

**ESTIMATING HABITAT CARRYING CAPACITY FOR AMERICAN BLACK
DUCKS WINTERING IN SOUTHERN NEW JERSEY**

by

Dane Martin Cramer

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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ABSTRACT

Midwinter waterfowl survey (MWS) data indicates a long-term decline in the number of wintering American black ducks (*Anas rubripes*), potentially due to the habitat limitations. My objectives were to (1) estimate the current carrying capacity of winter black duck habitat in southern New Jersey and (2) determine the type(s) of habitat most beneficial to wintering black ducks. I estimated the supply of energy (DUD_S) during 3 sampling periods, October, January, and April, 2006-2008, using core sampling to estimate landscape biomass of seeds and invertebrates (n=1,020). I collected upper gastrointestinal tracts from hunter-killed birds and late season collections to remove the biomass of non-food items from standing landscape biomass estimates (n=64). I estimated the daily energetic requirement both allometrically and using time-energy budgets based on instantaneous scan samples (n=690). I modeled the population demand of energy (DUD_D) using MWS results for the two winters of the study and annual abundance data to determine the proportion of black ducks in the study area during each sampling period.

Estimates of DUD_S ranged from 1,666,336 (\pm SE 577,906) to 2,167,281 (\pm SE 751,640), 1,698,567 (\pm SE 689,474) to 2,209,201 (\pm SE 896,748), and 889,968 (\pm SE 303,007) to 1,157,516 (\pm SE 394,098) in October, January, and April, respectively. DUD_D ranged from 658,152 to 1,058,954, 1,994,400 to 3,208,950, and 458,712 to 738,059 in October, January, April, respectively. DUD_D exceeded DUD_S during the

January sampling period, indicating that the availability of energy may be limiting the winter population of black ducks.

My estimates of DUD_S were limited by a lack of published true metabolizable energy values for important wintering black duck foods and equipment necessary to quantify nocturnal behavior to construct time-energy budgets. Further reductions to estimates of DUD_S may be attributed to interspecific competition for resources, avoidance of developed areas resulting in an overestimate of available habitat, or the temporary suspension of food availability during winter freeze events. Future research should address limitations of this study by (1) determining TME values and a foraging threshold for important winter foods, (2) quantifying nocturnal behaviors for inclusion in time-energy budgets, (3) measuring the effects of interspecific competition, (4) determining how black ducks orient their winter home range in response to coastal development, and (5) assessing the frequency and duration of freeze events.

Mangers can increase DUD_S by (1) reducing the individual daily energetic requirement by reducing flight behavior caused by disturbance or (2) increasing the acreage or consumable biomass of habitat. Establishing refuge areas of adequate size to accommodate winter requirements of black ducks reduces individual energetic costs brought on both directly through disturbance and indirectly through time spent in transit (i.e. flight). Mudflat habitat had the greatest availability of energy exploitable by black ducks. Habitat restoration potential exists with impounded waters, salt hay

farms, and dense stands of *Phragmites australis*. Restoration efforts should focus on restoring the total function of saltmarsh habitat with mudflat habitat as a focal component.

INTRODUCTION

Research has shown that waterfowl populations are affected by the condition of wintering habitat during multiple stages of their life cycle (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1986). The availability of wintering habitat, and hence food energy, may currently be a primary factor limiting waterfowl populations. The availability of food energy may be constrained due to poor habitat quality (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1986), severe weather conditions (Bergan and Smith 1993), or anthropogenic pressures such as disturbance (Morton et al. 1989*b*). Population limitations occur not only through poor physical condition and survival during the winter (Conroy et al. 1989), but through migration and the breeding season (Heitmeyer and Fredrickson 1981, Miller 1986) as well as in subsequent years (Haramis et al. 1986).

Midwinter waterfowl survey (MWS) data indicates a long-term decline of American black ducks (*Anas rubripes*) with the greatest declines being realized in the Mississippi and southern Atlantic Flyways (North American Waterfowl Management Plan [NAWMP] Plan Committee 2004). Recent breeding ground surveys have indicated a stabilization and slight population increase of black ducks (NAWMP Plan Committee 2004). The historic loss of coastal wetlands used as wintering habitat by black ducks has been severe (Dahl 1990) and their continued degradation (Dahl 2000, Dahl 2006) may limit the ability of the habitat to support wintering waterfowl (Morton et al. 1989*a*). The link between population objectives and habitat goals is fundamental concept to restoring waterfowl populations through scientifically-based habitat conservation (NAWMP Plan Committee 2004, Runge et al. 2006).

My objective was to estimate the energetic carrying capacity of wintering black duck habitat in southern New Jersey. I built a bioenergetics model that required estimates of local habitat and food resource availability, diet information, daily energetic requirements, and habitat use for wintering black ducks. Additional winter diet information and true metabolizable energy values were gleaned from published literature. Determining whether the current availability of habitat can support winter populations will inform future habitat management goals.

STUDY AREA

I conducted research in wetland habitat in Atlantic, Cape May, Cumberland, and southern Ocean and Burlington counties in New Jersey, USA (Figure 1). All 5 wetland and deepwater systems defined by the National Wetlands Inventory (NWI) existed in this area (marine, estuarine, palustrine, lacustrine, and riverine; Cowardin et al. 1979). Estuarine habitat was of particular importance to black ducks wintering in the Atlantic Flyway (Lewis and Garrison 1984). Consequently, I limited my assessment to include all 1:24,000 quadrangles of NWI data between the NWI upstream transition from estuarine to riverine systems and downstream transition from estuarine to marine systems. This delineation allowed the inclusion of habitat from the estuarine and adjacent coastal palustrine and lacustrine systems, while excluding habitat from marine, riverine, and inland palustrine and lacustrine systems. My study area encompassed 3 million ha of wetlands defined by the NWI, 99% of which were wetlands within the estuarine system.

Within the NWI estuarine system there were 4 commonly recognized habitat types which were categorized by the tidal regime and vegetative structure of each; high marsh, low marsh, mudflats, and subtidal waters (Tiner 1987, Figure 2). High marsh habitat was above the mean high tide line and therefore irregularly flooded. High marsh habitat was populated by the *Spartina patens* plant community (Tiner 1987, Collins and Anderson 1994). Pannes and quasi-tidal pools were additional features within the high marsh habitat type. Low marsh habitat laid between the mean high and low tide lines and was therefore regularly flooded. Low marsh habitat was dominated by a single species, tall form *S. alterniflora*, which was

more salt tolerant than *S. patens* and its allies. Mudflat habitat was also regularly flooded and exposed. Mudflat habitat was characterized by the general lack of vegetation and accumulation of detritus, but could have experienced colonization by tussocks of *S. alterniflora*. Mudflat habitat occurred in two general forms: extensive flats in estuarine bays or narrow ribbons along tidal creeks and ditches exposed at low tide. Subtidal water was below the mean low tide line and was therefore irregularly exposed. Additionally, lacustrine and palustrine water bodies and wetland habitat around their margins occurred within the study area. These environs were dominated by mixed hardwood overstory (e.g. sweet gum [*Liquidambar styraciflua*], red maple [*Acer rubrum*], and American holly [*Ilex opaca*]) and shrubby understory (e.g. Highbush blueberry [*Vaccinium corymbosum*], common greenbrier [*Smilax rotundifolia*], and poison ivy [*Toxicodendron radicans*]) (Collins and Anderson 1994).

METHODS

Quantifying Habitat Use

To quantify habitat use, I captured and attached Dwyer backpack-style (Dwyer 1972) very high frequency (VHF) transmitters (Advanced Telemetry Systems, Isanti, Minnesota, USA) to female black ducks in 2006-2007. I began trapping on or about 1 December each year using various styles of swim-in funnel traps and occasionally used rocket nets baited with whole kernel and cracked corn (*Zea mays*). I trapped ducks continuously until meeting my annual objective of 40 females. Upon capture, candidate females were transported to the New Jersey Division of Fish and Wildlife (NJDFW) Nacote Creek Research Station where I weighed females to ensure that the 26 g and 30 g transmitters used in 2006 and 2007, respectively, did not exceed 3% of body mass. In 2007, transmitters were modified so that the posterior loop exited perpendicular to the transmitter, resulting in a slightly heavier transmitter. I aged females using wing feather characteristics (Ashley et al. 2006) as hatching year (HY) or after hatching year (AHY) or second year (SY) or after second year (ASY) if trapping efforts continued into the month of January. Instrumented females were held for a minimum of 6 hours to acclimate to transmitters and provided food and water *ad libitum*. The University of Delaware's Institutional Animal Care and Use Committee approved these capture and handling procedures (Approval No. 1154)

I monitored instrumented hens from the time of release through death, departure from southern New Jersey, spring departure, or 15 April. I acquired locations once or twice daily by triangulation during all 24 one-hour periods of the

day using handheld telemetry receivers and 3-element yagis (Advanced Telemetry Systems, Isanti, Minnesota, USA). I estimated receiver locations using handheld Global Positioning System (GPS) units (Magellan® eXplorist™ 100 and 210, Thales Navigation, Inc., Santa Clara, California, USA). I collected a bearing only when the GPS unit estimated precision as <10 m. I obtained >4 bearings on each bird whenever possible. I attempted to obtain bearings within 15 minutes although bearings collected within 30 minutes of each other were used to calculate estimated locations. I made periodic aerial flights to locate missing and dispersed birds. When a signal was located from the air, a location was acquired as soon as possible using ground telemetry.

I entered data into Location of a Signal v.4.0.2.2 Beta (LOAS; Ecological Software Solutions, Sacramento, California, USA), a Windows-based program that calculates an estimated location from groups of bearings. Within LOAS, I used the Andrew's M-estimator (Lenth 1981*a*, Lenth 1981*b*) with default settings and a bearing declination of -12.288 degrees, the average declination across the study area during the period between 1 December 2006 and 15 April 2008. I used all possible combinations of >3 bearings to calculate estimated locations. I discarded all combinations except the one that yielded the smallest error ellipse. In some instances, the location with the smallest error ellipse provided a suspected erroneous location (e.g. a location in the Atlantic Ocean) in which case the location with the next smallest error ellipse was used. I used a Geographic Information System (GIS; ArcMap 9.3, Environmental Systems Research Institute, Redlands, California, USA), to calculate the number of locations within each habitat type.

Estimating the Supply of Duck-Use Days

Following Reinecke et al. (1989), I estimated the *supply* of energy in terms of duck-use days (DUD_s) for wintering black ducks as:

$$DUD_s = \frac{E}{DER} \quad \text{Equation 1}$$

where E = amount of energy available on the landscape (kcal) and DER = daily energetic requirement of a black duck (kcal/bird/day).

Estimating Energy Supply (E)

I estimated E during the months of October, January, and April (hereafter referred to as sampling periods) using the following:

$$E = \sum_{h=1}^n \left[A_h \times \left(\sum_{f=1}^n (B_f \times TME_f) - FT \right) \right] \quad \text{Equation 2}$$

where A_h = available area of the h^{th} habitat type (ha), B_f = consumable biomass of the f^{th} unique food item (g/ha), TME_f = true metabolizable energy (TME) of the f^{th} unique food item (kcal/g [dry]), and FT = foraging threshold of the habitat (kcal/ha). The October sampling period occurred just prior to the arrival of wintering waterfowl, the January sampling period occurred when the peak number of waterfowl were in the area, and the April sampling period occurred just after most waterfowl were expected to migrate north (Bellrose 1980). I assumed that the estimates of E that I generated applied to a 30 d period during each specified month.

