SEASONAL FOOD AVAILABILITY FOR WINTERING AND MIGRATING DABBLING DUCKS AND ITS IMPLICATIONS FOR MANAGEMENT AT THE HACKENSACK MEADOWLANDS OF NEW JERSEY

by

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ABSTRACT

Wetland loss and degradation in the Northeast has been especially severe and the ability of remaining wetland resources, heavily impacted by human populations, to support wintering and migrating waterfowl needs to be assessed. I conducted a food availability study in the Hackensack Meadowlands, New Jersey, to estimate available food biomass and duck use-days for dabbling ducks in tidally-influenced (tidal) and tidally-restricted (restricted) wetlands. I sampled invertebrates, seeds, roots and tubers, and vegetation in waterfowl-focused microhabitats during fall, winter, and spring in 2005-2006. Food availability was greater in tidal sites than restricted sites for all seasons ($P<0.05$). Food availability ranged from 82±14 kg/ha (spring) to 300±56 kg/ha (fall) at restricted sites and from 392±147 kg/ha (spring) to 586±121 kg/ha (fall) at tidal sites. I also conducted scan-sampling behavioral surveys in winter and spring 2006 to determine the extent of waterfowl foraging in the Meadowlands during my sampling periods. Duck use-days/ha (DUDs/ha) did not differ between tidal (1084±165 DUDs/ha) and restricted (774±136 DUDs/ha) sites in fall (P=0.166). In winter, more DUDs/ha were available in tidal sites (1123±259 DUDs/ha) compared to restricted sites (534±144 DUDs/ha; P=0.034). Spring estimates of carrying capacity were greater in tidal sites (853±246 DUDs/ha) than in restricted sites (173±41 DUDs/ha; $P\leq0.001$). I modeled the potential to sustain the energetic requirements of current and target waterfowl populations expected to use the Meadowlands as wintering and migration habitat. Under all modeling scenarios, a surplus of DUDs remained, which indicates the Meadowlands was capable of

supporting additional wintering and migrating waterfowl. The results of my research suggest that carrying capacity is greater in tidal habitat than in restricted habitat during waterfowl spring migration and wintering periods. Restoration activities in the Meadowlands should focus on restoring tidal hydrology and native saltmarsh vegetation to restricted and *phragmites*-dominated wetlands to maximize energetic carrying capacity for wintering and migrating dabbling ducks.

Chapter 1

INTRODUCTION

Tidal and nontidal wetlands in coastal zones of the Northeast function as important waterfowl migration and wintering habitat (Jorde et al. 1989); however, approximately 53% of the wetland resources in the continental United States have been lost during the last 200 years (Dahl 1990). Wetland loss and degradation in the Northeast has been especially severe (Dahl 1990) and the ability of remaining wetland resources, heavily impacted by human populations, to support wintering and migrating waterfowl needs to be assessed.

Habitat use by waterfowl in the North Atlantic States is primarily a function of food availability (Jorde et al. 1989). Food availability decreases from fall through winter (Jemison and Chabreck 1962, McKnight 1998), and reduced food availability may cause mortality and poor body condition for wintering and migrating waterfowl (Conroy et al. 1989, Demarest et al. 1997). Additionally, winter habitat conditions and availability can significantly impact waterfowl recruitment during the breeding season (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Raveling and Heitmeyer 1989). Therefore, current research priorities in the major waterfowl flyways are focused on determining available food biomass for migrating and wintering waterfowl and the potential for wetland habitats to sustain waterfowl populations during those lifecycle periods (Central Valley Joint Venture 2006, T. Yerkes, Ducks Unlimited Inc., personal communication).

The Hackensack Meadowlands represents one of the largest remaining urban estuaries in the North Atlantic States and has been designated an important waterfowl focus area in New Jersey (Tiner 1985, ACJV 2005). The extent to which waterfowl populations in the Atlantic Flyway and New Jersey can be supported by the Hackensack Meadowlands (hereafter the Meadowlands) is unknown. Information related to seasonal waterfowl food availability and habitat carrying capacity will be required to make appropriate management decisions regarding wetland food resources in the Meadowlands. My objectives were to estimate food availability for dabbling ducks in the Meadowlands during wintering and migration periods, estimate duck use-days available in the Meadowlands based upon food availability estimates, determine the ability of the Meadowlands to support current and target dabbling duck populations using duck use-days, determine the extent to which dabbling ducks are actively foraging in the Meadowlands during my biomass collection periods, and generate wetland restoration and management recommendations for the Meadowlands complex based on the results of my bioenergetics modeling.

Chapter 2

STUDY AREA

The Meadowlands, situated in Bergen and Hudson counties, contained approximately 2,242 ha of wetlands and was the largest mesohaline estuary in northern New Jersey (Tiner 1985, Tiner et al. 2002). It was a highly altered urban wetland system that originally consisted of 8,112 ha of wetlands and now only 28% of those wetlands remain (Tiner et al. 2002). Despite the high degree of urbanization and industrialization, the Meadowlands supported 275 species of plants and 332 species of birds (USFWS 2005).

I identified 2 macrohabitat types within the Meadowlands wetlands complex as important for wintering and migrating dabbling ducks based on hydrology and associated vegetation types: 1) tidally-restricted marsh and 2) tidally-influenced marsh (Tiner et al. 2002). I did not include a macrohabitat for freshwater wetlands because of the limited availability and suitability of these wetlands as foraging habitat for dabbling ducks. Tidally-restricted (hereafter restricted) marshes were irregularly flooded, emergent estuarine wetlands that did not receive full, daily, tidal inundation and that may have only been flooded during spring and storm tides (Cowardin et al. 1979, Tiner et al. 2002, USACOE 2004). In restricted wetlands, salinity ranged from 0.5-18 ppt (Tiner 1985). Tidally-influenced (hereafter tidal) marshes were regularly and irregularly flooded estuarine intertidal marshes. Regularly flooded areas were characterized by emergent vegetation, scrub-shrub vegetation, and mudflats with a salinity of 5-18 ppt, whereas irregularly flooded portions of tidal marshes were typically characterized by a predominance of common reed (*Phragmites australis*; Cowardin et al. 1979, Tiner et al. 2002).

To properly assess food resources available to waterfowl within my 2 macrohabitats, I identified specific dabbling duck microhabitat types. In restricted marsh, the microhabitat of interest (hereafter referred to as shallow water) was shallow water zones (depth <30 cm) of marsh characterized by open water and interspersed with emergent vegetation. Shallow water microhabitat represented available foraging habitat to dabbling ducks, which feed in waters <30 cm deep, depending on the species (Poysa 1985, Frederickson and Heitmeyer 1991, Johnson 1995, LeSchack et al. 1997). In tidal marsh, the microhabitats of interest were edge, cordgrass, and mudflat. The edge microhabitat (hereafter edge) was irregularly flooded, estuarine intertidal emergent zones with common reed as the dominant vegetation type. Large, monotypic stands of common reed are low quality habitat of little value to waterfowl (Cross and Fleming 1989, Baldassarre and Bolen 2006). Benoit and Askins (1999) studied bird community composition in *phragmites*-dominated marshes and found that waterfowl did not use the interior of these marshes, but observed wading birds and shorebirds foraging along the edge of common reed stands. Therefore, I made two assumptions regarding food availability and common reed. First, food resources in dense stands of common reed are inaccessible to dabbling ducks. Second, areas directly adjacent to common reed may have different types and abundances of food resources compared to other microhabitats, because tidal action may flush food items from the interior of common reed stands to the edges where waterfowl are able to consume them. Based on these assumptions, I concentrated my sampling effort in the edge microhabitat in areas adjacent to common reed stands. The cordgrass microhabitat (hereafter cordgrass) was regularly flooded, estuarine intertidal emergent zones with smooth cordgrass (*Spartina alterniflora*) as the dominant vegetation type ($\geq$ 50%) and an overall cover type of $\geq$ 75% emergent vegetation. The mudflat microhabitat (hereafter mudflat) was estuarine intertidal mudflats that were unvegetated, or vegetated with nonpersistent species (Cowardin et al. 1979).

