42 <sup>31</sup>	1.69 <sup>27</sup>
Cyperaceae: <i>Eleocharis</i> spp.	0.5 <sup>32</sup>	0.5 <sup>32</sup>	-0.18 <sup>33</sup>	–	0.58 <sup>34</sup>	–	0.58 <sup>34</sup>

Cyperaceae: <i>Schoenoplectus</i> spp.	0.82 <sup>35</sup>	0.82 <sup>35</sup>	0.57 <sup>36</sup>	0.93 <sup>37</sup>	0.93 <sup>37</sup>	1.93 <sup>38</sup>	0.93 <sup>37</sup>
Fabaceae: <i>Vicia</i> spp.	–	1.74 <sup>24</sup>	–	–	–	–	–
Haloragaceae: <i>Myriophyllum spicatum</i>	–	–	–	–	–	–	1.74 <sup>24</sup>
Juncaceae: <i>Juncus</i> spp.	–	1.21 <sup>39</sup>	1.21 <sup>39</sup>	–	–	–	–
Oxalidaceae: <i>Oxalis</i> spp.	–	1.74 <sup>24</sup>	–	–	–	–	–
Phytolaccaceae: <i>Phytolacca americana</i>	–	2.49 <sup>40</sup>	–	–	–	–	–
Poaceae: <i>Distichlis spicata</i>	2.46 <sup>41</sup>	–	2.3 <sup>42</sup>	2.47 <sup>43</sup>	2.47 <sup>43</sup>	2.47 <sup>43</sup>	–
Poaceae: <i>Echinochloa</i> spp.	2.67 <sup>44</sup>	–	2.67 <sup>44</sup>	2.73 <sup>45</sup>	2.73 <sup>45</sup>	2.82 <sup>46</sup>	2.73 <sup>45</sup>
Poaceae: <i>Leersia oryzoides</i>	3 <sup>47</sup>	–	2.94 <sup>48</sup>	–	2.94 <sup>48</sup>	2.82 <sup>49</sup>	2.94 <sup>48</sup>
Poaceae: <i>Leptochloa fascicularis</i>	–	–	–	–	–	–	2.47 <sup>43</sup>
Poaceae: <i>Panicum</i> spp.	2.75 <sup>50</sup>	2.75 <sup>50</sup>	–	–	–	2.45 <sup>51</sup>	–
Poaceae: <i>Spartina alterniflora</i>	1.39 <sup>52</sup>	1.39 <sup>52</sup>	1.39 <sup>52</sup>	–	–	1.39 <sup>52</sup>	1.39 <sup>52</sup>
Polygonaceae: <i>Polygonum</i> spp.	1.3 <sup>53</sup>	1.3 <sup>53</sup>	1.3 <sup>53</sup>	1.43 <sup>54</sup>	1.43 <sup>54</sup>	1.42 <sup>55</sup>	1.43 <sup>54</sup>
Polygonaceae: <i>Rumex</i> spp.	2.68 <sup>56</sup>	–	–	–	–	–	–
Potamogetonaceae: <i>Potamogeton</i> spp.	1.42 <sup>57</sup>	–	1.42 <sup>57</sup>				
Ruppiaceae: <i>Ruppia maritima</i>	–	–	–	–	1.10 <sup>58</sup>	–	–

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*Justifications for TME values*

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<sup>1</sup>Value for *Fundulus heteroclitus* (Coluccy et al. 2015)

<sup>2</sup>Mean of Arthropoda values

<sup>3</sup>Value for *Mulina lateralis* (Ballard et al. 2004)

<sup>4</sup>Mean of Mytiloidea values (Jorde and Owen 1988)