To quantify A_h , I categorized the NWI hierarchical wetland codes into 5 habitat types based on system, subsystem, class, and water regime (Table 1). Four

habitat types were generated from within the estuarine system (high marsh, low marsh, mudflat, and subtidal water) and 1 habitat type was generated from the lacustrine and palustrine systems (freshwater). Guillemain et al. (2000) showed that mallards (*Anas platyrhynchos*) can forage in water depths up to 35 cm deep. NWI wetland codes provided no way to discriminate between shallow subtidal and freshwater areas where black ducks could forage and deep water areas where they could not. Using only NWI codes to identify the availability of these two habitat types led to overestimations of available habitat. To estimate the amount of subtidal water available to foraging black ducks, I used the Atlantic City digital elevation model (DEM; Taylor et al. 2007) to discern the amount of subtidal habitat between the -1 m contour of the DEM and the transition from emergent marsh (i.e. high marsh or low marsh) to subtidal water identified by NWI. To estimate the amount of freshwater habitat ≤ 35 cm deep, I assumed that freshwater bodies were bowl-shaped and measured the distance perpendicular to the shoreline from the water's edge to the point where water depth was 35 cm. I made this measurement in 10 equal segments around the perimeter of 4 freshwater bodies ($n = 40$) starting from a random point and applied this average inside buffer width to NWI freshwater habitat. I considered the entirety of engineered freshwater impoundments available in lieu of recent bathymetry work at Edwin B. Forsythe National Wildlife Refuge (EBFNWR) suggesting that water depth is ≤ 35 cm during the winter (K. S. Holcomb, United States Fish and Wildlife Service, unpublished data). I applied this consideration to freshwater impoundments on EBFNWR and Tuckahoe Wildlife Management Area.

To estimate B_f , I sampled 85 random points across all 5 habitat types annually. In 2006-07 the distribution of samples reflected the proportion of available habitat according to NWI classification resulting in a large number of high marsh samples (Table 2). Conversely, in 2007-08 the distribution of samples reflected the use of habitats for foraging resulting from direct field observations collected during the previous year. I generated random points and located them in the field using a handheld GPS unit when the unit estimated precision to <10 m. At each location I established a permanent sampling point with a 1.2 m long piece of flagged reinforcing bar. In each sampling period, I collected a pair of core samples (51 mm in diameter and 120 mm in depth) at 2 m and 20 m from each sampling point in randomly selected directions. Habitat within the estuarine system: intertidal subsystem was highly variable. Individual core samples from a single sampling point were often not consistent with the habitat type that the sampling point was assigned to by NWI data. For this reason, I assumed individual core samples from a single sampling point were independent and recorded the actual habitat type of individual core samples to reduce variation within habitat specific biomass estimates. The actual habitat type was assigned based on the vegetative structure of the majority of the 1-m² area surrounding the core sample. I used habitat assessments from the 2 m samples collected during the October 2006 and 2007 sampling periods (n=128) to assemble correctness and redistribution percentages for NWI habitat classifications. For example, I found NWI “low marsh” samples only had the vegetative structure of low marsh 68% of the time with the remaining portion being comprised of 8% high marsh and 24% mudflat.

In the laboratory, I refrigerated samples for <3 days before sieving them with clean water through No. 10 (2 mm) and No. 35 (500 μ m) screens. During October 2006, 10 samples (4 high marsh, 4 low marsh, and 2 freshwater) were frozen but this method of storage was discontinued out of concern that invertebrate integrity might be adversely affected. I was unable to test for differences between storage techniques because the number of core samples affected with measurable masses was too small (n=12). Despite the potential adverse affects, these samples were used in analysis. Sieved material was placed in a 150 mL specimen storage cup, fixed with 10% formalin buffer solution, and stained with Rose Bengal for a minimum of 7 d. Prior to sorting the material, I washed samples twice with clean water. I identified seeds to Genus or species whereas I identified invertebrates to the lowest taxonomic level possible, usually Class, Order, Family, or more specifically when possible. For quality control, the first 10 samples completed by a technician and subsequently every third sample processed was redone by an experienced technician, albeit less intensively, to ensure that potential food items were not consistently being missed. Usually within 5 samples, new technicians missed very few seed or invertebrate items and subsequent checks rarely contained missed items. I dried seeds and invertebrates in an oven at 50-55°C for 48 hours and then weighed each sample. Samples with masses of seeds and invertebrates <0.0001 g were recorded as zeros.

Approximately one half of the sorted samples collected during the 2006-2007 field season were initially divided into seeds and invertebrates and then stored in 70% ethanol prior to identification. Although Anderson and Smith (1999) used this method, there was concern that invertebrate integrity might be adversely affected. I

discontinued storage in ethanol and subsequently dried and weighed samples directly after sorting. Because 2 different methods were used in the first year, I tested the null hypotheses that storing invertebrates or seeds into ethanol prior to identification would not adversely affect their weights. I examined biomass samples of invertebrates and seeds collected from high marsh habitat (where the greatest number of samples were taken) and in the month of October (when approximately half the samples were stored in ethanol). Of samples with weights of seeds and invertebrates >0 , I found no treatment effect (t-test assuming equal variances [separately tested for with Levene's test for equality of variances]) either with seeds ($t_{50}=0.368$, $P=0.714$) or invertebrates ($t_{45}=0.450$, $P=0.655$). Therefore, these samples were included in the final analysis.

To refine my biomass estimates of available energy, I removed potential food items that did not occur on a list of food taxa for wintering black ducks. I formulated a list of food taxa by collecting upper gastrointestinal (GI) tracts from 45 hunter-harvested black ducks during the open hunting season and 19 targeted late season collections by NJDFW personnel during the closed season. Upper GI tracts were frozen until the contents could be sorted and identified. I sorted contents to the same taxonomic level described for core samples. Because I was compiling a taxa list of consumed foods and not an abundance or frequency measurement, I included all identifiable contents of both the proventriculus and the gizzard (see Baldassarre and Bolen 1994). I supplemented my taxa list with a literature review of foods that black ducks were documented to consume along the unglaciated coastal marsh ($n=40$, Costanzo and Malecki 1989; $n=50$, B. Lewis, Southern Illinois University-Carbondale, unpublished thesis; Appendix A). The inclusion of items too large to be consumed or

accidentally ingested items would lead to an overestimate of available energy. I established criteria to determine whether potential food items from core samples were included. I first removed the biomass of bivalves which were too large to be consumed by black ducks. Upper GI contents were used to establish the maximum consumable size of bivalves. Secondly, because some items (e.g. Annelids) were very abundant, they may have been accidentally ingested. Because the winter black duck diet is comprised of approximately 93% animal foods and minor variations existed across the 3 studies, I conservatively included only those animal foods (almost exclusively invertebrates with the exception of *Fundulus* spp.) recognized in 2 of the 3 sources of diet information to account for accidental ingestion. Conversely, I included all seeds recognized among the 3 sources because seeds make up a small portion of the winter black duck diet in the study area (Costanzo and Malecki 1989).

To determine values for TME_f , I conducted a literature review of published TME values (Appendix B). Whenever possible, I used species-specific TME values for food items. In instances where there were multiple TME values, I used an average of all values. In instances where TME values for a specific food item did not exist, I used the value for the closest related taxon or an average of TME values from the closest related level of taxonomic classification so that all food items were included in the summation of available energy.

I used the Reinecke et al. (1989) FT of 50 kg/ha for rice (*Leersia oryzoides*) in the Mississippi Alluvial Valley. I chose this estimate because it is the most conservative estimate of FT available and little research has addressed a threshold for non-crop foods (although see Naylor 2002 for moist-soil seeds) and none

for invertebrate foods. To convert the foraging threshold units from mass per area to energy per area, I multiplied 50 kg/ha by the average published TME value I obtained for rice (2.94 kcal/g, Appendix C), producing a foraging threshold of 147,000 kcal/ha.

I summarized E following Equation 2 for each sampling period during both years. I tested for differences among habitat type and sampling period using an Analysis of Variance (ANOVA, $\alpha \leq 0.10$) with the main effects and interaction of habitat types and sampling period. I used protected Tukey's post hoc tests to identify significant variables within the ANOVA ($\alpha \leq 0.10$). I chose an $\alpha \leq 0.10$ because previous studies in similar habitats using similar methods (e.g. DiBona 2007, B. Lewis, Southern Illinois University-Carbondale, unpublished thesis) identified large amounts of variation. Therefore, this level of significance is more likely to detect statistical significance when a biologically significant trend exists (Tacha et al. 1982).

Estimating Daily Energy Requirement (DER)

I utilized two methods that are available for researchers to estimate DER ; however, each method has its limitations. Most recently, Miller and Eadie (2006) presented an allometric method, hereafter DER_1 , which predicts an average resting metabolic rate given a correlational relationship with body mass. DER_1 allows managers to estimate the energetic demand with little labor investment and can do so for multiple species of waterfowl (e.g. Heitmeyer 1989, Bishop and Vrtiska 2008). However, it does not allow for changes in behavioral responses to external variation (e.g. temperature, tide, time of day, month of year, latitude, harvest pressure, disturbance, etc.) that are known to influence both daily activities and DER (Weathers

1979, Albright et al. 1983, Brodsky and Weatherhead 1985). To account for external variations affecting *DER*, researchers can also assemble time-energy budgets, hereafter *DER*₂, based on instantaneous scan samples to determine the percentage of time individuals spend in different behavioral states (Paulus 1988). *DER*₂ is labor intensive and time consuming and assumes random observability, which is currently limited to diurnal scan samples (Jorde and Owen 1988b). Each method of *DER* produced a unique value of *DUD*_S (Equation 1). I used the two values to produce an estimated range of *DUD*_S.

I estimated *DER*₁ using the following:

$$DER_1 = aMass^b \times 3 \quad \text{Equation 3}$$

where *a* = mass proportionality coefficient, *Mass* = body mass (kg), and *b* = slope of the regression line on a log scale (Miller and Eadie 2006). Collectively, the *aMass*^{*b*} expression predicts the resting metabolic rate (RMR) of a waterfowl (kcal/bird/day) and 3 is the multiple of RMR used to represent *DER* (Prince 1979). Terms *a* and *b* were for the group “dabbling ducks” (*a* = 457, *b* = 0.77; Miller and Eadie 2006). I used a sample of black ducks (n = 140; 26 SY-M, 35 SY-F, 55 ASY-M, 25 ASY-F) trapped in the study area in January 2009 to estimate *Mass* as 1167.8 g (± SE 11.1) (T.C. Nichols, New Jersey Division of Fish and Wildlife, unpublished data).