I selected 8 sample sites: 5 in restricted marsh, and 3 in tidal marsh (Figure 1, Table 1). Harrier Meadows and Mill Creek Impoundments were 2 restricted sites that had been hydrologically restored and connected to adjacent tidal wetlands that facilitated partial, daily tidal exchange (USACOE 2004). Kearny Brackish Marsh was classified as a candidate restoration site within the Meadowlands because tidal flow was restricted through a water control structure installed in a dike that ran along the entire eastern boundary of the wetland (USACOE 2004). Research Park (no official name: located in Secaucus, Parcel 2477/Block 227) was a wetland located adjacent to Mori Tract and had restricted tidal flow due to the presence of a tidal gate. Kingsland Impoundment was an actively managed open water wetland; water levels were controlled through a sluice gate for waterfowl and shorebirds (USACOE 2004). All 3 tidal sites, Marsh Resources Meadowlands Mitigation Bank (MRMMB), Mill Creek Marsh (MCM), and Saw Mill Wildlife Management Area (SMWMA), were restored wetland sites. MRMMB was restored to allow daily tidal inundation and reshaped to promote low marsh, high marsh and upland vegetative communities and hydrologic regimes (USACOE 2004). MCM was restored to daily tidal exchange and enhanced to encourage low marsh and upland habitat zones (USACOE 2004). SMWMA was naturally restored due to storm activity in 1950 that destroyed the man-made dikes and tide gates that were restricting tidal exchange

(Bragin, personal communication). Post-restoration, SMWMA was subjected to daily tidal flow, was dominated by low marsh vegetation and common reed, and contained extensive mudflats (USACOE 2004). Additional site-specific information can be found in the Meadowlands Environmental Site Investigation Compilation (USACOE 2004).

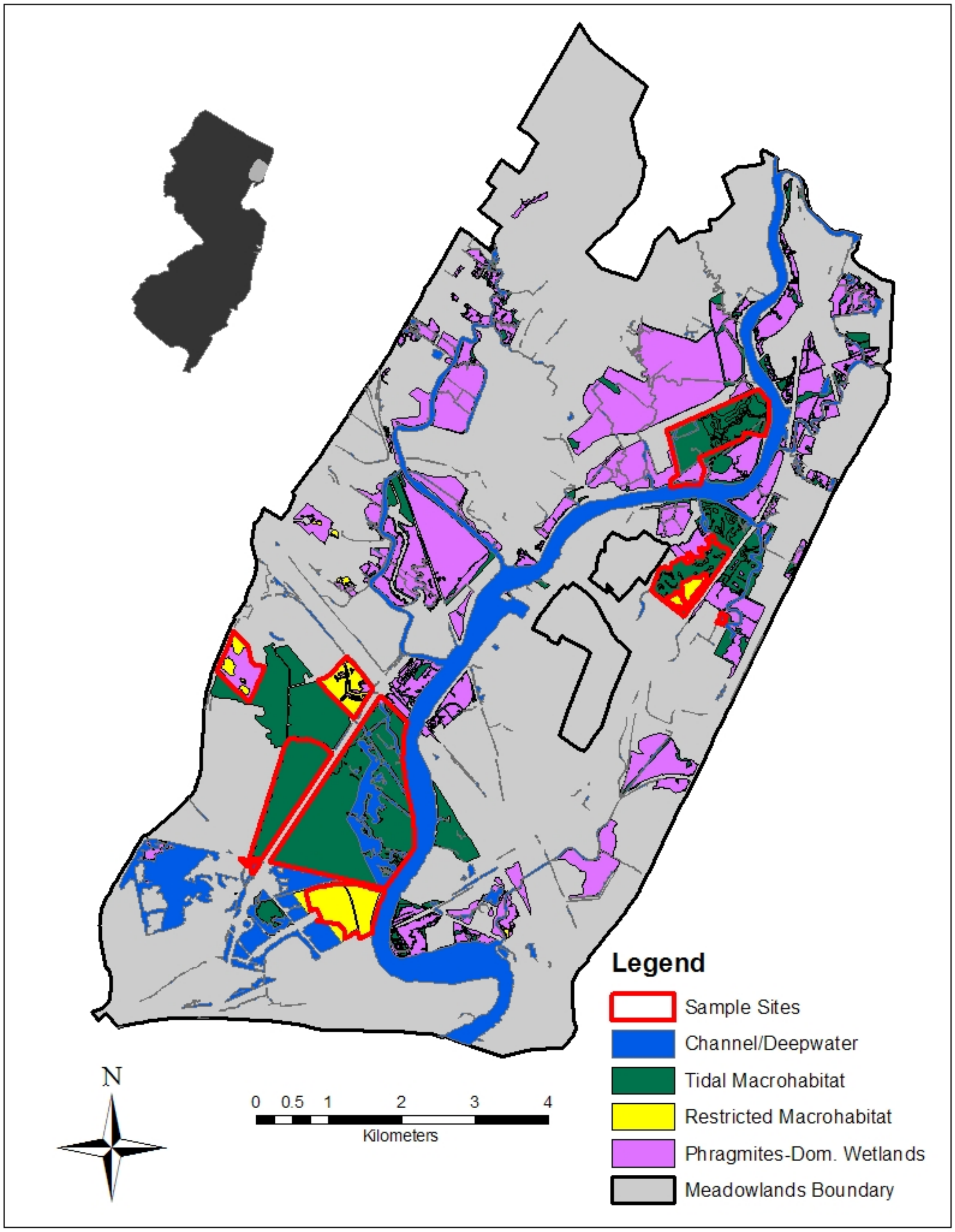

Figure 1 Map of study area, sample sites, major habitat types in the Hackensack Meadowlands, New Jersey, USA, 2005-2006.

Chapter 3

METHODS

Food Availability

To assess the ability of the Meadowlands to support wintering and migratory populations of dabbling ducks, I collected estimates of available food biomass during winter, spring, and fall in 2005-2006. I chose American Black Duck (*Anas rubripes*), American Wigeon (*Anas americana*), Gadwall (*Anas strepera*), Green-winged Teal (*Anas crecca*), Mallard (*Anas platyrhynchos*), Northern Pintail (*Anas acuta*) and Northern Shoveler (*Anas clypeata*) as my target species. I targeted these species because previous waterfowl surveys in the Meadowlands indicated these dabbling ducks were more abundant than other waterfowl during winter (USFWS 2007a). These species restrict feeding to a water depth of <30cm, but the depth may vary depending on the species and food availability (Poysa 1985, Frederickson and Heitmeyer 1991, Johnson 1995, LeSchack et al. 1997).

I used a series of transects to establish permanent sampling plots. At each sample site, I used a random azimuth and distance (10-20 m) relative to an access route to determine the starting point for the first transect. I spaced transects 100 m apart and extended them for a maximum of 400 m. As I walked each transect, I established 10 m^2 plots where suitable, homogenous portions of microhabitat existed (minimum of a 10 m radius around the transect point containing the desired microhabitat). A minimum of 30 m separated each sampling plot established along each transect. At Kingsland Impoundment, I could only find suitable microhabitat along the wetland perimeter. Therefore, I established plots along the perimeter; each plot was separated by ≥ 30m. Research Park was too small for transects, so I systematically established plots ≈ 20-25 m equidistant from each other along the perimeter of the entire site. At MCM and SMWMA, I used existing canoe trails in place of transects to establish plots. I marked each sample plot with either a 1.5 m or 3.05 m length of 1.9 cm Schedule 40 PVC pipe and used a Magellan® SporTrak Pro Marine Handheld GPS unit (Magellan, San Dimas, California, USA) to record the latitude/longitude of each plot. I established 10 permanent sampling plots for each microhabitat at each sample site (Table 1). In spring 2005, I established 133 permanent sample plots at 8 study sites. During the fall 2005 sampling period, when cordgrass and edge microhabitats were at peak density, I established the remaining sample plots and made placement adjustments to previously established plots to ensure plots were in suitable microhabitat. In total, I established 140 plots (Table 1, Appendix A).

To measure changes in food availability during dabbling duck migration and wintering, I sampled available food biomass during 3 periods (fall, winter, and spring) from spring 2005 until spring 2006, which provided 4 sampling periods. In the fall, I sampled from mid-August to mid-September, before most dabbling ducks migrated through the Meadowlands (Bellrose 1980), and when available food resources for waterfowl were the greatest (Appendix B). My winter sampling period occurred in mid-December through early February while wintering waterfowl were using the Meadowlands (Appendix B). My spring sampling occurred from March through May, after most wintering and migrating waterfowl had left the Meadowlands (Bellrose 1980; Appendix B).

I sampled microhabitats in tidal marsh at, or near, low tide because dabbling ducks are more active foragers during this period in the tidal cycle (Jorde 1986). In contrast, I sampled restricted marsh irrespective of the tidal cycle, with the exception of Mill Creek Impoundments which was sampled at, or near, low tide when available foraging habitat was greatest relative to water depth.