- <sup>5</sup>Mean of *Mya arenaria* values (Jorde and Owen 1988)
- <sup>6</sup>Mean of Gastropoda family values for ABDU (Jorde and Owen 1988)
- <sup>7</sup>Value for Gastropoda (Sherfy 1999)
- <sup>8</sup>Mean of Gastropoda family values for all species (Jorde and Owen 1988, Sherfy 1999, Ballard et al. 2004)
- <sup>9</sup>Value for *Melampus bidentatus* (Coluccy et al. 2015)
- <sup>10</sup>Mean of *Littorina* spp. values (Jorde and Owen 1988)
- <sup>11</sup>Mean of values for Diptera and Hemiptera (Sherfy 1999)
- <sup>12</sup>Value for Diptera (Sherfy 1999)
- <sup>13</sup>Value for Hemiptera (Sherfy 1999)
- <sup>14</sup>Mean of *Gammarus oceanicus* values for ABDU (Jorde and Owen 1988)
- <sup>15</sup>Mean of Gammarus spp. for BWTE (Fredrickson and Reid 1988, Sherfy 1999)
- <sup>16</sup>Mean of Gammarus spp. values for ABDU, BWTE, NOPI (Jorde and Owen 1988, Fredrickson and Reid 1988, Sherfy 1999, Ballard et al. 2004)
- <sup>17</sup>Value for *Palaemonetes* spp. (Coluccy et al. 2015)
- <sup>18</sup>Value for *Uca* spp. (Coluccy et al. 2015)
- <sup>19</sup>Mean of Arthropoda values for ABDU (Jorde and Owen 1988)
- <sup>20</sup>Mean of Arthropoda values for all species
- <sup>21</sup>Value for *Amaranthus* spp. (Checkett et al. 2002)
- <sup>22</sup>Value for *Bidens cernua* (Sherfy 1999)
- <sup>23</sup>Value for *Lepidium latifolium* (Dugger et al. 2007)
- <sup>24</sup>Mean of all seed orders for all species
- <sup>25</sup>Mean of Cyperaceae genera values for MALL (Hoffman and Bookhout 1985, Checkett et al. 2002, Dugger et al. 2007)

- <sup>26</sup>Mean of Cyperaceae genera values for BWTE (Sherfy 1999)
- <sup>27</sup>Mean of *Cyperus* spp. values for NOPI, BWTE (Sherfy 1999, Ballard et al. 2004)
- <sup>28</sup>Value for *Cyperus esculentus* (Sherfy 1999)
- <sup>29</sup>Mean of Cyperaceae genera values for all species
- <sup>30</sup>Mean of Cyperaceae genera values for NOPI (Hoffman and Bookhout 1985, Ballard et al. 2004)
- <sup>31</sup>Value for *Cyperus* spp. for NOPI (Ballard et al. 2004)
- <sup>32</sup>Value for *Eleocharis palustris* (Dugger et al. 2007)
- <sup>33</sup>Value for *Eleocharis obtusa* (Sherfy 1999)
- <sup>34</sup>Mean of *Eleocharis* spp. values for all species (Sherfy 1999, Ballard et al. 2004, Dugger et al. 2007)
- <sup>35</sup>Mean of *Schoenoplectus maritimus* and *Scirpus validus* for MALL (Hoffman and Bookhout 1985, Dugger et al. 2007)
- <sup>36</sup>Mean of *Scirpus pungens* and *Scirpus americanus* for BWTE (Sherfy 1999)
- <sup>37</sup>Mean of *Scirpus* spp. and *Schoenoplectus* spp. for all species (Hoffman and Bookhout 1985, Sherfy 1999, Ballard et al. 2004, Dugger et al. 2007)
- <sup>38</sup>Value for *Scirpus* spp. for NOPI (Ballard et al. 2004)
- <sup>39</sup>Value for *Juncus canadensis* (Sherfy 1999)
- <sup>40</sup>Mean of Caryophyllales family values for MALL (Hoffman and Bookhout 1985, Checkett et al. 2002)
- <sup>41</sup>Mean of Poaceae genera values for MALL, ABDO (Hoffman and Bookhout 1985, Reinecke et al. 1989, Checkett et al. 2002, Coluccy et al. 2015)
- <sup>42</sup>Mean of Poaceae genera values for BWTE (Sherfy 1999, Sherfy et al. 2001)
- <sup>43</sup>Mean of Poaceae genera values for all species
- <sup>44</sup>Mean of *Echinochloa* spp. values for MALL (Hoffman and Bookhout 1985, Reinecke et al. 1989, Checkett et al. 2002)
- <sup>45</sup>Mean of *Echinochloa* spp. values for all species

<sup>46</sup>Value for *Echinochloa walteri* for NOPI (Hoffman and Bookhout 1985)

<sup>47</sup>Value for *Leersia oryzoides* for MALL (Hoffman and Bookhout 1985)

<sup>48</sup>Mean of *Leersia oryzoides* values for all species

<sup>49</sup>Value for *Leersia oryzoides* for NOPI (Hoffman and Bookhout 1985)

<sup>50</sup>Value for *Panicum dichotomiflorum* for MALL (Checkett et al. 2002)

<sup>51</sup>Mean of *Panicum* spp. values for all species (Sherfy 1999, Checkett et al. 2002)

<sup>52</sup>Value for *Spartina alterniflora* for ABDU (Coluccy et al. 2015)