I reproduced the methods used by Albright et al. (1983) to estimate *DER*₂ using the following:

$$DER_2 = \sum_{i=1}^n [((RMR \times a_i) + CT) \times T_i] \quad \text{Equation 4}$$

where RMR = average RMR (kcal/bird/h) predicted in Equation 3 (Miller and Eadie 2006), a_i = activity specific multiple of RMR for the i^{th} behavioral activity, CT = cost of thermoregulation at a specified temperature (kcal/bird/h), and T_i = time engaged in the i^{th} behavioral activity (h). I used the values estimated by Wooley (1976) for a_i which were 1.2 for sleeping and loafing, 1.7 for feeding and walking, 2.1 for comfort, 2.2 for swimming and agonistic, 2.4 for courtship, and 12.5 for flying. Albright et al. (1983) derived various values for CT from Wooley (1976). I chose the CT at 5°C of 1.4 kcal/bird/h because the average daily temperature observed in Atlantic City, New Jersey, USA between 1 December and 15 April 2006-2008 was 5.3°C (NOAA, National Climatic Data Center). I was unable to use a specific value of CT for each sampling period because the October sampling period occurred prior to the arrival of wintering black ducks. To estimate T_i , I conducted instantaneous scan samples (Altmann 1974) from ½ hour before sunrise to ½ hour after sunset in all 5 habitat types between 1 December and 15 April 2006-2008 using binoculars and/or spotting scopes. I was unable to collect any nocturnal observations because night vision equipment proved ineffective under most field conditions. Given this limitation, I assumed that diurnal and crepuscular observations were representative of the entire 24-hour period to calculate DER_2 . Once I located a group of birds, a 10-minute acclimation period followed. I scanned the group every 15 minutes for a one-hour period or until the group of birds left. I assumed that the scans collected every 15 minutes on the same group of birds (≤ 4 scans) were not independent of each other and averaged them together to avoid pseudoreplication. I dictated bird behaviors into a micro-cassette recorder as feeding, loafing, sleeping, swimming, flying, walking,

comfort, agonistic, or courtship (Albright et al. 1983, Morton et al. 1989b). Although Michot et al. (2006) stated that flying may not be well represented by scan sampling methods, this activity remains very energetically demanding (Wooley 1976). Therefore, I included this activity in scans rather than collectively forming a locomotion category (i.e. walk, swim, and fly) to attempt to account for some of this energetic cost. For each behavioral scan, I recorded the temperature, wind speed, tidal stage, and habitat type. I used Osczevski and Bluestein (2005) to calculate wind chill for each set of scans based on field conditions. To examine the effects of the independent variables (temperature, calculated wind chill, tide, and habitat type) on the dependent variables (time spent in each respective behavior), I used an ANOVA for each behavior ($\alpha \leq 0.05$) with temperature and wind chill as covariates and tide and habitat type as fixed factors. I used protected Tukey's post hoc tests to identify if tide and habitat type affected mean percent time in each behavior ($\alpha \leq 0.05$).

Estimating the Demand of Duck-Use Days

To estimate the energetic *demand* placed on the landscape (DUD_D) for each sampling period, I used the following equation:

$$DUD_D = (MWS \times p) \times 30 \quad \text{Equation 5}$$

where MWS = black ducks counted during the MWS in the study area and p = average proportion of the winter population present in the study area for each sampling period. Collectively, the term $(MWS \times p)$ estimates the number of ducks on the landscape each day. The constant, 30, is used to scale the demand to the month level (i.e. DUD_D per month). To estimate MWS , I used the MWS results for black ducks counted in New

Jersey's zones 2 and 3, flight segments 11 through 29 (i.e. those corresponding to the study area) from 2007 and 2008. To estimate p , I assembled migration graphs using the relative abundance from volunteer bird surveys compiled by eBird (2009) from sites in Atlantic, Cape May, and Cumberland counties, 2000-2009. I verified the values I attained using state waterfowl surveys flown during the months of November and March in conjunction with MWS results, 1992-1995 (T.C. Nichols, New Jersey Division of Fish and Wildlife, unpublished data) and migration chronology graphs from Bellrose (1980). I estimated DUD_D for each sampling period for the two survey years to produce an estimated range of DUD_D . Comparing ranges of DUD_D to DUD_S allowed me to highlight possible surpluses and/or deficiencies in the ability of the landscape to supply necessary energetic requirements to wintering black ducks over the three time periods.

RESULTS

Habitat Use

I captured and attached VHF transmitters to 42 females (12 HY, 26 AHY, 4 SY) in 2006-07 and 44 females (19 HY, 20 AHY, 5 SY) in 2007-08. Transmitters represented 2.3% and 2.5% of the mean body mass of instrumented females in 2006-2007 and 2007-08, respectively. I was able to estimate 2,295 locations in habitats considered available to foraging black ducks (Table 3). Female black ducks were located most often in high marsh (78%) and subtidal (14%) habitats. Freshwater (6%), low marsh (2%), and mudflat (<1%) habitat made up the balance.

Estimated Supply of Duck-Use Days

Estimated E

The NWI estimated 3 million ha of wetland habitat among the 5 habitat types in the study area. This was comprised of 87,308 ha of high marsh, 848 ha of low marsh, 919 ha of mudflat, 2,903,779 ha of subtidal water and 5,453 ha of freshwater habitats. For habitats types within the estuarine system: intertidal subsystem, the percent correctness and redistribution percentages resulted in drastic changes in the amount of available habitat considered available to foraging black ducks. I found that high marsh habitat identified by NWI was correct 75% of the time, was low marsh 21%, and mudflat 4%. Low marsh habitat was correctly identified 68% of the time, was high marsh 8%, and mudflat 24 %. Mudflat habitat was correctly identified 70% of the time, was high marsh 14%, and low marsh 16 %. My

redistribution of habitat within the estuarine system: intertidal subsystem estimated 65,678 ha of high marsh, 19,058 ha of low marsh and 4,339 ha of mudflat habitats. The NWI estimated there to be 2,903,779 ha of subtidal water which I reduced to 9,994 ha \leq 1 m in depth using the NWI delineation and the Atlantic City DEM. I estimated the average distance from the water's edge to the point where water depth was 35 cm to be 7.62 m (SE=1.16 m) in freshwater habitats. The NWI estimated 5,453 ha of freshwater habitat which I reduced to 1,948 ha using my inside buffer width estimate. In total, I estimated 101,017 ha of habitat considered available to foraging black ducks.

I collected 1,020 core samples to estimate the standing landscape biomass (Figure 3a). The supply of energy was influenced mainly by the biomass of invertebrates and very little by the biomass of seeds (Table 4). Core samples identified 30 invertebrate taxa, 1 vertebrate taxon, and 54 seed taxa. Of these, I identified only 13 taxa of invertebrates and 23 taxa of seeds as consumable foods (Appendix A). Only one invertebrate food item, Malacostraca: Decapoda: *Palaemonetes* spp., occurred in 2 of the 3 sources of diet information while all other incorporated food items occurred in all three sources (Appendix A). The largest bivalve from an upper GI tract was a 21.4 mm long ribbed mussel (*Geukensia demissa*). Removal of bivalves too large to be consumed greatly reduced the apparent availability of energy (Figure 3b). The further removal of non-food items resulted in less drastic changes but further reductions in the availability of energy (Figure 3c). Non-food items primarily consisted of Annelids and their removal had the greatest impact on subtidal and mudflat habitat. Annelids were abundant on these habitats but were found only in

trace amounts in one upper gastrointestinal tract. My literature search identified TME values for all consumable foods (Appendix B). Rationale for TME values assigned to the food items included in my energy estimates are found in Appendix C.

I found that habitat type impacted E ($F_{4,1005} = 2.19$, $P = 0.068$) while sampling period and the interaction between habitat type and sampling period did not ($F_{2,1005} = 0.25$, $P = 0.777$ and $F_{8,1005} = 0.41$, $P = 0.917$, respectively). Estimated E was higher in mudflat habitat than high marsh habitat ($P = 0.033$), while no other habitat comparisons were significant.

Estimated DER

I estimated DER_1 as 369.0 kcal/bird/day (95% CI 283.2–478.9) and DER_2 as 283.7 kcal/bird/day (95%CI 255.0-312.5). DER_2 was formulated based on 690 instantaneous scan samples. Behavior was affected little by wind chill and temperature (with the exception of comfort and walking behaviors; Table 5). Habitat type affected time spent in feeding, loafing, sleeping, comfort, swimming, and walking behaviors ($F_{4,665} > 6.52$, $P < 0.01$). Tide affected time spent swimming and walking ($F_{3,665} > 2.83$, $P < 0.04$; Table 5). Black ducks foraged greatest in subtidal and mudflat habitat ($P \leq 0.05$, Figure 4a-b). Foraging behavior decreased across freshwater, low marsh, and high marsh habitats (Figure 4c-e). Loafing and sleeping behaviors had a corresponding increase in these habitat types. The habitat*tide interaction affected feeding behavior (Table 5). Black ducks generally foraged more intensively during low tide in subtidal and mudflat habitat than during any tide in high marsh habitat ($P \leq 0.05$; Table 6). Foraging was also greater during an ebb tide on

mudflat habitat that during high, ebb, and flood tides in high marsh habitat ($P \leq 0.05$; Table 6).

I estimated 18,446,443,684 (\pm SE 6,397,451,978), 18,803,242,523 (\pm SE 7,632,517,909), and 9,852,000,512 (\pm SE 3,354,300,410) kcal of energy available during October, January, and April, respectively. This resulted in 1,666,336 (\pm SE 577,906), 1,698,567 (\pm SE 689,474), and 889,968 (\pm SE 303,007) DUD_S available during October, January, and April, respectively, using DER_1 and 2,167,281 (\pm SE 751,640), 2,209,201 (\pm SE 896,748), and 1,157,516 (\pm SE 394,098) DUD_S , respectively, using DER_2 (Figure 5).

Estimated Demand of Duck-Use Days

During the 2007 and 2008 MWS, 66,480 and 106,965 black ducks were counted in the study area, respectively, to estimate MWS (USFWS MBDC 2008). I estimated p to be 0.33, 1.00, and 0.23 during the months of October, January, and April, respectively. Data obtained from eBird (2009) generally closely agreed with state waterfowl surveys and published migration graphs. Despite comparisons varying slightly between years and survey timing, winter surveys showed the highest numbers of black ducks in the study area. Fall surveys had one-third to one-half as many birds as winter surveys. Spring surveys had one-third to one-quarter as many birds as winter surveys. These values produced estimates of 658,152, 1,994,400, and 458,712 DUD_D demanded during October, January, and April 2006-07, respectively, and 1,058,954, 3,208,950, and 738,059 DUD_D demanded during October, January, and April 2007-08, respectively (Figure 5).

DISCUSSION

Based on my estimates, the current demand for energy is very near the threshold that the landscape can supply (Figure 5). Demand most nearly exceeds the range of supply during the January sampling period and does exceed the supply estimated by DER_1 during this time. While the population of black ducks in the study area was most limited by energetic resources during the January sampling period, the overall supply of energy was lowest during the April sampling period (Figure 5). Although I was unable to detect a statistically significant difference due to the variation in estimates of E , my estimates likely represent a biologically significant trend (Tacha et al. 1982). Other studies have shown that the availability of energy during spring periods is lower than fall and/or winter periods (Naylor 2002, DiBona 2007, Straub 2008). Additionally, similar amounts of variation had been reported using similar methods for estimating E (DiBona 2007, Kross et al. 2008, Straub 2008, B. Lewis, Southern Illinois University-Carbondale, unpublished thesis).

Morton et al. (1989b) suggested that nocturnal and diurnal behaviors of wintering black ducks differ and telemetry data by Costanzo (1988) indicated that they use different habitats nocturnally. The time-energy budgets I constructed to estimate DER_2 were limited to observations of black ducks during the diurnal and into crepuscular periods. If black ducks are making nocturnal movements and are engaged in different behaviors nocturnally, it is possible that my estimates of DER_2 are underestimates because they did not identify flight behavior between habitats. This would lead to further reductions in my estimates of DUD_S and further deficiency of resources during the January sampling period. This is a particularly important time of

year when it is thought that black ducks move between areas of refuge and forage in response to hunting pressure and freeze events (Conroy et al. 1987).

Telemetry results should be received with caution due to the inaccuracies of NWI data identified previously and the inherent limitations of VHF telemetry. Telemetry results located black ducks on mudflat habitat <1% of the time. This conflicts with results of habitat sampling and behavioral observations indicating that the availability of energy and foraging behavior were most prevalent on mudflat habitat. This is likely resulted from the failure of NWI to identify the presence of mudflat habitat due to its small patch size and the inability of telemetry to locate birds in the narrow ribbons of this habitat type. Although I was able to correct the NWI data for habitat core sampling, it is likely not a sufficient data layer for evaluating telemetry locations at this scale.