During each visit to a sampling plot, I located the central stake marking the sampling plot. Each sample plot consisted of a 10 m x 1 m rectangle of microhabitat (Figure 2). I collected the food sample in each plot using 3 subsamples (water column, vegetation, and benthic). I sampled a different 1 m x 1 m square each visit and an empty square separated each sample (Figure 2). I divided the 1 m x 1 m plot into 3 equal, 0.33 m x 1 m rectangles (Figure 2). Next, I assigned 1 subsample to each of these rectangles (Figure 2). I divided each 0.33 m x 1 m rectangle into equal quarters and randomly selected 1 quarter to subsample biomass. First, I subsampled invertebrates in the water column with a sweep net (0.5 mm mesh; Kaminski and Murkin 1981). I removed invertebrates from the net and temporarily stored them in a small sample jar (Kaminski and Murkin 1981, Baldwin and Lovvorn 1994). I also measured water depth so that a quantitative measure of nektonic invertebrate density could be calculated (Kaminski and Murkin 1981, Baldwin and Lovvorn 1994). To measure epiphytic invertebrates and consumable plant biomass, I placed a 0.25 m x 0.25 m PVC quadrat over the wetland surface (Wiegert 1962, Kirby and Gosselink 1976, Downing and Cyr 1985, Eichholz, personal communication). I clipped and bagged vegetation lying within the boundaries of the quadrat. Finally, I collected a sediment core (depth: 10 cm, diameter: 5.08 cm) using a hand corer to subsample benthic invertebrates, seeds, and below ground vegetative structures (e.g., tubers and rhizomes; Swanson 1978, Swanson 1983). Following extraction of the core, I bagged the subsample for transport to the laboratory. I collected 533 samples (Table 2).

At the laboratory, I washed and sieved each sample core (#35 Sieve, 0.5 mm; Baldwin and Lovvorn 1994). I fixed and stored invertebrates, seeds, and vegetative structures in 10% formalin (Murkin et al. 1996, Gaston et al. 1996). I identified invertebrates to the level of phylum, class, order, or family and seeds and plant parts to the level of family or genus, if possible (Appendix C). I dried invertebrates and seeds at 100˚C, and consumable vegetation at 80°C for 24 hr in a Lab-Line Instruments L-C Oven Model 3511 (Lab-Lines Instruments, Inc., Melrose Park, Illinois, USA) to remove all moisture (Atkinson and Wacasey 1983, Michot and Chadwick 1994, Higgins et al. 1996). I weighed benthic invertebrates, seeds, and consumable vegetation using a Mettler Balance AE 100 (readability: 0.1 mg; Mettler-Toledo, Inc., Columbus, Ohio, USA). For core samples, I reported biomass as dry mass per volume (Southwood and Henderson 2000). I reported my nektonic invertebrate biomass as dry mass per area of the water column. For vegetation, seeds, and epiphytic invertebrates harvested within the quadrats, I reported dry biomass per 0.25 m^2 (Southwood and Henderson 2000). I converted my biomass estimates of each microhabitat to kg/ha.

I conducted a literature review of dabbling duck feeding ecology and diet to determine if food items collected in my biomass samples were actually items dabbling ducks would actively forage for and consume (Krapu 1974, Serie and Swanson 1976, Swanson and Meyer 1977, Krapu 1979, Swanson et al. 1979, Reinecke and Owen 1980, Swanson et al. 1985, Euliss and Gilmer 1991, Dabbert and Martin 2000). Based on my review, I excluded all records of Annelids and Crustacea:Cirripedia biomass when calculating food availability and energetic carrying capacity for dabbling ducks.

Microhabitat Availability/Classification

The calculation of food availability required area estimates of my 4 microhabitat types available to dabbling ducks. I ran a series of transects through each of my tidal and restricted sample sites between 28 September 2006 and 23 October 2006 to estimate the amount of available microhabitat present at each site. Microhabitat area estimates for each sample site were used to proportionally weight food availability estimates associated with each microhabitat in order to generate an estimate of food available per hectare of macrohabitat at each sample site.

The availability of shallow water microhabitat at restricted sample sites was dependent upon a water depth threshold of <30 cm. I collected water depth measurements irrespective of the tide cycle, except at Mill Creek Impoundments when I sampled within 2 hours of low tide. At each sample site, I used a random azimuth relative to an access route to determine the starting point for the first transect. I spaced transects 50m apart and extended them for a maximum of 400 m. Every 15 m along a transect, I recorded a water depth measurement. I continued running transects through a site until a minimum of 100 water depth measurements were recorded. Due to size constraints at Research Park, I spaced transects 10 m apart in an effort to maximize my sampling effort. I collected 30 readings at this site. I calculated habitat availability within each restricted site as the proportion of measurements with a water depth of <30cm (Appendix D).

At tidal sites, I used a random azimuth relative to an existing access route to determine the starting point for the first transect. I spaced transects 200 m apart and extended them for a maximum of 400 m. At tidal sites accessible by canoe, I extended transects perpendicular to the channel bank. Every 20 m along a transect I established a 5-m radius from the point along the transect and recorded the relative percent cover of 'mudflat', 'cordgrass', 'common reed', 'other-available', and 'other-unavailable'. Edge microhabitat focused on food resources directly adjacent to large, dense stands of common reed. As such, I recorded the number of meters of common reed perimeter present within my 5-m radius plot to determine the availability of edge microhabitat within tidal sample sites. I calculated habitat availability within each tidal sample site as the mean percentage of each cover type category listed above (Appendix E).

Macrohabitat Availability/Classification

I classified wetlands within the Meadowlands District to determine the overall availability of tidal and restricted macrohabitat so I could calculate total food biomass available to dabbling ducks in the Meadowlands from my kg/ha food availability estimates. I calculated macrohabitat availability using ArcGIS9 Geographic Information Systems software (ESRI, Redlands, California, USA). Photo interpretation of 2002 digital color infrared orthoquads (scale 1:2400, resolution: 1ft) was provided by Ducks Unlimited, Inc. and I classified available estuarine marsh as '*phragmites* dominant' and '*phragmites* non-dominant'. *Phragmites* dominant marsh consisted of dense stands of common reed and was considered unavailable to dabbling ducks. *Phragmites* non-dominant areas consisted of habitat representative of my 3 tidal microhabitat types. I used NWI deepwater coverages and elevation data from the Digital Meadowlands website (Meadowlands Environmental Research Institute 2007), to exclude subtidal and deepwater wetland areas that would be unavailable to dabbling ducks in tidal wetland units. I classified restricted habitat based on site descriptions provided in the Meadowlands Environmental Site Investigation Compilation (USACOE 2004), photo interpretation, NWI deepwater coverages, and elevation data provided by the Digital Meadowlands website. I classified 1,909 ha of estuarine marsh habitat: restricted habitat accounted for 103.3 ha of wetlands, tidal habitat comprised 831.2 ha of classified marsh, and *phragmites* dominant habitat accounted for the remaining 974.5 ha.

Extrapolating Estimates of Food Availability to the Macrohabitat Level

I estimated food availability using waterfowl-focused microhabitats to determine dabbling duck food resources in my macrohabitat types of interest, restricted and tidal wetlands. To extrapolate my microhabitat estimates of available food biomass to the macrohabitat level, I weighted my biomass estimates based upon the proportional availability of each microhabitat within its respective macrohabitat. For each tidal sample site, I multiplied each microhabitat biomass estimate by the corresponding percent cover type estimate for that microhabitat type. Then I summed the weighted microhabitat biomass estimates together to calculate a macrohabitat-level estimate of available food biomass (kg/ha) for each tidal sample site. For each restricted sample site, I multiplied the shallow water microhabitat biomass estimate by the proportional area estimate of the wetland with a water depth of <30cm to determine the macrohabitat-level estimate of available food biomass (kg/ha).

Bioenergetics Modeling – Calculations

To express biomass estimates of food availability in terms of the Meadowlands' ability to support wintering and migrating dabbling duck populations, I selected a daily ration model that predicts the carrying capacity of a site based on total biomass available and the daily energy requirements of the species of interest (Goss-Custard et al. 2003). Duck use-days (DUDs) were calculated as the amount of food needed to support 1 duck for 1 day (Prince 1979, Reinecke et al. 1989):

$$\text{Duck use-days} = \frac{\text{Food available (g[dry])} \times \text{Metabolizable energy (kcal/g [dry])}}{\text{Daily energy requirement (kcal/day)}}$$

Duck use-days require 3 primary inputs: available food biomass, True Metabolizable Energy (TME) values for those food items, and the Daily Energy Requirement (DER) of each waterfowl species of interest (Sibbald 1976, Prince 1979, Reinecke et al. 1989). Available food biomass for each seasonal sampling period was determined for tidal and restricted study sites using my estimates of food and available habitat. DUDs were expressed as DUDs/ha of habitat. Total available DUDs/macrohabitat/season were calculated by multiplying the DUDs/ha estimate by its corresponding area estimate of available macrohabitat.