<sup>53</sup>Mean of *Polygonum* spp. values for MALL (Hoffman and Bookhout 1985, Checkett et al. 2002)

<sup>54</sup>Mean of *Polygonum* spp. values for all species (Hoffman and Bookhout 1985, Fredrickson and Reid 1988, Sherfy et al. 2001, Checkett et al. 2002, Ballard et al. 2004)

<sup>55</sup>Mean of *Polygonum* spp. values for NOPI (Hoffman and Bookhout 1985, Ballard et al. 2004)

<sup>56</sup>Value for *Rumex crispus* (Checkett et al. 2002)

<sup>57</sup>Value for *Potamogeton* spp. for NOPI (Ballard et al. 2004)

<sup>58</sup>Value for *Ruppia maritima* for ABDU (Coluccy et al. 2015)

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Note: Preferred foods were compiled from Anderson (1959), Stewart (1962), Paulus (1982), Jorde et al. (1983), and Cramer (2009).

## Appendix B

### MORPHOMETRIC MEASUREMENTS (MM) OF DABLERS USED TO CALCULATE COST OF THERMOREGULATION (*CT*) AND DAILY ENERGY EXPENDITURE (*DEE*) OF DABBING DUCKS WINTERING ON THE DELAWARE BAYSHORE, NOVEMBER–MARCH, 2011–2013.

Measurement	Sex	ABDU		MALL		AGWT		NOPI		NSHO		AMWI		GADW	
		$\bar{x}$	SE												
Head Length [A]	M	–	–	6.50	0.44	6.50	–	6.01	0.32	5.64	0.15	6.37	0.75	5.45	–
	F	–	–	6.39	0.71	4.37	0.16	6.06	–	5.87	0.37	5.88	0.11	6.15	0.23
	Both	7.54	0.18	6.44	0.34	5.08	0.72	6.03	0.19	5.75	0.18	6.13	0.34	5.92	0.27
Head Height [B]	M	–	–	4.88	0.21	4.30	–	4.24	0.02	4.01	0.04	3.54	0.07	4.12	–
	F	–	–	4.28	0.17	3.15	0.08	4.22	–	4.01	0.10	3.87	0.04	4.05	0.26
	Both	4.38	0.11	4.58	0.25	3.54	0.39	4.23	0.01	4.01	0.04	3.71	0.10	4.07	0.15
Head Width [C]	M	–	–	3.41	0.23	4.20	–	3.48	0.30	3.18	0.20	4.06	1.12	2.59	–
	F	–	–	3.11	0.28	2.31	0.05	3.52	–	3.15	0.19	2.77	0.01	2.61	0.11
	Both	4.07	0.06	3.26	0.17	2.94	0.63	3.49	0.17	3.17	0.11	3.41	0.59	2.61	0.07
Body Width [D]	M	–	–	13.23	1.24	10.50	–	10.99	1.15	10.90	0.08	11.25	0.87	10.94	–
	F	–	–	12.64	0.23	7.84	0.23	12.21	–	11.28	0.01	9.59	0.25	9.89	0.40
	Both	13.98	0.23	12.93	0.54	8.73	0.90	11.40	0.78	11.09	0.11	10.42	0.60	10.24	0.42
Body Length [F]	M	–	–	28.75	0.25	22.00	–	28.00	0.50	21.75	0.25	22.50	1.50	28.00	–
	F	–	–	27.00	1.50	19.40	4.40	24.50	–	19.75	0.75	22.25	0.25	23.50	1.00
	Both	22.22	0.43	27.88	0.80	20.26	2.69	26.83	1.20	20.75	0.66	22.38	0.63	25.00	1.61
Body Height [G]	M	–	–	10.28	1.25	8.50	–	10.54	0.09	9.95	0.16	8.78	0.21	9.63	–
	F	–	–	9.05	0.15	6.89	0.47	9.31	–	9.92	0.57	9.11	0.48	8.15	0.67
	Both	9.53	0.21	9.67	0.62	7.43	0.60	10.13	0.41	9.93	0.24	8.95	0.23	8.64	0.63
	M	–	–	4.82	0.18	3.60	–	6.97	0.16	3.56	0.39	4.80	0.03	6.37	–