The majority of studies focus on quantifying the abundance of seeds as foods for wintering and migrating waterfowl for energetics modeling and conservation planning. The winter black duck diet in the estuarine ecosystem is made up largely of invertebrate foods (Mendall 1949, Hartman 1963, Jorde and Owen 1988*a*, Costanzo and Malecki 1989). As a result, my estimates were hampered by a lack of published TME values for important winter black duck food items (Appendix A vs. Appendix B). Additionally, I was unable to locate a foraging threshold specific to invertebrate food items. Comparisons of my results to studies investigating seed abundance in different habitats (e.g. managed moist-soil impoundments, playas, forested wetlands, etc.) have limited utility.

My estimates of seed biomass were generally far less than published values for managed wetland habitats with the exception of seed biomass in the freshwater habitat type that were similar but varied considerably. The biomass of potential food items consisted of a much larger proportion of invertebrate biomass than seed biomass (Table 4). My invertebrate biomass estimates for subtidal, high marsh, and low marsh habitats during all sampling periods were slightly less than those reported by DiBona (2007) for tidal habitat in the Hackensack Meadowlands of New Jersey. In contrast, my invertebrate biomass estimates for mudflat habitat were 3.6 to 11 times greater depending on the sampling period. My seed biomass estimates were much less than those reported by DiBona (2007) with the exception of freshwater habitat estimates.

The considerable overlap of supply and demand observed during all sampling periods suggests that the landscape may be limiting the current population of black ducks. The 2007 MWS count was below the 5-year mean (75,190 black ducks) whereas the 2008 MWS count was well above it. In my estimates of supply and demand, the below average count did not exceed the supply whereas the above average count did. This provides support for the conclusions of Conroy et al. (2002) that the availability of winter habitat may be limiting. Considering my estimates, this limitation occurs between the January and April sampling periods. This notion is supported by observations of black duck mortality with regard to resource availability during the winter (Reinecke et al. 1982, Conroy et al. 1989).

My results probably represent overestimates of DUD_S . Further decreases in DUD_S are caused by interspecific competition for resources, avoidance of

developed areas resulting in an overestimate of available habitat, and the temporary suspension of food availability during winter freeze events. These factors most likely occur in an additive fashion, resulting in further separation of DUD_D and DUD_S ranges and deficiency of food resources during the winter.

Black ducks are the most abundant dabbling duck (Anatidae) in the study area, comprising approximately 80% annually. Mallards and green-winged teal (*Anas crecca carolinensis*) are the second and third most abundant dabbling ducks although the rank changes annually (USFWS MBDC 2008). Pöysä (1986) and Pöysä et al. (1994) showed that different species separate themselves into foraging niches. Despite this, considerable niche overlap and an increase in demand are reasonable assumptions. If the remaining dabbling ducks in the study area forage on the same foods, have the same DER, and the proportion of individuals present during the sampling periods is the same, it would result in a 25% reduction in available food for black ducks. Rails (Rallidae), herons (Ardeidae), and other marine organisms would lead to further increases in demand. These groups would however have less niche overlap than other dabbling ducks and minimal impact during the winter months. Considering only additional dabbling ducks, DUD_S is further reduced by 193,694 to 207,108, 586,950 to 627,600, and 134,999 to 144,348, in October, January, and April, respectively. This leads to a reduced surplus during October and April and a deficiency in January.

My estimates of E included all available wetland habitats within the estuarine system among the 4 habitat types. Although the entirety of this area may be available, it is likely not all used by black ducks (Johnson 1980). Waterfowl often

avoid developed areas because of perceived danger resulting from increased levels of disturbance (Madsen 1995, Gill et al. 2001). Most waterfowl species observed by McKinney et al. (2006) were more abundant in areas of less adjacent residential development. Black ducks require habitats free from disturbance (Lewis and Garrison 1984, Morton et al. 1989b, Longcore et al. 2000). There is currently no metric available to apply to developed areas to determine the acreage that may go unused. Knowing how black ducks orient their winter home ranges around developed areas should be a research priority to accurately estimate the quantity of habitat included in bioenergetics modeling, thus preventing overestimates of DUD_S . Removal of avoided areas can have considerable impacts in coastal areas where development is prevalent.

Freeze events with extensive ice have the potential to temporarily reduce or suspend the availability of food resources (i.e. DUD_S plummets to near zero; Albright et al. 1983, Jorde and Owen 1988a, Jorde et al. 1989). Jorde et al. (1989) noted that periods of extreme cold lead to weight loss and was a cause of winter black duck mortality. During freeze events when food resources are limited or unavailable, birds rely solely on reserves of lipids (Albright et al. 1983, Baldassare and Bolen 1994). Reinecke et al. (1982) estimated the reserves of wintering female black ducks to be approximately 1,000-1,100 kcal for adults and 500-600 kcal for juveniles. Using my estimates of DER , females would have between 2.8 and 3.9 survival days for adults and 1.4 and 2.1 survival days for juveniles using DER_1 and DER_2 , respectively. Albright et al. (1983) estimated 4.5 and 2.5 survival days for adult and juvenile female black ducks, respectively, during periods of resource limitation brought on by extensive ice cover. Conroy et al. (1989) found that the survival rates of juvenile

female black ducks was lower than adults and suggested that management activities may be able to focus on the recruitment of juveniles into the next age class. Data for the periodicity and duration of these freeze events is currently unavailable but may be derived from mean daily temperature data (M. Gerbush, Rutgers University, personal communication). Population models should account for the periodicity of freeze events due to their potential to limit critical segments of the population on the winter grounds.

My results suggest that deficiencies in the availability of energy are currently limiting the wintering population of black ducks in southern New Jersey. This supports the conclusions of Conroy et al. (2002) regarding the loss in quantity and quality of winter habitat. Managers can increase the carrying capacity of habitat within the estuarine system along two avenues: decreasing *DER* by reducing disturbance or increasing A_h and/or B_f by acquiring habitat or enhancing existing habitat.

Flight is often elicited in response to disturbance (Morton et al. 1989b, Gill et al. 2001). While some authors have questioned behavioral changes as an indicator of disturbance vulnerability (Gill 2007), flight remains approximately 6 times more costly than any other behavior (Albright et al. 1983, Fredrickson and Reid 1988). I only observed black ducks engaged in flight behavior for 3% of the diurnal period. A hypothetical 50% reduction in flight leads to an 8.8% increase in DUD_s for the black ducks I observed. Although quantifying disturbance was not one of my objectives, I recorded 71 disturbance events and their causes during my scan samples (n=690). Flight was the primary response to disturbance which resulted most often

from automobiles (n=20), unknown causes (n=16), avian predators (n=10), and pedestrians (n=9). I was less likely to observe birds where hunting pressure was prevalent. As a result, I did not record any disturbance events that resulted from hunting activities. This may have misrepresented the amount of disturbance due to hunting. Regardless of the type of disturbance, the scan sampling technique is considered to be negatively biased in its ability to quantify flight behavior (Michot et al. 2006). Because flight behavior may be underestimated, a similar 50% reduction in flight behavior could potentially produce larger increases in DUD_S . This is particularly important if black ducks make nocturnal movements in order to avoid disturbance, specifically hunting.

Increasing the amount of available habitat or enhancing the energetic production of current habitat also leads to increases in carrying capacity. There is less potential for increasing the amount of habitat and more potential for enhancing existing poor quality habitat. Mudflat habitat had the greatest amount of energy available specific to foraging black ducks during all sampling periods (Figure 6). Black ducks foraged most intensively on mudflat habitat (Figure 4a). Enhancement efforts should focus on maintaining ecologically functioning mudflat habitat. DiBona (2007) showed that the availability of energy was less at tidally restricted sites than at tidally unrestricted sites. Restoring full tidal exchange and range to habitats increases the intertidal zone, and hence the amount of mudflat habitat (Boumans et al. 2002). Habitats with the greatest potential for enhancement include salt hay farms and impounded waters (Hinkle and Mitsch 2005), as well as areas dominated by invasive *Phragmites australis* (Roman et al. 1984).

MANAGEMENT IMPLICATIONS

My research identified a deficiency in the supply of duck-use days (DUD_S) during the January sampling period, highlighting a possible limitation to black ducks during the wintering segment of their annual cycle. Managers can increase DUD_S by (1) reducing individual daily energetic requirements (DER) by reducing flight behavior caused by disturbance and/or (2) increasing the availability (A_h) and/or the consumable biomass (B_f) of winter black duck habitat.

Flight is the most costly behavior (Albright et al. 1983, Fredrickson and Reid 1988) and the most often elicited response to disturbance (Morton et al. 1989b, Gill et al. 2001). Reductions in disturbance directly reduce DER by reducing flight in response to disturbance and indirectly by reducing flight time between refuge areas and foraging habitats that black ducks avoid as a result of disturbance. The most frequent anthropogenic disturbances I observed were automobiles and pedestrians. Managers should establish refuge areas that minimize disturbance and supply adequate energy by providing undisturbed loafing and feeding areas in close proximity to each other. If refuge areas lack adequate energy, they should be situated on the landscape in a manner that reduces flight time between refuge areas and foraging habitats.

Mudflat habitat had the greatest availability of energy exploitable by black ducks. The acquisition and enhancement of habitat should focus on ecologically functioning saltmarsh habitat with an emphasis on mudflat habitat. Restoring full tidal range and flow to formerly tidally restricted areas has the highest potential for creating ecologically functioning saltmarsh and mudflat habitat. Impoundments, salt hay

farms (Hinkle and Mitsch 2005), and dense stands of *Phragmites australis* (Roman et al. 1984) can be reverted to saltmarsh/mudflat by removing impeding devices (e.g. tide gates and dikes; Boumans et al. 2002). Allowing full tidal range and flow increases the intertidal zone, and hence, mudflat ribbons along tidal creeks and ditches. This in turn promotes the growth of native plant species (e.g. *Spartina* spp.) and the invertebrate communities associated with them. Restoration of salt hay farms and marshes dominated by *Phragmites australis* stands has been successfully accomplished in the Delaware Bay and are reviewed by Teal and Peterson (2005).

Future research should address limitations of this study by (1) determining TME values and a foraging threshold for important winter foods, (2) quantifying nocturnal behaviors for inclusion in time-energy budgets, (3) measuring the effects of interspecific competition, (4) determining how black ducks orient their winter home range in response to coastal development, and (5) assessing the frequency and duration of freeze events.

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Table 1. Habitat types formed using NWI hierarchical classification scheme. Freshwater and subtidal water habitat types were further reduced using an inside buffer and the Atlantic City DEM, respectively, to estimate the amount of shallow water habitat available to foraging black ducks.

Habitat type	NWI hierarchical classification scheme				Example Code
	System	Subsystem	Class	Water Regime	
High marsh	Estuarine (E)	Intertidal (2)	Emergent wetland (EM1)	Irregularly flooded (P)	E2EM1P
Low marsh	Estuarine (E)	Intertidal (2)	Emergent wetland (EM1)	Regularly flooded (N)	E2EM1N
Mudflat	Estuarine (E)	Intertidal (2)	Unconsolidated shore (US)	Regularly flooded (N)	E2USN
Subtidal	Estuarine (E)	Subtidal (1)	Unconsolidated bottom (UB)	Subtidal (L)	E1UBL
Freshwater	Palustrine (P), Lacustrine (L)	-----	-----	-----	PUB, L2

Table 2. Number of core samples (2 core samples per sampling point) collected from each habitat type during each sampling period among years. In 2006-07 the distribution of sampling points reflected the proportion of available habitat according to NWI classification. In 2007-08 the distribution of sampling points reflected the use of habitats for foraging from instantaneous scan samples collected in 2006-07.