TME values represent the energy available to waterfowl from a food item, corrected for endogenous (nonfood) excretory energy, and are considered the most appropriate measure of food energy for modeling carrying capacity (Sibbald 1976, Miller and Reinecke 1984). Since TME values are equivalent for closely-related species with similar diets (Miller 1984, Castro et al. 1989), I assigned each food item found at my sample sites a TME value based on the available published literature, irrespective of the test species used (Appendix F). Published TME values were not available for all of the food items found in my samples. Where possible, published TME values for closely related food items were substituted, however, for some items published TME values could not be readily substituted. In those cases, mean TME values for the most closely related family, order, class, or phylum were substituted to ensure all food items were accounted for energetically (Appendix G).

Waterfowl species' DER, or daily energy expenditure, is the amount of energy expended by 1 duck in 1 day. A DER incorporates the energetic costs of feeding and non-feeding behaviors and excludes energetic demands directly related to reproduction, molt, and migration (Baldassarre and Bolen 2006). Observed waterfowl behaviors are expressed as a multiple of a bird's Basal Metabolic Rate, the rate of energy expended by an animal at rest, and behaviors are summed to calculate the DER (Kendeigh et al. 1977, Baldassarre and Bolen 2006). However, DERs vary within species depending environmental conditions (e.g., temperature, wind) that can affect thermoregulatory costs. Wooley and Owen (1977) found that DERs increased for waterfowl as ambient temperature decreased. Based on published estimates of DERs for dabbling ducks (Table 3), I selected a DER value of 292 kcal/day for the calculation of duck use-days. This DER was the most energetically-costly of the published values and was calculated based on the average weight of a free-living mallard (Reinecke et al. 1989). Using this DER in the calculation of DUDs produced the most conservative estimates of available DUDs in the Meadowlands

In addition to modeling DUDs as described above (hereafter referred to as raw DUDs), I attempted to factor in foraging efficiency in relation to food availability and its associated impact on DUDs. Reinecke et al. (1989) proposed a food density threshold of 50 kg/ha, below which waterfowl would be unable to efficiently exploit food resources. Therefore, I also modeled DUDs after adjusting available food biomass to account for the 50 kg/ha foraging threshold (hereafter referred to as adjusted DUDs/ha):

$$\text{Adjusted Duck use-days} = \frac{(\text{Food available (g[dry])} - 50{,}000\text{g}) \times \text{Metabolizable energy (kcal/g [dry])}}{\text{Daily energy requirement (kcal/day)}}$$

I calculated total available adjusted DUDs/macrohabitat/season by multiplying the adjusted DUDs/ha estimate by its corresponding area estimate of available macrohabitat.

Population Modeling

Using my estimates of raw and adjusted DUDs, I predicted the ability of the Meadowlands to support existing and target dabbling duck populations. Waterfowl population data collected within the Meadowlands was limited to Mid-Winter Inventory (MWI) survey data (Appendix H; USFWS 2007a). MWI is an annual aerial survey of waterfowl distribution and habitat conditions in winter (Baldassarre and Bolen 2006). I estimated fall and spring migration data for the Meadowlands using weekly bird survey data collected at the nearby Edwin B. Forsythe National Wildlife Refuge in Southern New Jersey (Appendices I and J; USFWS 2007b). For the purposes of this modeling exercise, I made the assumption that dabbling ducks using the Forsythe NWR during migration would use the

Meadowlands as a stopover/staging area on the way to breeding and/or wintering grounds.

For each population data set, I assigned a corresponding seasonal period, based on regional migration chronology (Bellrose 1980), that established the number of days associated with waterfowl migration and wintering life cycle events, (i.e., the number of days the Meadowlands would have to support dabbling ducks during each event). I considered fall migration to occur from 1 September – 14 December, wintering from 15 December – 31 January, and spring migration from 1 February – 1 May. Using the seasonal periods and population data, I calculated the number of duck use-days necessary to meet the energetic requirements of dabbling ducks during migration and wintering periods and compared them to available duck use-days in the Meadowlands during the same periods to determine if there was surplus or deficit in food availability.

In addition, I evaluated the ability of the Meadowlands to support target waterfowl populations in support of the objectives of the North American Waterfowl Management Plan (NAWMP; North American Waterfowl Management Plan, Plan Committee 2004). Continental population objectives were ‘stepped-down’ to the county-level based upon state-level MWI data and county-level harvest data (Koneff, unpublished data). Two versions of county-level population objectives were calculated, one based on MWI and harvest data from 1970-1979, and the other based on data from 1990-2002 (harvest data was only available from 1990-1999). I combined the county-level dabbling duck population objectives for Bergen and Hudson counties to represent a target wintering dabbling duck population (Appendix K) and assessed the ability of the Meadowlands to meet both population objectives. I calculated the number of required duck use-days using the population objectives and my established wintering season length (15 December – 31 January) and compared them to available duck use-days in the Meadowlands to determine if there was a surplus or deficit in food availability.

Waterfowl Behavioral Monitoring

To determine the extent to which dabbling ducks were actively foraging in the Meadowlands during my winter 2006 and spring 2006 biomass collection periods, I recorded the behavior of dabbling ducks present at my sample sites. I did not collect behavior data during the spring 2005 and fall 2005 collection periods because the behavioral monitoring component of the study was not developed until late fall 2005, after preliminary data indicated that food resources might be scarce and limiting dabbling duck use of the Meadowlands. I chose scan-sampling to survey dabbling duck flocks found at each sample site because this technique allowed me to obtain behavioral information on a large group of individuals in a short time (Altmann 1974). My survey periods occurred during the same periods as biomass sampling with the intention of conducting 2 surveys/sample site/period. I conducted winter surveys from mid-December 2005 through early February 2006 and spring surveys during April 2006.

Where possible, I used fixed observation points located on existing roads, berms, and walkways. However, at SMWMA, I surveyed primarily using a canoe and available canoe trails and channels. I collected my observations using a 27-80 x 80 mm spotting scope and/or 10 x 42 mm binoculars. Once located, I surveyed an entire flock, starting my scan at one end of the flock and working across to the other. At wetlands where large flocks were not present, I recorded the behaviors of all dabbling ducks visible from my observation point. As each individual entered my field-of-view, I recorded its species, sex, and behavior (Feeding or Non-feeding; Altmann 1974). After I completed a scan, a minimum of 1 minute buffered the commencement of the next scan to promote independence of scan data (Morton et al. 1989). Similarly, I monitored each flock for a maximum of 1 hour or 20 scans (whichever occurred first) to avoid flock bias of behavioral activities (Morton et al. 1989). I classified the location of each individual or group of individuals (in large flocks) as shallow water/mudflat, bank, open water/channel, emergent, or perimeter. In Winter and Spring 2006, I completed 30 behavioral surveys; however, due to freeze-over conditions in December and an absence of birds during some surveys, only 25 surveys contained behavioral information.

Statistical Analyses

I estimated the individual food type (i.e., invertebrates, seeds, roots and tubers, and vegetation) and total (invertebrates + seeds + roots and tubers + vegetation) biomass available in restricted and tidal sample sites. For all analyses, I used $\alpha \leq 0.10$ to determine statistical significance. To investigate if differences in food availability existed between macrohabitat types, I used an analysis of variance (ANOVA) with the main effect of macrohabitat types (SAS version 9.1, Cary, North Carolina, USA). I investigated differences in raw and adjusted DUDs/ha between macrohabitat types using an ANOVA. I summarized behavioral observations by treating each scan of a survey as the sample unit. I converted the individual behavior observations of each scan to represent focal observations following the procedures of Albright et al. (1983). I averaged focal observations to estimate percent of the time spent feeding per scan. In addition to analyzing the extent that dabbling ducks were feeding in the Meadowlands, I used a 2-way ANOVA with the main effect of macrohabitat types to detect differences in feeding behavior between restricted and tidal macrohabitats during winter and spring survey periods.

Table 1 Microhabitat sample distribution among sample sites at the Hackensack Meadowlands, New Jersey, USA, 2005-2006.