Neck Length [H]	F	–	–	4.72	0.06	2.47	0.39	4.82	–	4.57	0.27	4.31	0.71	6.17	1.07
	Both	4.99	0.11	4.77	0.08	2.85	0.44	6.25	0.72	4.07	0.35	4.55	0.32	6.23	0.62
Neck Width [I]	M	–	–	2.98	0.29	2.55	–	2.04	0.22	2.36	0.05	2.56	0.25	1.82	–
	F	–	–	2.30	0.42	2.22	0.05	1.78	–	2.44	0.09	2.14	0.01	1.80	0.08
	Both	2.04	0.08	2.64	0.29	2.33	0.11	1.95	0.15	2.40	0.05	2.35	0.16	1.80	0.05
Neck Height [J]	M	–	–	3.71	0.40	2.69	–	2.68	0.28	3.20	0.13	3.30	0.29	2.56	–
	F	–	–	3.11	0.06	2.86	0.46	3.01	–	3.38	0.48	3.23	0.06	2.45	0.38
	Both	3.60	0.17	3.41	0.24	2.81	0.27	2.79	0.20	3.29	0.21	3.26	0.12	2.49	0.22
Integument Depth Body [ $\Delta X_{\text{body}}$ ]	M	–	–	1.22	0.05	0.37	–	0.67	0.11	1.64	0.02	0.81	0.09	0.91	–
	F	–	–	0.82	0.02	0.42	0.03	0.78	–	1.48	0.21	0.87	0.11	0.82	0.14
	Both	1.46	0.07	1.02	0.12	0.40	0.02	0.71	0.07	1.56	0.10	0.84	0.06	0.85	0.08
Integument Depth Head [ $\Delta X_{\text{head}}$ ]	M	–	–	0.47	0.02	0.41	–	0.51	0.01	0.53	0.05	0.50	0.05	0.41	–
	F	–	–	0.37	0.03	0.38	0.02	0.36	–	0.54	0.15	0.49	0.04	0.46	0.08
	Both	0.78	0.05	0.42	0.03	0.39	0.02	0.46	0.05	0.53	0.07	0.49	0.03	0.44	0.05
Integument Depth Neck [ $\Delta X_{\text{neck}}$ ]	M	–	–	1.01	0.06	0.84	–	0.67	0.04	0.89	0.04	1.00	0.09	0.52	–
	F	–	–	0.67	0.08	0.73	0.01	0.81	–	0.82	0.12	0.90	0.08	0.63	0.01
	Both	0.94	0.08	0.84	0.11	0.77	0.04	0.71	0.06	0.85	0.06	0.95	0.06	0.59	0.04
$n$	M			2		1		2		2		2		1	
	F			2		2		1		2		2		2	
	Both	15		4		3		3		4		4		3	

### Appendix C

**ONE-WAY ANALYSIS OF VARIANCE (ANOVA,  $\alpha = 0.05$ ) RESULTS FOR TESTS OF SEASONAL (FALL, WINTER, SPRING) DEPLETION OF FOOD RESOURCES FOR 7 DABBLER SPECIES WINTERING ON THE DELAWARE BAYSHORE, OCTOBER–MARCH, 2011–2013.**

Habitat	ANOVA Results	Species						
		ABDU	MALL	NOPI	NSHO	AGWT	AMWI	GADW
Freshwater Impoundment	$F_{2, 234}$	0.145	0.963	0.594	0.483	0.292	0.097	0.217
	$P$	0.866	0.383	0.553	0.617	0.745	0.908	0.805
	df	236	236	236	236	236	236	236
Brackish Impoundment	$F_{2, 588}$	0.199	0.067	0.074	0.100	0.051	0.330	0.307
	$P$	0.820	0.935	0.929	0.905	0.950	0.719	0.736
	df	590	590	590	590	590	590	590
High Marsh	$F_{2, 104}$	0.015	0.176	0.308	0.066	0.301	0.333	1.649
	$P$	0.986	0.839	0.736	0.936	0.741	0.717	0.197
	df	106	106	106	106	106	106	106
Low Marsh	$F_{2, 123}$	0.954	0.517	0.215	1.288	0.466	0.989	0.090
	$P$	0.388	0.598	0.807	0.279	0.629	0.375	0.914
	df	125	125	125	125	125	125	125
Mudflat	$F_{2, 115}$	0.227	0.053	0.067	1.201	0.014	0.394	0.194
	$P$	0.797	0.949	0.935	0.305	0.986	0.675	0.824

	df	117	117	117	117	117	117	117
Subtidal	$F_{2, 109}$	0.407	0.092	0.084	0.808	0.622	0.743	0.463
	$P$	0.667	0.912	0.920	0.449	0.539	0.478	0.631
	df	111	111	111	111	111	111	111
Quasi-tidal Pool	$F_{2, 52}$	2.666	1.984	0.077	0.547	2.393	0.582	0.090
	$P$	0.079	0.148	0.926	0.582	0.101	0.563	0.914
	df	54	54	54	54	54	54	54

## Appendix D

### CANDIDATE MODELS FOR ESTIMATING DENSITY OF DABBING DUCKS WINTERING IN 3 HABITATS ON THE DELAWARE BAYSHORE, NOVEMBER–MARCH, 2011–2013.