Habitat Type	2006-07			2007-08				
	Sampling Points	Core Samples Collected			Sampling Points	Core Samples Collected		
		October	January	April		October	January	April
High marsh	51	81	67	77	20	31	37	39
Low marsh	10	36	43	37	20	47	41	37
Mudflat	7	19	26	22	20	42	42	44
Subtidal	9	18	18	18	13	26	26	26
Freshwater	8	16	16	16	12	24	24	24
Total	85	170	170	170	85	170	170	170

Table 3. Telemetry locations from 86 female black ducks wintering in southern New Jersey, December through April, 2006-2008.

Habitat Type	Study Area (ha)	Study Area (%)	Locations	Locations (%)
Subtidal	9,994	10%	312	14%
High marsh	65,678	65%	1,785	78%
Low marsh	19,058	19%	53	2%
Mudflat	4,339	4%	11	0.5%
Freshwater	1,948	2%	134	6%
Total	101,017		2,295	

Table 4. Biomass of invertebrates and seeds (kg/ha) by habitat type and sampling period in southern New Jersey, October January, and April, 2006-2008. The supply of energy was influenced mainly by the biomass of invertebrates and very little by the biomass of seeds.

Habitat Type		October		January		April	
		\bar{x}	SE	\bar{x}	SE	\bar{x}	SE
Invertebrates	Subtidal	1,033.5	1,008.1	26.5	25.4	142.6	94.5
	Freshwater	0.5	0.5	0.5	0.3	3.0	2.1
	High marsh	75.4	27.3	133.8	56.2	23.3	6.6
	Low marsh	110.1	56.1	105.1	43.1	147.6	68.7
	Mudflat	735.3	465.8	2,181.4	1,994.2	793.4	720.0
Seeds	Subtidal	80.5	78.3	11.7	8.4	52.2	44.9
	Freshwater	252.6	51.4	402.9	94.6	419.2	111.1
	High marsh	18.3	9.8	5.9	2.6	11.0	4.2
	Low marsh	4.4	3.0	4.7	2.2	6.9	5.2
	Mudflat	1.7	1.7	5.7	5.7	0.6	0.6

Table 5. The effects of tide, habitat, and habitat*tide interaction on time spent in each respective black duck behavior, southern New Jersey, December through April, 2006-2008. Table summarizes results of analysis of variance (ANOVA) with a total error degrees of freedom = 687.

Behavior	Corrected Model (df=21)		Habitat (df=4)	Tide (df=3)	Habitat * Tide (df=12)
	F-stat	p-value	p-value	p-value	p-value
Feeding	5.258	0.000	0.000	0.063	0.033
Loafing	2.903	0.000	0.000	0.333	0.158
Sleeping	3.030	0.000	0.000	0.222	0.803
Comfort	3.551	0.000	0.000	0.551	0.635
Agonistic	0.793	0.730	0.926	0.939	0.370
Flying	1.089	0.354	0.072	0.327	0.991
Swimming	3.039	0.000	0.000	0.024	0.976
Walking	5.305	0.000	0.000	0.035	0.310
Courtship	0.459	0.982	0.790	0.836	0.926

Table 6. Matrix of Tukey’s post hoc tests results on the effect of the habitat*tide interaction on feeding behavior. Matrix indicates comparison between row interactions against column interactions. For example, “.002” in row 3 column 2 indicates that feeding behavior in subtidal habitat during low tide was significantly higher than feeding behavior in subtidal habitat during an ebb tide. Non-significant p-values have been omitted.

		Subtidal				High marsh				Low marsh				Mudflat			Freshwater						
	Tide	n	high	ebb	low	flood	high	ebb	low	flood	high	ebb	low	flood	high	ebb	low	flood	high	ebb	low	flood	
Subtidal	high	52																					
	ebb	57																					
	low	90		.002			.000	.000	.000	.000	.006									.000			
	flood	61																					
High marsh	high	36																					
	ebb	57																					
	low	44																					
	flood	47																					
Low marsh	high	39																					
	ebb	18																					
	low	27																					
	flood	10																					
Mudflat	high	11																					
	ebb	16					.037	.012		.043													
	low	37					.004	.000	.006	.003										.008			
	flood	15																					
Freshwater	high	22																					
	ebb	21																					
	low	22																					
	flood	8																					

Figure 1. Map of study area, Cumberland, Cape May, Atlantic, and southern Ocean and Burlington counties, New Jersey, USA used to estimate energetic carrying capacity for American black ducks October, January, and April 2006-2008.

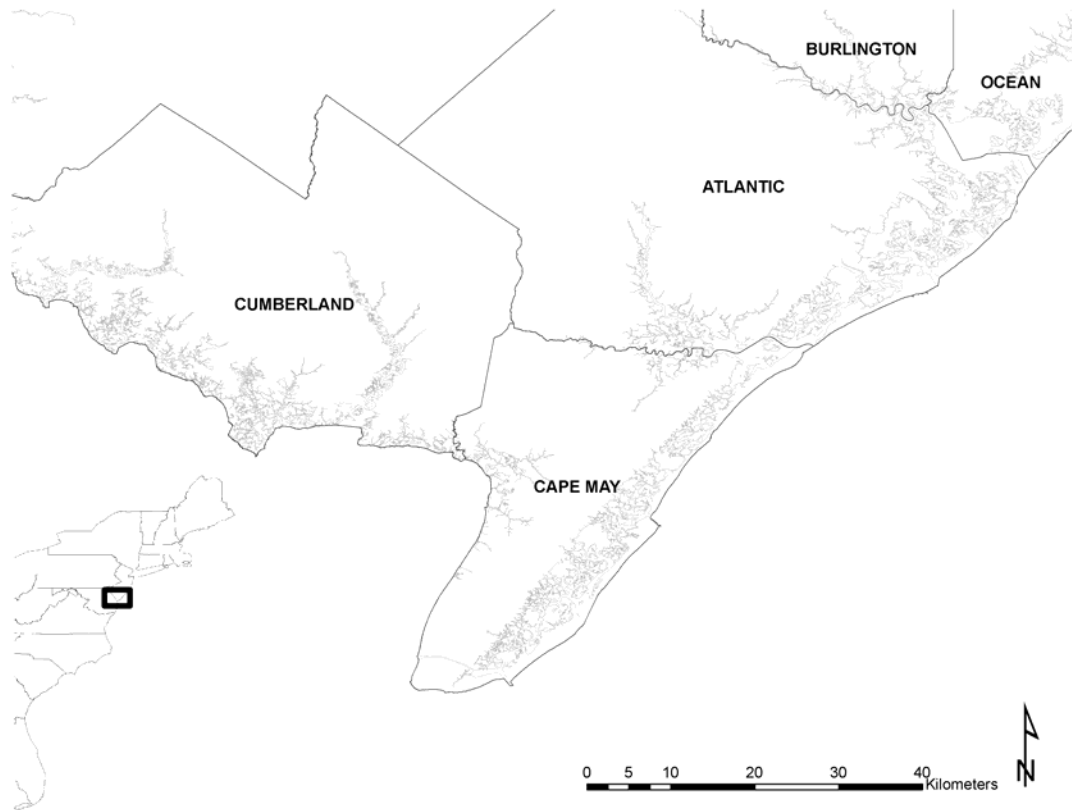


Figure 2. Basic structure of 4 habitat types within the NWI estuarine system defined by the tidal regime and characterized by their associated vegetative structure or lack thereof.

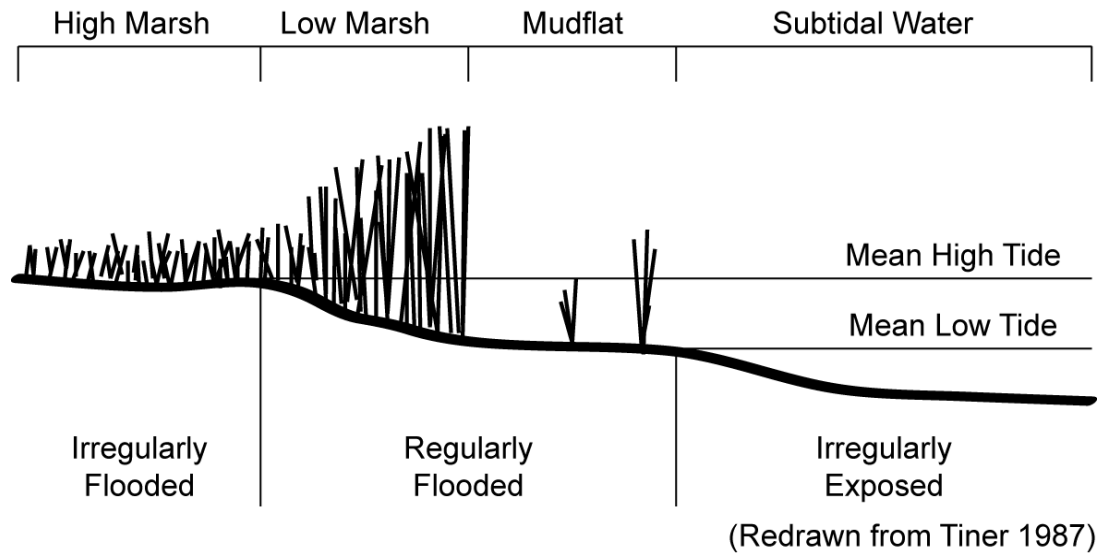


Figure 3. Total landscape biomass estimates (a), landscape biomass estimates with bivalves too large to be consumed by black ducks removed (b), and landscape biomass estimates with bivalves too large to be consumed and non-food items removed (c) by habitat type per sampling period ($\bar{x} \pm SE$), southern New Jersey, October, January, and April, 2006-2008.

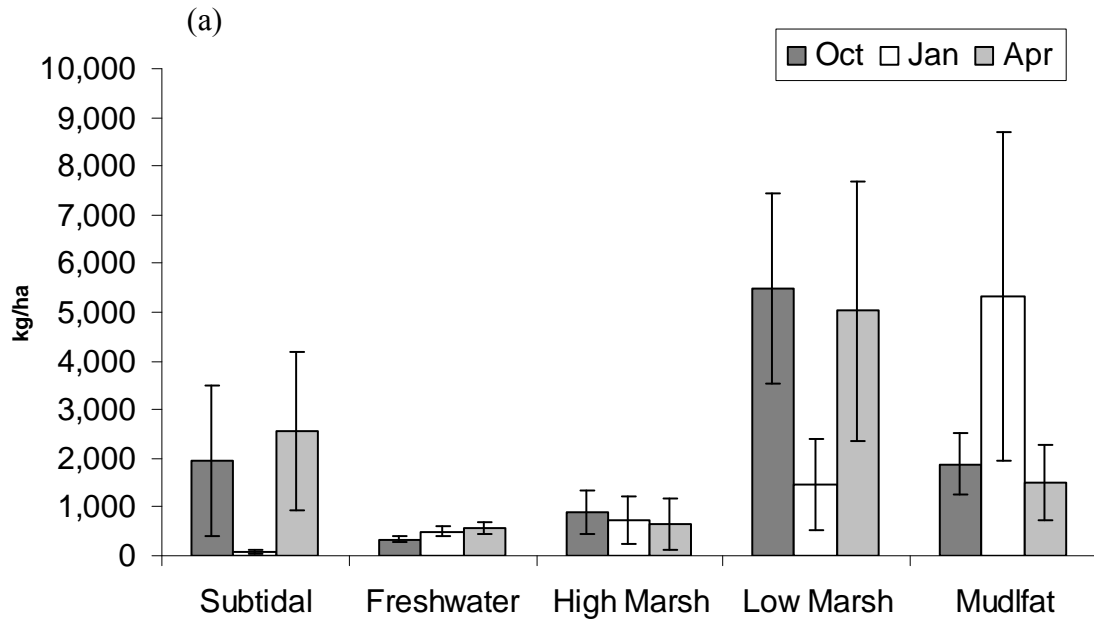


Figure 3. (cont.)