	Microhabitat				
Macrohabitat	Shallow water	Edge	Cordgrass	Mudflat	Total
Restricted Marsh					
Research Park	10				10
Mill Creek Impoundments	10				10
Kingsland Impoundment	10				10
Kearny Brackish Marsh	10				10
Harrier Meadows	10				10
Tidal Marsh					
Saw Mill Wildlife Management Area		10	10	10	30
Mill Creek Marsh		10	10	10	30
Marsh Resources Meadowlands Mitigation Bank		10	10	10	30
Total	40	30	30	30	140

Table 2 Summary of food biomass samples collected at each site during my 4 sampling periods at the Hackensack Meadowlands, New Jersey, USA, 2005-2006.

Sample Site	Spring 05	Fall 05	Winter 06	Spring 06	Total
Restricted Marsh					
Research Park	10	10	10	10	40
Mill Creek Impoundments	10	10	10	10	40
Kingsland Impoundment	9	10	10	10	39
Kearny Brackish Marsh	9	10	10	10	39
Harrier Meadows	10	10	9	10	39
Tidal Marsh					
Saw Mill Wildlife Management Area	26	29	30	28	113
Mill Creek Marsh	23	30	30	30	113
Marsh Resources Meadowlands Mitigation Bank (MRI)	22	28	30	30	110
Total	119	137	139	138	533

Table 3 Published Daily Energy Requirements (DER) for dabbling ducks

Species	DER (kcal/d)	Temp (°C)	Source
American Black Duck	159	5	Albright et al. 1983
American Black Duck	239	-20	Albright et al. 1983
American Black Duck	163	5	Morton et al. 1989
American Black Duck	222 (♂)	5	Hickey[a]
Mallard	280-290	0-20	Prince 1979
Mallard	292[b]	0-20	Reinecke et al. 1989
Northern Pintail	190-244 (♂)[c]	-	Miller and Newton 1999
Northern Pintail	188-244 (♀)[c]	-	Miller and Newton 1999
Northern Pintail	235-282 (♂)[d]	-	Miller and Newton 1999
Northern Pintail	218-239 (♀)[d]	-	Miller and Newton 1999
Northern Pintail	229[e]	-	Miller and Newton 1999
Northern Pintail	212[e]	-	Miller and Newton 1999

[a] in Albright et al. 1983
[b] based on Prince 1979
[c] DER during fall (period not specified)
[d] DER during fall (August-November)
[e] DER during winter (November-February)
[f] DER during spring (February-March)

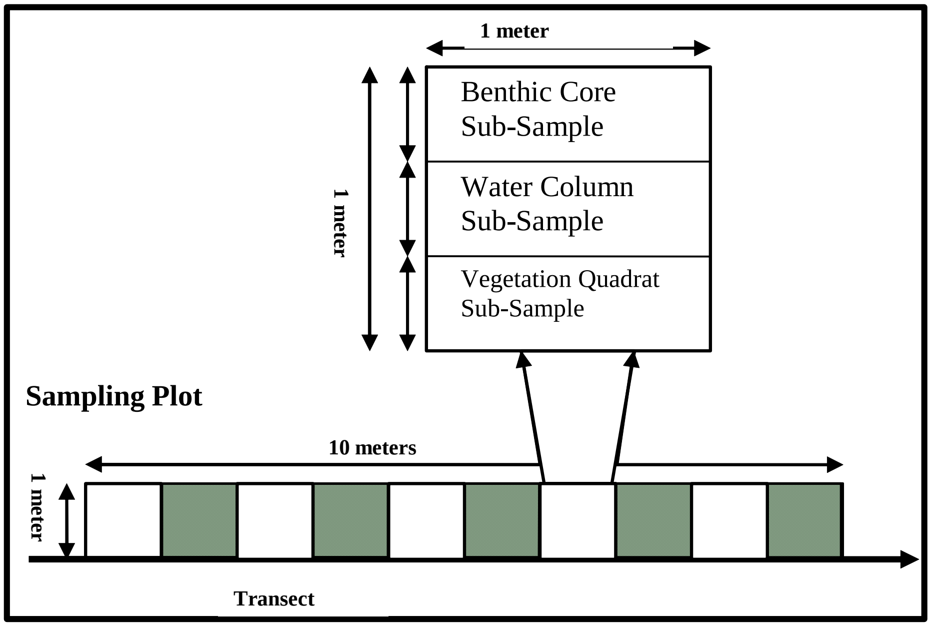

Figure 2 Diagram of sampling plot used to sample food availability at the Hackensack Meadowlands, New Jersey, USA, 2005-2006.

Chapter 4

RESULTS

Food Availability

Food resources differed between restricted and tidal macrohabitat types for all seasons (Table 4). Tidal sample sites had 286, 328, and 310 kg/ha of additional total food biomass available than in restricted sites in fall, winter, and spring, respectively (Table 4). Seeds and invertebrates were the primary food types found at tidal sites in all seasons (Table 4). At restricted sites consumable vegetation, mostly in the form of algae, was the most abundant food type in fall, whereas seeds and invertebrates were the most abundant food type in winter and spring (Table 4).

In fall, tidal sites had more than three times (≈258 kg/ha) the seeds available in restricted sites (Table 4). Roots and tubers were largely unavailable in restricted sites and accounted for a small proportion of available food biomass in tidal sites (Table 4). Consumable vegetation was nearly absent from tidal sites, but in restricted sites available biomass was equivalent to the amounts provided by seeds and invertebrates (Table 4). Tidal sites contained more than twice (≈111 kg/ha) the invertebrate biomass found in restricted sites, but this difference was not statistically significant.

Tidal sites had more than twice the winter seed biomass (≈163 kg/ha) as restricted sites (Table 4). Although not statistically significant because of high variation, tidal sites, on average, provided almost five times more (≈151 kg/ha) invertebrate biomass compared to restricted sites in winter. Availability of roots and tubers in restricted sites was minimal, but was more abundant (≈15 kg/ha) in tidal sites. Consumable vegetation was unavailable in tidal sites and almost absent (<1 kg/ha) from restricted sites in winter (Table 4).

Invertebrate biomass in spring was over seven times greater (≈158 kg/ha) in tidal sites compared to restricted sites (Table 4). At tidal sites, seed biomass was over three times greater (≈143 kg/ha) than at restricted sites (Table 4). Root and tuber biomass was negligible at restricted sites (<0.1 kg/ha) and more available in tidal sites (Table 4). The contribution of consumable vegetation to spring food biomass was minimal and showed no statistical difference between macrohabitats (Table 4).

Bioenergetics Modeling

Seasonal estimates of raw DUDs/ha differed between tidal and restricted macrohabitat (Table 5). In winter, an additional 635 DUDs/ha (i.e., 527,812 additional raw DUDs in the Meadowlands) were available in tidal habitat compared to restricted habitat (Tables 5-6). Differences in spring DUDs/ha were even more pronounced, with tidal habitat having 727 more DUDs/ha (i.e., 604,282 additional raw DUDs in the Meadowlands) than restricted habitat (Tables 5-6). DUDs/ha were not statistically different for fall, however tidal habitat provided an average of 345 more DUDs/ha (i.e., 286,764 additional raw DUDs in the Meadowlands) than restricted habitat during this sampling period (Tables 5-6).

Differences in adjusted DUDs/ha existed between restricted and tidal habitat. Tidal habitat had 589 additional DUDs/ha (i.e. 489,576 additional adjusted DUDs in the Meadowlands) in winter compared to restricted habitat (Tables 5-6). In spring, 680 more DUDs/ha (i.e. 565,216 additional adjusted DUDs in the

Meadowlands) were available in tidal habitat compared to restricted habitat (Tables 5-6). Differences in DUDs/ha available in fall were not statistically different between macrohabitats, but an additional 310 DUDs/ha (i.e. 257,672 additional adjusted DUDs in the Meadowlands) were available in tidal habitat versus restricted habitat (Tables 5-6).

Population Modeling

A surplus of duck use-days existed within available dabbling duck foraging habitat for all modeling scenarios using current and target dabbling duck population data (Tables 7-8). At current estimated levels of waterfowl use, the Meadowlands could support an additional 4,547-5,748 ducks (adjusted vs. raw) during fall migration (Table 7). Based on available MWI data, an additional 19,398-21,878 (adjusted vs. raw) ducks could be supported during the wintering period (Table 7). During spring migration, 6,803-8,110 more ducks (adjusted vs. raw) could be supported (Table 7).

County-level wintering waterfowl population objectives for Bergen and Hudson counties can be met solely by the food resources available within the Meadowlands (Table 8). In addition to the target population based on the 1970's MWI/harvest data, 15,873-18,353 more ducks (adjusted vs. raw) could be supported during winter. When modeling carrying capacity based on population objectives generated from the 1990's MWI/harvest data, 9,845-12,324 ducks (adjusted vs. raw) could be sustained in addition to the target population (Table 8).