Habitat	Model	Key Function	Series Expansion	AIC	ΔAIC
Freshwater	DIST+OBS	Half-normal	Cosine	7170.66	0.00
Impoundment	DIST+OBS	Hazard-rate	Cosine	7182.87	12.21
	DIST+OBS+WEATH	Hazard-rate	Cosine	7193.94	23.27
	DIST+PRECIP	Hazard-rate	Cosine	7194.49	23.83
	DIST+OBS+WEATH	Half-normal	Cosine	7216.18	45.52
	DIST+OBS+WEATH	Half-normal	Hermite polynomial	7216.18	45.52
	DIST+OBS	Half-normal	Hermite polynomial	7222.32	51.66
	DIST+WEATH	Half-normal	Cosine	7256.76	86.09
	DIST	Half-normal	Cosine	7282.92	112.25
	DIST	Half-normal	Hermite polynomial	7323.02	152.36
	DIST+WEATH	Half-normal	Hermite polynomial	7328.15	157.49
	DIST+WEATH	Hazard-rate	Simple polynomial	7368.27	197.61
	DIST+OBS	Hazard-rate	Simple polynomial	7374.27	203.61
	DIST+OBS+WEATH	Hazard-rate	Simple polynomial	7378.27	207.61
	* DIST	Hazard-rate	Cosine	–	–
	* DIST	Hazard-rate	Simple polynomial	–	–
Brackish	DIST	Half-normal	Cosine	12864.69	0.00
Impoundment	DIST+WEATH	Half-normal	Cosine	13091.42	226.73

	DIST+WEATH	Half-normal	Hermite polynomial	13145.52	280.83
	DIST	Half-normal	Hermite polynomial	13187.09	322.40
	DIST+WEATH	Hazard-rate	Cosine	13265.88	401.19
	DIST+WEATH	Hazard-rate	Simple polynomial	13265.88	401.19
	DIST+OBS	Hazard-rate	Cosine	13290.20	425.51
	DIST+OBS	Hazard-rate	Simple polynomial	13290.20	425.51
	DIST+OBS+WEATH	Hazard-rate	Cosine	13321.88	457.19
	DIST+OBS+WEATH	Hazard-rate	Simple polynomial	13321.88	457.19
*	DIST	Hazard-rate	Cosine	–	–
*	DIST	Hazard-rate	Simple polynomial	–	–
*	DIST+OBS	Half-normal	Cosine	–	–
*	DIST+OBS	Half-normal	Hermite polynomial	–	–
*	DIST+OBS+WEATH	Half-normal	Cosine	–	–
*	DIST+OBS+WEATH	Half-normal	Hermite polynomial	–	–
Salt Marsh	DIST	Half-normal	Hermite polynomial	7584.25	0.00
	DIST	Half-normal	Cosine	7589.46	5.21
	DIST+OBS	Hazard-rate	Cosine	7601.69	17.44
	DIST+OBS	Hazard-rate	Simple polynomial	7601.69	17.44
	DIST+OBS+WEATH	Hazard-rate	Cosine	7621.02	36.77
	DIST+OBS+WEATH	Hazard-rate	Simple polynomial	7621.02	36.77
*	DIST	Hazard-rate	Cosine	–	–
*	DIST	Hazard-rate	Simple polynomial	–	–
*	DIST+OBS	Half-normal	Cosine	–	–

* DIST+OBS	Half-normal	Hermite polynomial	—	—
* DIST+WEATH	Half-normal	Cosine	—	—
* DIST+WEATH	Half-normal	Hermite polynomial	—	—
* DIST+WEATH	Hazard-rate	Cosine	—	—
* DIST+WEATH	Hazard-rate	Simple polynomial	—	—
* DIST+OBS+WEATH	Half-normal	Cosine	—	—
* DIST+OBS+WEATH	Half-normal	Hermite polynomial	—	—

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Note: Interpret covariate abbreviations as DIST = distance (m), OBS = observer, PRECIP = precipitation. Asterisks (\*) denote models that failed to converge or produced unrealistic estimates and thus were excluded from comparison.