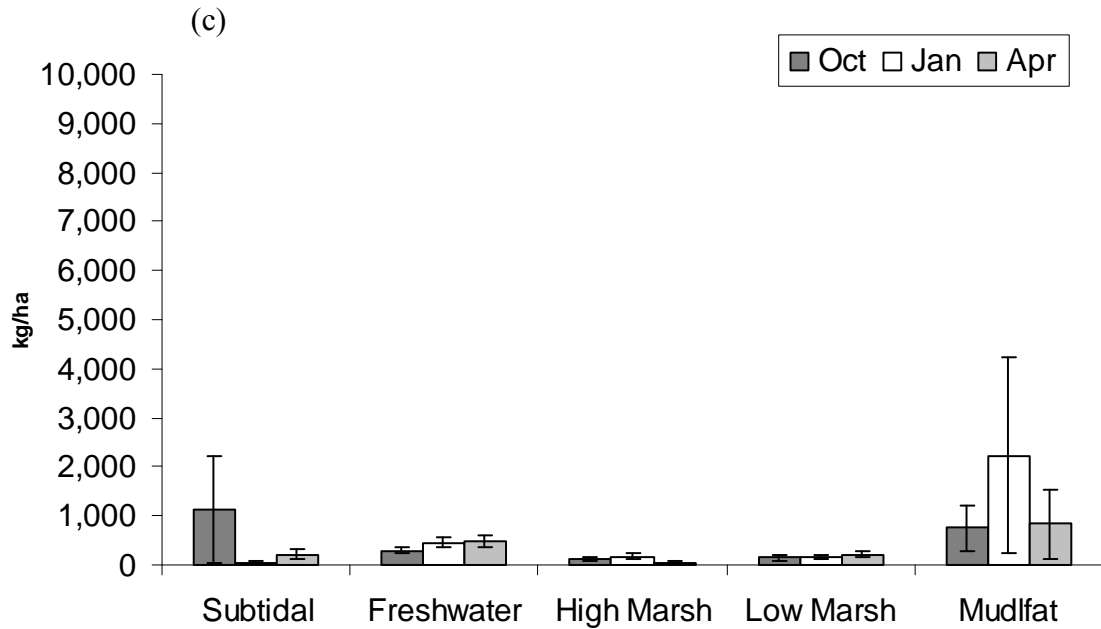
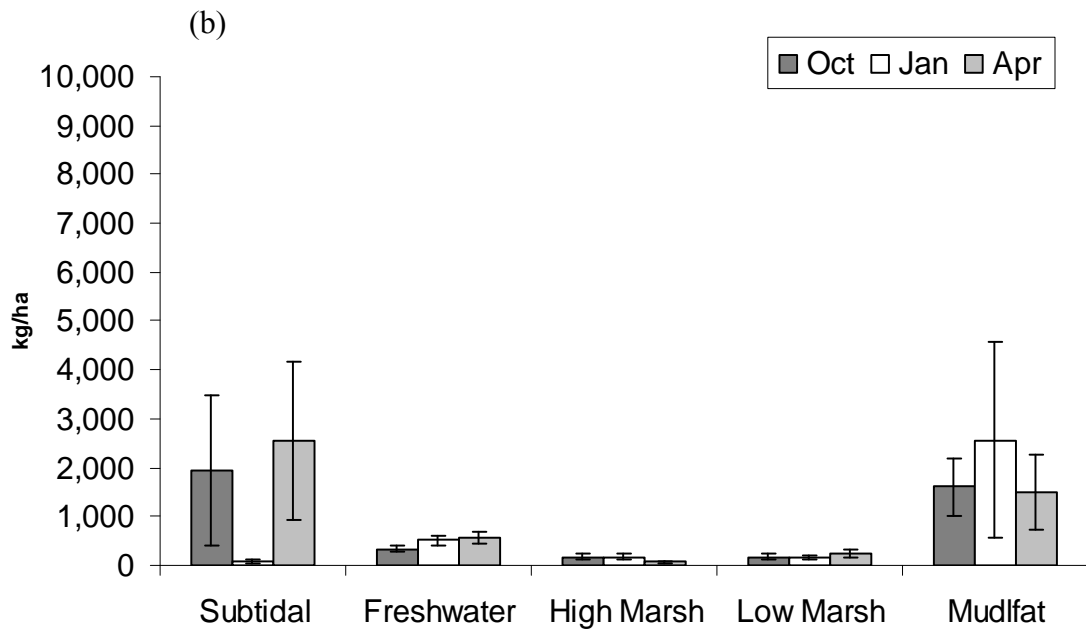


Figure 4. Mean (\pm SE) percent of black ducks observed in various behaviors in (a) mudflat (n=79), (b) subtidal (n=260), (c) freshwater (n=73), (d) low marsh (n=94), and (e) high marsh (n=184) habitats, southern New Jersey, December through April, 2006-2008.

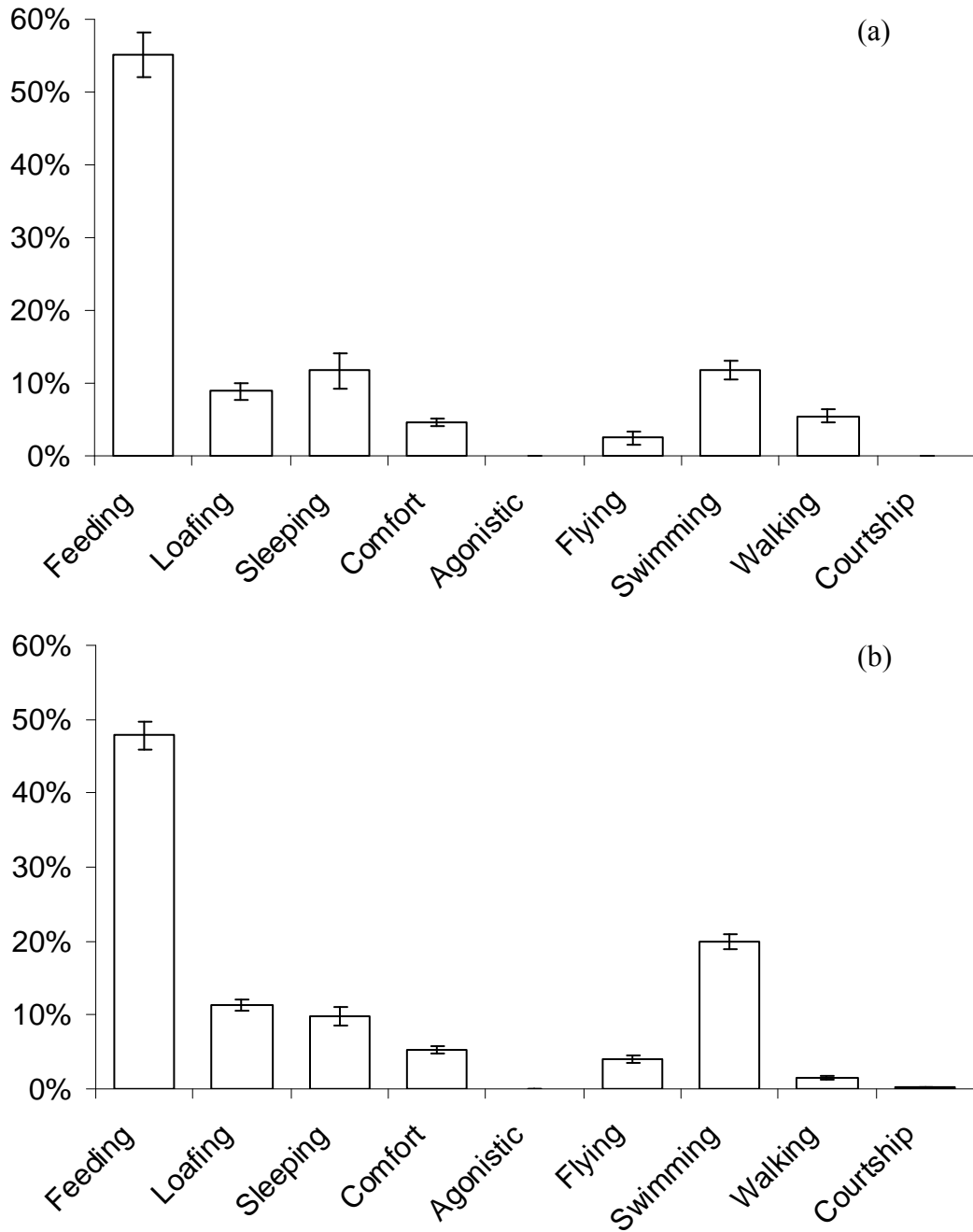


Figure 4. (cont.)

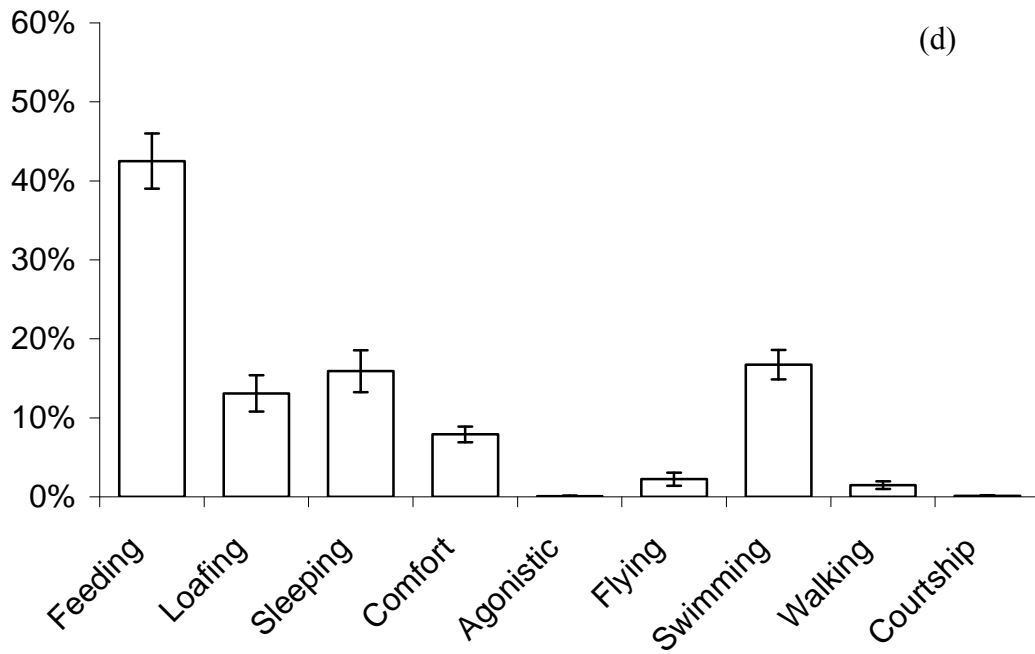
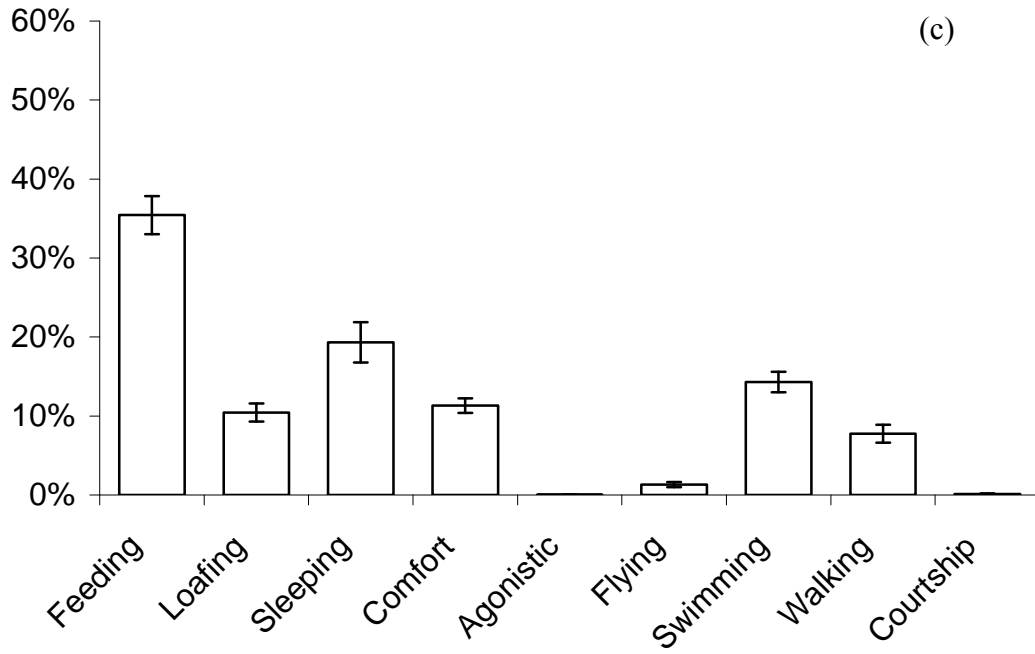


Figure 4. (cont.)