Waterfowl Behavioral Monitoring

Waterfowl engaged in feeding behavior in both restricted and tidal macrohabitats during winter and spring sampling periods. Dabbling duck feeding behavior did not differ between restricted habitat and tidal habitat in winter ($F_{1, 204}$ = 1.10, $P = 0.296$). In winter, dabbling ducks observed in restricted habitat spent 42% of their time feeding compared to 46% in tidal habitat. However, differences in feeding behavior between restricted and tidal habitat were observed in spring ($F_{1, 282}$ = 51.35, $P \leq 0.001$). Dabbling ducks observed in tidal habitat spent 71% of their time feeding, compared with ducks in restricted habitat, which only spent 48% of their time engaged in feeding behavior.

Table 4 Seasonal biomass estimates (kg/ha) of food availability in the Hackensack Meadowlands, New Jersey, 2005-2006.

		Restricted			Tidal				
Food	Season	n[a]	$\bar{x}$	SE	n	$\bar{x}$	SE	F_{df}	*P*
Invertebrates									
	Fall	50	91.85	35.12	27	203.26	69.11	$F_{1, 75}$ = 2.56	0.114
	Winter	49	41.62	15.61	30	192.30	140.34	$F_{1, 77}$ = 1.84	0.179
	Spring	98	23.83	5.98	43	181.37	143.26	$F_{1,139}$ = 2.76	0.099
Seeds									
	Fall	50	98.04	24.95	27	355.73	106.20	$F_{1, 75}$ = 9.25	0.003
	Winter	49	141.20	45.08	30	303.96	49.23	$F_{1,77}$ = 5.51	0.022
	Spring	98	58.24	13.42	43	201.20	29.91	$F_{1, 139}$ = 25.51	<0.001
Roots and tubers									
	Fall	50	0.25	0.08	27	26.18	5.58	$F_{1, 75}$ = 40.46	<0.001
	Winter	49	0.20	0.08	30	15.09	4.03	$F_{1, 77}$ = 22.42	<0.001
	Spring	98	0.04	0.02	43	8.69	2.53	$F_{1,139}$ = 26.98	<0.001
Vegetation									
	Fall	50	109.88	44.66	27	1.03	1.03	$F_{1, 75}$ = 3.19	0.078
	Winter	49	0.41	0.37	30	0.00	0.00	$F_{1, 77}$ = 0.76	0.388
	Spring	98	0.30	0.24	43	0.76	0.65	$F_{1, 139}$ = 0.65	0.421
Total									
	Fall	50	300.03	55.65	27	586.21	121.05	$F_{1, 75}$ = 6.02	0.016
	Winter	49	183.44	46.24	30	511.35	146.50	$F_{1, 77}$ = 6.50	0.013
	Spring	98	82.41	14.47	43	392.02	146.59	$F_{1,139}$ = 9.76	0.002

[a] n=number of samples. For each tidal sample site, edge, cordgrass, and mudflat microhabitat samples were averaged together to generate 10 weighted tidal macrohabitat biomass estimates for statistical comparisons against restricted sample site biomass estimates.

Table 5 Seasonal estimates of duck use-days/ha (DUDs/ha) in the Hackensack Meadowlands, New Jersey, 2005-5006.

		Restricted			Tidal					
Season	Model	n[a]	$\overline{x}$	SE	n	$\overline{x}$	SE	F	df	*P*
Fall	DUD_{raw}[b]	50	859.2	137.3	27	1204.6	163.6	$F_{1, 75}$ = 2.41	76	0.125
	DUD_{adj}[c]	50	773.7	135.9	27	1083.6	165.3	$F_{1, 75}$ = 1.96	76	0.166
Winter	DUD_{raw}	49	620.3	146.7	30	1255.3	258.2	$F_{1, 77}$ = 5.32	78	0.024
	DUD_{adj}	49	533.5	143.7	30	1122.9	258.7	$F_{1, 77}$ = 4.66	78	0.034
Spring	DUD_{raw}	98	256.5	42.0	43	983.8	246.6	$F_{1, 139}$ = 17.35	140	<0.001
	DUD_{adj}	98	172.8	40.8	43	852.7	245.9	$F_{1, 139}$ = 15.36	140	<0.001

[a] n=number of samples. For each tidal sample site, edge, cordgrass, and mudflat microhabitat samples were averaged together to generate 10 weighted tidal macrohabitat biomass estimates for statistical comparisons against restricted sample site biomass estimates.
[b] DUD_{raw} excludes a food density threshold
[c] DUD_{adj} assumes a food density threshold of 50 kg/ha, below which waterfowl will not exploit available food resources

Table 6 Seasonal estimates of total available duck use-days (DUDs) in the Hackensack Meadowlands, New Jersey, 2005-2006.

Season	Model	Restricted	Tidal	Total
Fall	DUD_{raw}[a]	88,755 ± 14,152	1,001,264 ± 135,984	1,090,019
	DUD_{adj}[b]	79,923 ± 14,038	900,688 ± 137,397	980,611
Winter	DUD_{raw}	64,077 ± 15,154	1,043,405 ± 214,719	1,107,482
	DUD_{adj}	55,111 ± 14,844	933,354 ± 215,031	988,465
Spring	DUD_{raw}	26,496 ± 4,339	817,735 ± 205,073	844,231
	DUD_{adj}	17,850 ± 4,215	708,764 ± 204,392	726,614

[a]DUD_{raw} excludes a food density threshold.
[b]DUD_{adj} assumes a food density threshold of 50 kg/ha, below which waterfowl will not exploit available food resources.

Table 7 Model of waterfowl food availability relative to sample waterfowl populations migrating and wintering in the Hackensack Meadowlands, New Jersey.

Season	Model	$\bar{x}$ birds/d[a]	Required DUDs	Available DUDs	Δ DUDs
Fall[b]	DUD_{raw}[e]	6,233	566,862	1,090,019	523,157
	DUD_{adj}[f]	6,233	566,862	980,611	413,749
Winter[c]	DUD_{raw}	1,195	57,360	1,107,482	1,050,122
	DUD_{adj}	1,195	57,360	988,465	931,105
Spring[d]	DUD_{raw}	721	114,316	844,231	729,915
	DUD_{adj}	721	114,316	726,614	612,298

[a] Fall and spring migrating population data taken from weekly surveys conducted on Edwin B. Forsythe National Wildlife Refuge, New Jersey (Source: USFWS 2007a). Wintering population data taken from Mid-Winter Inventory surveys conducted from 2001-2005 in the Hackensack Meadowlands, New Jersey (Source USFWS 2007b)
[b] Fall migration period from 15 September – 14 December
[c] Wintering period from 15 December – 31 January
[d] Spring migration period from 1 Feb – 1 May
[e] DUD_{raw} excludes a food density threshold.
[f] DUD_{adj} assumes a food density threshold of 50 kg/ha, below which waterfowl will not exploit available food resources.

Table 8 Model of waterfowl food availability in the Hackensack Meadowlands relative to the North American Waterfowl Management Plan wintering waterfowl population objectives for Bergen and Hudson counties, New Jersey.

Population Objectives[a]	Target Model	Population[b]	Required DUDs	Available DUDs	Δ DUDs
1970's	DUD_{raw}[c]	4,720	226,560	1,107,482	880,922
	DUD_{adj}[d]	4,720	226,560	988,465	761,905
1990's	DUD_{raw}	10,748	515,904	1,107,482	591,578
	DUD_{adj}	10,748	515,904	988,465	472,561

[a] population objectives were calculated under two scenarios, one based on Mid-Winter Inventory (MWI) survey data and harvest data from 1970-1979, and the other based on MWI survey data from 1990-2002 and harvest data from 1990-1999 (Source: Koneff, unpublished data)
[b] target population objectives are for Bergen and Hudson counties combined (Source: Koneff, unpublished data)
[c] DUD_{raw} excludes a food density threshold
[d] DUD_{adj} assumes a food density threshold of 50 kg/ha, below which waterfowl will not exploit available food resources

Chapter 6

DISCUSSION

Food Availability

Food availability in the Hackensack Meadowlands was greater in tidal habitat compared to restricted habitat for all seasonal sampling periods. Available food resources were at their annual peak in the fall sampling period, which was timed to occur prior to waterfowl migration. Waterfowl food biomass decreased in the winter sampling period, after fall migration had ended and waterfowl were overwintering. Most food biomass available during this period would also be available to waterfowl migrating through the Meadowlands in spring. Food biomass was lowest in the spring sampling period, after most waterfowl had migrated through the Meadowlands.