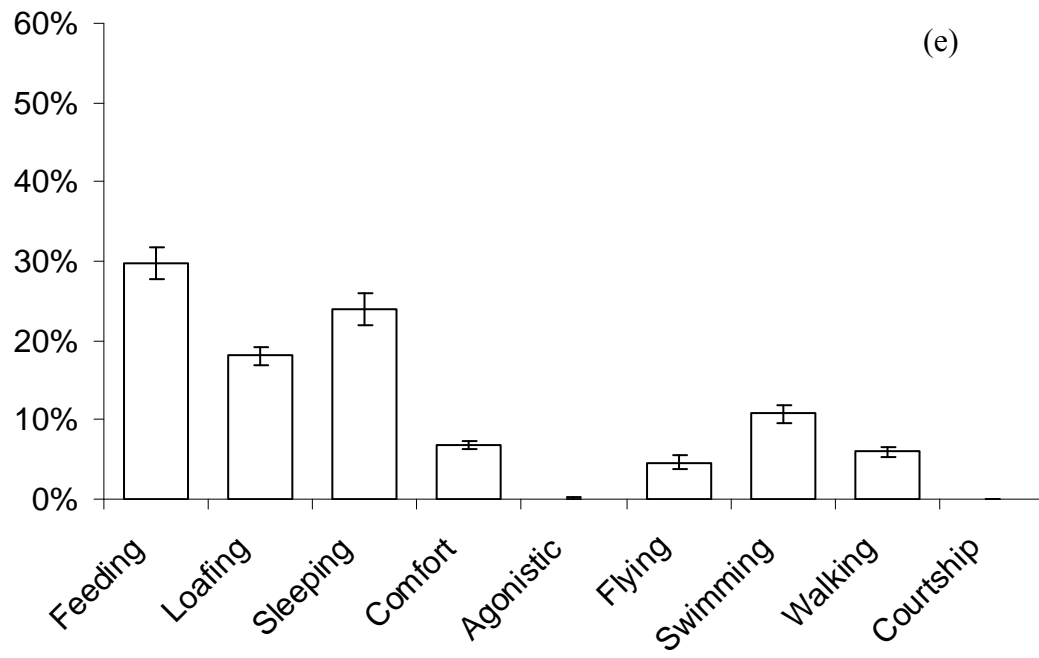


Figure 5. Estimated ranges of DUD_S and DUD_D for American black ducks wintering in southern New Jersey, USA, 2006-2008. DUD_S ($\bar{x} \pm SE$) are represented by the solid region and DUD_D by dotted-hollow region. Energy is most limited during the January sampling period when the population demand is greatest.

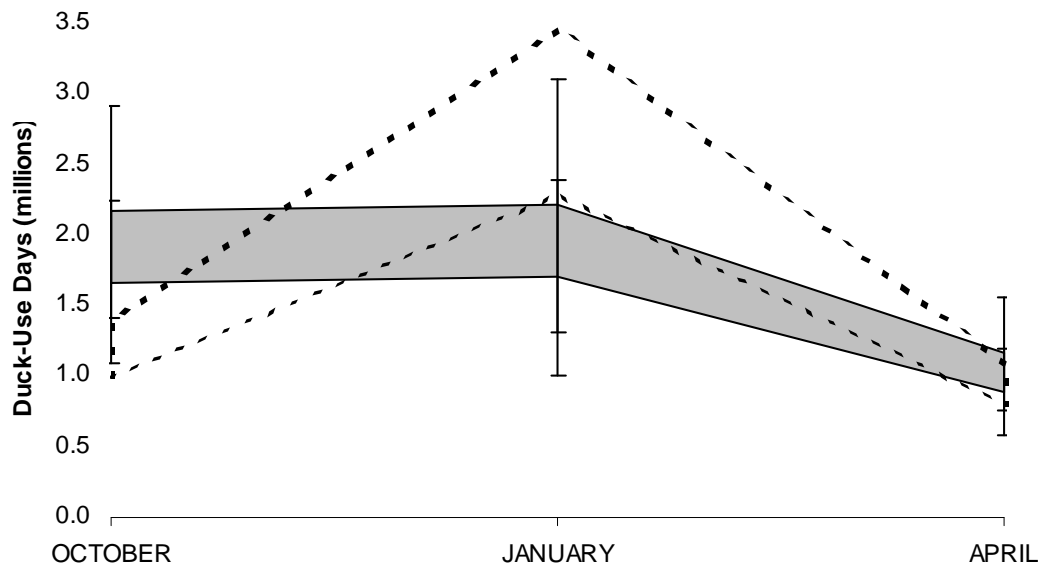
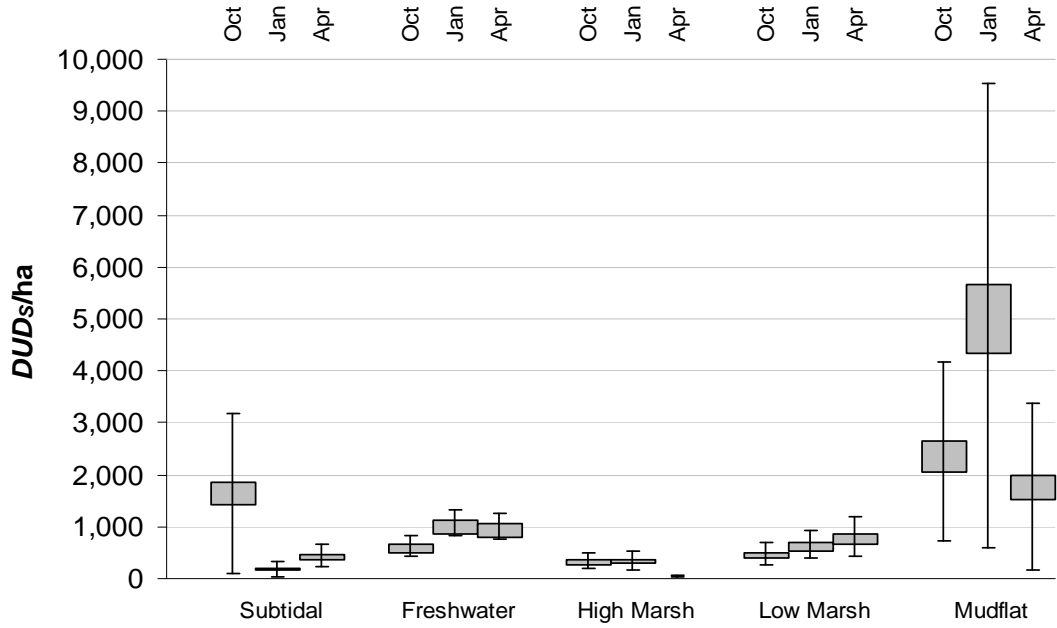


Figure 6. Mean (\pm SE) potential supply of energy (i.e. DUD_s) by habitat type and sampling period gained for each hectare of specified habitat, southern New Jersey, October, January, and April, 2006-2008.



APPENDIX A. WINTER BLACK DUCK FOODS ALONG THE UNGLACIATED SALTMARSH.

	This study (n=64)	Costanzo and Malecki (1989) (n=40)	B. Lewis, unpublished thesis ^b (n=50)	Included based on criteria?
Animal material				
Actinopterygii: Cyprinodontiformes: <i>Fundulus</i> spp.	X	X	X	Yes
Arachnida	X			No
Bivalvia	X	X		Yes
Bivalvia: Mytiloidea: <i>Geukensia demissa</i> (<21.7 mm)	X	X	X	Yes
Bivalvia: Mytiloidea: <i>Mytillus edulus</i>		X	X	Yes
Bivalvia: Veneroidea: Veneridae	X	X	X	Yes
Gastropoda: Pulmonata: <i>Melampus bidentatus</i>	X	X	X	Yes
Gastropoda: Sorbeoconcha: <i>Hydrobia</i> spp.	X	X	X	Yes
Gastropoda: Sorbeoconcha: <i>Nassarius obsolete</i>	X			No
Hirudinea	X			No
Insecta	X			No
Insecta: Coleoptera	X	X		Yes
Insecta: Diptera	X	X		Yes
Insecta: Odonata: Anisoptera		X		No
Malacostraca: Amphipoda: <i>Gammarus</i> spp.	X	X	X	Yes
Malacostraca: Decapoda: Brachyura		X		No
Malacostraca: Decapoda: <i>Palaemonetes</i> spp.		X	X	Yes
Malacostraca: Decapoda: <i>Uca</i> spp.	X	X	X	Yes
Malacostraca: Isopoda	X	X	X	Yes
Oligochaeta	X			No
Polychaeta: <i>Polychaete</i> spp. and <i>Nereis</i> spp.		X		No

Plant material^a

Alismataceae: <i>Sagittaria</i> spp.			X	Yes
Aquifoliaceae: <i>Ilex opaca</i>	X			Yes
Asteraceae: <i>Aster</i> spp.	X			Yes
Asteraceae: <i>Sonchus asper</i>	X			Yes
Brassicaceae: <i>Brassica</i> spp.	X			Yes
Cannabaceae: <i>Humulus japonicas</i>	X			Yes
Chenopodiaceae: <i>Salicornia</i> spp.	X	X		Yes
Convolvulaceae: <i>Ipomoea</i> spp.			X	Yes
Cyperaceae: <i>Carex</i> spp.			X	Yes
Cyperaceae: <i>Eleocharis parvula</i>		X		Yes
Cyperaceae: <i>Schoenoplectus americanus</i>	X		X	Yes
Fabaceae: <i>Vicia</i> spp.	X			Yes
Filamentous algae		X	X	N/A ^c
Juncaceae: <i>Juncus</i> spp.	X			Yes
Miscellaneous foliage		X		N/A ^c
Oxalidaceae: <i>Oxalis</i> spp.	X			Yes
Phytolaccaceae: <i>Phytolacca Americana</i>	X			Yes
Poaceae: <i>Panicum</i> spp.	X		X	Yes
Poaceae: <i>Spartina alterniflora</i>	X	X	X	Yes
Poaceae: <i>Spartina alterniflora</i> vegetation	X			N/A ^c
Polygonaceae: <i>Eriogonum</i> spp.			X	Yes
Polygonaceae: <i>Polygonum</i> spp.	X	X	X	Yes
Rosaceae: <i>Photinia melanocarpa</i>	X			Yes
Ruppiaceae: <i>Ruppia maritima</i> vegetation		X	X	N/A ^c
Ulvaceae: <i>Ulva lactuca</i> vegetation	X	X	X	N/A ^c

^aSeeds unless otherwise specified.

^bAmounts <5 g were excluded.

^cNon-applicable. Algae and vegetation were excluded from habitat samples.

APPENDIX B. PUBLISHED TME VALUES FOR ANIMAL AND SEED FOODS.

Food Item	TME (kcal/g)	Test Species ^a	Source
ANIMAL			
Actinopterygii: Clupeiformes: <i>Clupea harengus</i>	0.66	GBHE	Bennett and Hart 1993
Actinopterygii: Perciformes: <i>Scomber scombrus</i>	0.87	GBHE	Bennett and Hart 1993
Actinopterygii: Salmoniformes: <i>Oncorhynchus mykiss</i> ^b	0.87	GBHE	Bennett and Hart 1993
Bivalvia: Myoida: <i>Mya arenaria</i>	0.93	ABDU	Jorde and Owen 1988a
Bivalvia: Mytiloidea: <i>Mytilus edulis</i>	1.23	ABDU	Jorde and Owen 1988a
Bivalvia: Veneroidea: <i>Mulinia lateralis</i>	0.00	NOPI	Ballard et al. 2004
Crustacea: Anomopoda: Daphniidae	0.82	BWTE	Fredrickson and Reid 1988
Gastropoda	0.60	NOPI	Ballard et al. 2004
Gastropoda	-0.09	BWTE	Sherfy 1999
Gastropoda: Pulmonata: Lymnaeidae	0.59	BWTE	Fredrickson and Reid 1988
Gastropoda: Pulmonata: <i>Littorina</i> spp.	0.60	ABDU	Jorde and Owen 1988a
Insecta: Diptera: Chironomidae	0.27	BWTE	Sherfy 1999
Insecta: Hemiptera: Corixidae	0.48	BWTE	Sherfy 1999
Malacostraca: Amphipoda	0.33	BWTE	Sherfy 1999
Malacostraca: Amphipoda: <i>Gammarus</i> spp.	2.32	BWTE	Fredrickson and Reid 1988
Malacostraca: Amphipoda: <i>Gammarus</i> spp.	2.36	NOPI	Ballard et al. 2004
Malacostraca: Amphipoda: <i>Gammarus oceanicus</i>	2.32	ABDU	Jorde and Owen 1988a
Malacostraca: Decapoda: <i>Uca</i> spp.	1.90	WHIM	Zwarts and Blomert 1990
Malacostraca: Isopoda	0.08	BWTE	Sherfy 1999

SEED

Alismataceae: <i>Sagittaria latifolia</i>	3.06	MALL	Hoffman and Bookhout 1985
Amaranthaceae: <i>Amaranthus</i> spp.	2.97	MALL	Checkett et al. 2002
Asteraceae: <i>Bidens cernua</i>	0.55	BWTE	Sherfy 1999
Brassicaceae: <i>Lepidium latifolium</i>	1.31	MALL	Dugger et al. 2007
Chenopodiaceae: <i>Chenopodium album</i>	2.52	MALL	Dugger et al. 2007
Cyperaceae: <i>Cyperus esculentus</i>	1.96	BWTE	Sherfy 1999
Cyperaceae: <i>Eleocharis obtusa</i>	-0.18	BWTE	Sherfy 1999
Cyperaceae: <i>Eleocharis palustris</i>	0.50	MALL	Dugger et al. 2007
Cyperaceae: <i>Fimbristylis annua</i>	0.49	BWTE	Sherfy 1999
Cyperaceae: <i>Rhynchospora corniculata</i>	1.86	MALL	Checkett et al. 2002
Cyperaceae: <i>Schoenoplectus maritimus</i>	0.65	MALL	Dugger et al. 2007
Cyperaceae: <i>Schoenoplectus tabernaemontani</i>	0.99	MALL	Hoffman and Bookhout 1985
Cyperaceae: <i>Schoenoplectus tabernaemontani</i>	0.85	NOPI	Hoffman and Bookhout 1985
Cyperaceae: <i>Scirpus (Schoenoplectus) americanus</i>	0.64	BWTE	Sherfy 1999
Cyperaceae: <i>Scirpus (Schoenoplectus) pungens</i>	0.50	BWTE	Sherfy 1999
Fabaceae: <i>Vicia ervilia</i>	3.18	GALL	Farran et al. 2001
Fabaceae: <i>Vicia sativa</i>	2.93	GALL	Farran et al. 2001
Juncaceae: <i>Juncus canadensis</i>	1.21	BWTE	Sherfy 1999
Poaceae: <i>Digitaria ischaemum</i>	3.10	MALL	Checkett et al. 2002
Poaceae: <i>Digitaria sanguinalis</i>	3.09	MALL	Checkett et al. 2002
Poaceae: <i>Echinochloa crus-galli</i>	2.61	MALL	Checkett et al. 2002
Poaceae: <i>Echinochloa crus-galli</i>	2.99	UNK (♀)	Fredrickson and Reid 1988
Poaceae: <i>Echinochloa crus-galli</i>	2.63	UNK (♂)	Fredrickson and Reid 1988
Poaceae: <i>Echinochloa crus-galli</i>	3.29	CAGO	Petrie et al. 1999
Poaceae: <i>Echinochloa crus-galli</i>	2.65	BWTE	Sherfy 1999
Poaceae: <i>Echinochloa crus-galli</i>	2.67	BWTE	Sherfy et al. 2001

Poaceae: <i>Echinochloa walteri</i>	2.86	MALL	Hoffman and Bookhout 1985
Poaceae: <i>Echinochloa walteri</i>	2.82	NOPI	Hoffman and Bookhout 1985
Poaceae: <i>Leersia oryzoides</i>	3.00	UNK (♂)	Fredrickson and Reid 1988
Poaceae: <i>Leersia oryzoides</i>	3.00	MALL	Hoffman and Bookhout 1985
Poaceae: <i>Leersia oryzoides</i>	2.82	NOPI	Hoffman and Bookhout 1985
Poaceae: <i>Panicum dichotomiflorum</i>	2.75	MALL	Checkett et al. 2002
Poaceae: <i>Panicum dichotomiflorum</i>	2.54	BWTE	Sherfy 1999
Poaceae: <i>Panicum virgatum</i>	2.05	BWTE	Sherfy 1999
Poaceae: <i>Paspalum laeve</i>	1.57	MALL	Checkett et al. 2002
Poaceae: <i>Setaria lutescens</i>	2.88	MALL	Checkett et al. 2002
Poaceae: <i>Spartina patens</i>	0.05	BWTE	Sherfy 1999
Poaceae: <i>Zizania aquatica</i>	3.47	BWTE	Sherfy 1999
Polygonaceae: <i>Polygonum lapathifolium</i>	1.52	MALL	Checkett et al. 2002
Polygonaceae: <i>Polygonum pensylvanicum</i>	1.10	DABB (♀)	Fredrickson and Reid 1988
Polygonaceae: <i>Polygonum pensylvanicum</i>	1.12	DABB (♂)	Fredrickson and Reid 1988
Polygonaceae: <i>Polygonum pensylvanicum</i>	1.08	MALL	Hoffman and Bookhout 1985
Polygonaceae: <i>Polygonum pensylvanicum</i>	1.25	NOPI	Hoffman and Bookhout 1985
Polygonaceae: <i>Polygonum pensylvanicum</i>	1.59	CAGO	Petrie et al. 1998
Polygonaceae: <i>Polygonum pensylvanicum</i>	1.30	BWTE	Sherfy et al. 2001
Polygonaceae: <i>Rumex crispus</i>	2.68	MALL	Checkett et al. 2002

^aSpecies abbreviations: ABDU=*Anas rubripes*, BWTE=*Anas discors*, CAGO=*Branta canadensis*, DABB=unknown dabbling duck (Anatidae: Anatinae), GALL=*Gallus gallus*, GBHE=*Ardea herodias*, LESC=*Athya affinis*, MALL=*Anas platyrhynchos*, NOPI=*Anas acuta*, UNK=unknown duck, WHIM=*Numenius phaeopus*

^bAverage of gutted and ungutted

APPENDIX C. RATIONALE FOR TME VALUES USED FOR ANIMAL AND SEED FOODS.

Food Item	TME (kcal/g)	Rationale
ANIMAL		
Actinopterygii: Cyprinodontiformes: <i>Fundulus</i> spp.	0.82	average of published TME values for Class Actinopterygii
Bivalvia	0.72	average of published TME values for Class Bivalvia
Bivalvia: Veneroida: Veneridae	0.72	average of published TME values for Class Bivalvia
Bivalvia: Mytiloidea: <i>Geukensia demissa</i> (<21.7 mm)	1.23	TME value for Bivalvia: Mytiloidea: <i>Mytilus edulus</i>
Gastropoda	0.43	average of published TME values for Class Gastropoda
Gastropoda: Sorbeoconcha: <i>Hydrobia</i> spp.	0.43	average of published TME values for Class Gastropoda
Gastropoda: Pulmonata: <i>Melampus bidentatus</i>	0.43	average of published TME values for Class Gastropoda
Insecta: Coleoptera	0.38	average of published TME values for Class Insecta
Insecta: Diptera	0.27	TME value for Insecta: Diptera: Chironomidae
Malacostraca: Amphipoda	1.83	average of published TME values for Order Amphipoda
Malacostraca: Decapoda	0.96	average of TME values of Class Malacostraca
Malacostraca: Decapoda: <i>Uca</i> spp.	1.90	TME value for Malacostraca: Decapoda: <i>Uca</i> spp.
Malacostraca: Isopoda	0.08	TME value for Order Isopoda
SEED		
Aquifoliaceae: <i>Ilex opaca</i>	1.96	average of published seed TME values
Asteraceae: <i>Aster</i> spp.	0.55	TME value for Asteraceae: <i>Bidens cernua</i>
Asteraceae: <i>Sonchus asper</i>	0.55	TME value for Asteraceae: <i>Bidens cernua</i>
Brassicaceae: <i>Brassica</i> spp.	1.31	TME value for Brassicaceae: <i>Lepidium latifolium</i>
Cannabaceae: <i>Humulus japonicus</i>	1.96	average of published seed TME values
Chenopodiaceae: <i>Salicornia</i> spp.	2.52	TME value for Chenopodiaceae: <i>Chenopodium album</i>
Convolvulaceae: <i>Ipomoea</i> spp.	1.96	average of published seed TME values

Cyperaceae: <i>Schoenoplectus americanus</i>	0.64	TME value for Cyperaceae: <i>Schoenoplectus americanus</i>
Cyperaceae: <i>Carex</i> spp.	0.83	average of TME values for Cyperaceae
Cyperaceae: <i>Eleocharis parvula</i>	0.41	average of TME values for Cyperaceae: <i>Eleocharis</i> spp.
Fabaceae: <i>Vicia</i> spp.	3.06	average of TME values for Fabaceae: <i>Vicia</i> spp.
Juncaceae: <i>Juncus gerardii</i>	1.21	TME value for Juncaceae: <i>Juncus canadensis</i>
Oxalidaceae: <i>Oxalis</i> spp.	1.96	average of published seed TME values
Phytolaccaceae: <i>Phytolacca americana</i>	1.96	average of published seed TME values
Poaceae: <i>Spartina alterniflora</i>	0.05	TME value for Poaceae: <i>Spartina patens</i>
Poaceae: <i>Panicum</i> spp.	2.45	average of TME values for Poaceae: <i>Panicum</i> spp.
Polygonaceae: <i>Polygonum</i> spp.	1.31	average of TME values for Polygonaceae: <i>Polygonum</i> spp.
Rosaceae: <i>Photinia melanocarpa</i>	1.96	average of published seed TME values