Although net differences in food biomass between tidal and restricted habitat remained fairly constant from fall through spring, the relative differences in food biomass more than doubled, which suggests tidal habitats may be more important for meeting the energetic requirements of migrating waterfowl in spring. Conversely, differences in available food biomass may also be an indication that dabbling ducks do not utilize tidal habitat to the same extent they do restricted habitat during spring migration; however, my feeding behavior data suggest otherwise. More importantly, the amount of food biomass available after waterfowl had migrated in the spring, especially in tidal habitat, represents an energetic surplus and suggests the

Meadowlands is theoretically capable of supporting additional dabbling ducks during migration and/or wintering seasons. The extent to which my observed food/energetic surplus could support additional migrating and wintering dabbling ducks cannot be fully evaluated because I did not measure food availability and depletion during the summer, when breeding waterfowl, waterbirds, shorebirds, fish, and other wildlife would be consuming some portion of the surplus food biomass identified in my study.

My estimates of food availability in the fall were generally below published estimates for seeds and consumable vegetation; however, only three studies of this type have been conducted in coastal marshes during fall. Singleton (1951) looked at food production in wetlands in the Texas Gulf Coast region and found seed biomass averaged 413.9 kg/ha. Winslow (2003) found seasonally-flooded coastal impoundments in Louisiana provided 244.2 kg/ha of seeds, and Jeminson and Chabreck (1962) estimated such impoundments provided 590.2-642.6 kg/ha of seeds. Production of submerged aquatic vegetation (SAV) in Louisiana coastal impoundments was estimated at 262.3 kg /ha (Winslow 2003). Other fall food availability studies have examined food production in moist-soil impoundments. Moist-soil impoundments were found to provide 790 kg/ha in Illinois (Bowyer et al. 2005), 432-820 kg in Arkansas (Moser et al. 1990), and 331-1,084 kg/ha of seeds Missouri (Reinecke and Hartke 2005). Comparisons of fall invertebrate and root and tuber biomass to published literature could not be made because of a lack of studies dealing with these food items during fall.

Winter invertebrate biomass was similar to published estimates, depending on the wetland type examined. My restricted sites had invertebrate biomass estimates comparable to moist-soil impoundments in Mississippi (0.9-31.2

kg/ha; Gray et al. 1999), and tidal invertebrate biomass was similar to playa wetlands in Texas, which produced 225-1548 kg/ha (Anderson and Smith 2000). Managed ricefields in Mississippi averaged 6.3 kg/ha of invertebrates (Manley et al. 2004), whereas green tree reservoirs in Missouri contained 13.7 kg/ha (White 1985). My seed biomass estimate for restricted sites was less compared to other studies; however, my estimate for tidal sites were similar to Winslow's (2003) estimate of 318.9 kg/ha of seed in coastal impoundments, but below Jemison and Chabreck's (1962) seed biomass estimate of 498.1-858.3 kg/ha. Winter seed biomass estimates in other wetland types ranged from 3.1-19.6 kg/ha in managed ricefields (Manley et al. 2004) to 172-1210 kg/ha in moist-soil impoundments (Gray et al. 1999). My winter estimates of consumable vegetation were effectively 0 kg/ha, but Winslow (2003) estimated winter SAV biomass was 199.4-273.6 kg/ha in coastal impoundments in Louisiana, and Manley et al. (2004) estimated green forage available to waterfowl in managed ricefields was 2.1-58.9 kg/ha. No published values of winter root and tuber biomass could be found to compare with my estimates.

Published studies examining food availability in the spring are more limited compared to other seasons. Invertebrate biomass in restricted sites was similar to published values for ricefields in Louisiana (22 kg/ha; Hohman et al. 1996) and impounded wetlands in New York (18.57 kg/ha; Krull 1976). Tidal invertebrate biomass estimates were much greater than published values. Although my spring seed biomass estimate for restricted sites was well below published estimates, my tidal seed biomass estimate was similar to estimates for coastal wetland impoundments in Louisiana (491.1-737.7 kg/ha; Jeminson and Chabreck 1962) but well below published estimates for ricefields in Louisiana (1,014 kg/ha; Hohman et al. 1996).

Root and tuber biomass estimates for both macrohabitat types were well below Hohman et al.'s (1996) estimate of 53 kg/ha of root and tuber biomass in Louisiana ricefields. No published values of spring consumable vegetation could be found to compare with my biomass estimates

Bioenergetics Modeling

The ability to estimate carrying capacity is an important tool for wildlife managers and conservation planning purposes (Prince 1979, Reinecke et al. 1989, Upper Mississppi River and Great Lakes Region Joint Venture 1998, Guthery 1999, LMVJV Migratory Bird Science Team 2002, Central Valley Joint Venture 2006). My estimates of available DUDs/ha suggest tidal habitats are able to sustain greater dabbling duck numbers compared to restricted habitat, per unit of time during winter and spring migration periods. Available DUDs/ha prior to fall migration were similar between macrohabitat types. However, fewer DUDs/ha were available in restricted habitat than in tidal habitat during the winter and spring sampling periods. In winter, twice the number of wintering waterfowl could be supported on 1 ha of tidal habitat compared to 1 ha of restricted habitat (Table 5). In spring, tidal habitat could support 4 times more migrating waterfowl than restricted habitat could per ha (Table 5). More importantly, my post spring migration (i.e. spring sampling period) modeling predicted that though the number of DUDs/ha were lower than during other sampling periods, a substantial surplus of DUDs/ha remained and most of those DUDs, approximately 3/4, were available in tidal habitat.

In my review of the published literature, no previous research has modeled carry capacity for coastal wetlands in the Atlantic Flyway in terms of their ability to meet the energetic requirements of wintering and migrating dabbling ducks.

Therefore, comparisons of my DUD/ha estimates with estimates from similar studies, in other wetland types, are of limited value. However, ongoing research evaluating carrying capacity of coastal wetlands for American black ducks in southern New Jersey, Long Island Sound, and Virginia should provide comparable estimates in the future (T. Yerkes, Ducks Unlimited, Inc., personal communication).

My fall estimates of available DUDs/ha were below published estimates in other wetland types. Bowyer et al. (2005) estimated moist-soil impoundments in Illinois provided 6,769 DUDs/ha. My DUD/ha estimates for winter exceeded DUD/ha estimates based solely on waste rice available in ricefields in Mississippi (325 DUDs/ha; Stafford et al. 2006), but were similar to managed ricefields when incorporating available moist-soil seeds, invertebrates, and green forage (265-686 DUDs/ha; Manley et al. 2004). In winter, unmanaged playa wetlands in Texas provided 679 DUDs/ha and moist-soil managed playas contained 8,094 DUDs/ha (Anderson and Smith 1999). I could not find estimates of DUDs/ha available in spring in the published literature. My research suggests that estimates of carrying capacity should include a post spring migration period to 1) determine the ability of wetlands to support additional waterfowl that may contribute towards regional and continental waterfowl population goals and 2) properly assess whether or not food availability could be a limiting factor for waterfowl survival and condition prior to the breeding season.

Population Modeling

The energetic requirements of current and target waterfowl populations potentially using the Meadowlands as migration and wintering habitat can be satisfied based on the results of my bioenergetics modeling (Tables 7-8). My model of carrying capacity relative to estimated use by current dabbling duck populations indicated a surplus of available DUDs during each seasonal sampling period that could be used to support additional waterfowl during migration and winter. However, a duck use-day represents an energetic unit that may only be used once during the annual food production cycle. For example, if the Meadowlands were to support an additional 1,000 ducks during the fall migration, the surplus of DUDs available during each season based on current waterfowl use (Table 7) would decline by 91,000 DUDs. Therefore, the remaining duck use-days available after spring migration most accurately reflects the surplus of available waterfowl food that could theoretically be used to support additional numbers of ducks during wintering and migration periods. However, my calculations of carrying capacity focused exclusively on wintering and migrating dabbling ducks, and ignored the energetic requirements of other wildlife species that would exploit the same food resources during the breeding season.

Though useful for planning and evaluation purposes, the calculation of county–level waterfowl population objectives has some limitations. County-level population objectives 'stepped-down' from the continental population objective were primarily artifacts of state-level MWI data and county-level harvest data. MWI data were used in the 'step-down' analysis to distribute the continental population objective to the state level based on the proportional abundance of each waterfowl species observed in the state relative to the entire continent (Koneff, unpublished data). County-level harvest data are then used to distribute the MWI-based state-level population objective among the counties within a state (Koneff, unpublished data). However, neither MWI survey data nor harvest data were ever intended to be used for this purpose. The MWI flies each survey transect within a state only once per year, which limits detectability and may result in high year-to-year variation in waterfowl distribution (e.g., Appendix B) depending on weather conditions and other environmental factors. At the same time, harvest data are not a direct measure of waterfowl distribution, and ‘step-down’ analysis involves using county-level harvest data that include harvest for the entire hunting season, rather than just for the winter period when MWI data is collected, which may overestimate the number of waterfowl each county would need to support (Koneff, unpublished data). Conversely, harvest in urban wetlands areas is likely restrictive and may underestimate the amount of waterfowl the Meadowlands would need to support in order meet state-level population objectives.

Waterfowl Behavioral Monitoring

The original intent of my waterfowl behavioral monitoring component was to assess whether or not dabbling ducks were engaging in foraging behavior during my biomass sampling periods. My results demonstrate that dabbling ducks are actively feeding in tidal and restricted sampling sites during winter and spring sampling periods. Proper assessment and explanation of observed differences in feeding behavior between tidal and restricted sampling sites is confounded by the small number of surveys I conducted. The observed lack of difference in time spent feeding in tidal versus restricted sample sites during winter may relate to availability of food resources and/or as a behavioral response to environmental conditions. Although food resources were more available in tidal sites compared to restricted sampling sites, the relative effect size of differences in food availability were not as substantial as in the spring sampling period. Therefore, food abundance may have been sufficient in both macrohabitat types in winter to preclude a behavioral response that favored one macrohabitat type over another as predicted under optimal foraging theory (OFT; MacArthur and Pianka 1966). In addition, dabbling ducks are most actively feeding in tidal sites during the period around low tide (Jorde 1986). Restricted sites may offer important foraging opportunities for dabbling ducks when the tidal cycle renders large tracts of tidal habit unavailable to waterfowl. Finally, environmental conditions in winter, such as low temperatures, can depress feeding behavior in waterfowl (Albright et al. 1983). Therefore, cold temperatures during the winter sampling period may have contributed to the observed behavioral activity in tidal and restricted sample sites.

My observed differences in feeding behavior for the spring sampling period are most likely explained by differences in the quantity and quality of food resources between tidal and restricted sites. During the spring sampling period, food biomass was nearly five times greater in tidal sites compared to restricted sites. The observed difference in time waterfowl spent feeding in tidal sampling sites compared to restricted sites could be predicted under OFT, which suggests individuals will seek the largest benefit in energy gained per unit of time expended during feeding activities (MacArthur and Pianka 1966). Related to food availability is the possibility of food selection influencing waterfowl use of available food resources. Taylor (1978) and Manley et al. (1992) both found that spring-migrating teal demonstrated a preference for animal foods high in protein. Spring availability of invertebrates in the Meadowlands was much greater in tidal habitat compared to restricted habitat. Waterfowl food requirements relative to available habitat may best explain the observed difference in feeding behavior between macrohabitat types in spring.

Chapter 6

MANAGEMENT IMPLICATIONS

Maximizing the ability of the Hackensack Meadowlands to support migrating and wintering populations of waterfowl is a function of increasing available food resources. The results of my research indicate food availability is greater in tidal habitat than in restricted habitat. Concurrent with trends in food availability, duck use-days/ha were greater in tidal habitats compared to restricted habitat. Where possible, restoration strategies in the Meadowlands should focus on restoring full tidal hydrology to restricted sites, and restoring/enhancing *phragmites*-dominated wetlands to promote vegetation and wetland features (e.g., mudflats) associated with natural salt marsh systems. Restoring restricted wetlands to the extent they approximate conditions in existing tidal habitats could provide an additional 286 kg of available food (i.e., 345 DUDs) for each hectare restored. Based on my assumptions regarding food availability and common reed, the 975 ha of *phragmites*-dominated wetlands in the Meadowlands could provide an additional 586 kg of available food (i.e., 984 DUDs) for each hectare restored to native saltmarsh, or a total of 571,350 kg (i.e., 959,400 DUDs).

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APPENDIX A

Locations of permanent sampling plots used to collect seasonal estimates of available food biomass for dabbling ducks at the Hackensack Meadowlands, New Jersey, 2005-2006.

Site	Macrohabitat	Microhabitat	Plot	Latitude	Longitude
Research Park	Restricted	Shallow Water	1	40.79153	74.03968
			2	40.79168	74.03951
			3	40.79189	74.03925
			4	40.79211	74.03931
			5	40.79232	74.03944
			6	40.79241	74.03976
			7	40.79225	74.03992
			8	40.79196	74.03994
			9	40.79176	74.04006
			10	40.79147	74.03989
Mill Creek Impoundments	Restricted	Shallow Water	1	40.79524	74.04585
			2	40.79570	74.04565
			3	40.79616	74.04456
			4	40.79479	74.04640
			5	40.79469	74.04745
			6	40.78463	74.10060
			7	40.79397	74.04765
			8	40.79409	74.04723
			9	40.79422	74.04676
			10	40.79623	74.04449
Kingsland Impoundment	Restricted	Shallow Water	1	40.78463	74.10061
			2	40.78514	74.10091
			3	40.78514	74.10055
			4	40.78578	74.10064
			5	40.78660	74.10116
			6	40.78676	74.10160
			7	40.78051	74.10018
			8	40.78028	74.09983
			9	40.78019	74.09927
			10	40.78121	74.09836

Appendix A Continued

Site	Macrohabitat	Microhabitat	Plot	Latitude	Longitude
Kearny Brackish Marsh	Restricted	Shallow Water	1	40.75858	74.09534
			2	40.75718	74.10033
			3	40.75691	74.09655
			4	40.75326	74.09729
			5	40.75942	74.09803
			6	40.75979	74.10080
			7	40.75904	74.10082
			8	40.75253	74.10129
			9	40.75967	74.10236
			10	40.75361	74.09938
Harrier Meadows	Restricted	Shallow Water	1	40.78292	74.11694
			2	40.78368	74.11690
			3	40.78575	74.11935
			4	40.78609	74.11928
			5	40.78661	74.11905
			6	40.78624	74.12034
			7	40.78938	74.11911
			8	40.78958	74.11847
			9	40.78910	74.11781
			10	40.78887	74.11872
Saw Mill Wildlife Management Area	Tidal	Mudflat	1	40.76258	74.09305
			2	40.76407	74.09735
			3	40.76381	74.09810
			4	40.76496	74.09753
			5	40.76537	74.09846
			6	40.76599	74.09741
			7	40.76846	74.09907
			8	40.76992	74.09827
			9	40.77113	74.09844
			10	40.77193	74.09893
		Edge	1	40.76997	74.09352
			2	40.76204	74.09381
			3	40.76293	74.09536
			4	40.76596	74.09657
			5	40.76879	74.09768
			6	40.77003	74.09800
			7	40.77153	74.09794
			8	40.77123	74.09588
			9	40.76939	74.09327
			10	40.76877	74.09170
		Cordgrass	1	40.76325	74.09540
			2	40.77039	74.09577

Appendix A Continued

Site	Macrohabitat	Microhabitat	Plot	Latitude	Longitude
			3	40.76286	74.09488
			4	40.76422	74.09558
			5	40.76582	74.09625
			6	40.76795	74.09788
			7	40.76946	74.09755
			8	40.77050	74.09719
			9	40.77321	74.09873
			10	40.77212	74.09693
Mill Creek Marsh	Tidal	Mudflat	1	40.79930	74.04372
			2	40.79948	74.04267
			3	40.80031	74.04300
			4	40.80054	74.04183
			5	40.80162	74.04186
			6	40.80206	74.04118
			7	40.80285	74.04106
			8	40.80370	74.04091
			9	40.80398	74.03995
			10	40.80309	74.04197
		Edge	1	40.80429	74.03945
			2	40.80290	74.03839
			3	40.80249	74.03955
			4	40.80222	74.03981
			5	40.80267	74.04077
			6	40.79894	74.04404
			7	40.80252	74.04233
			8	40.80386	74.04107
			9	40.80409	74.03972
			10	40.80344	74.04220
		Cordgrass	1	40.80389	74.03856
			2	40.80315	74.03777
			3	40.79781	74.04445
			4	40.79772	74.04556
			5	40.79639	74.04892
			6	40.79496	74.04793
			7	40.80435	74.04262
			8	40.80368	74.04280
			9	40.80301	74.04237
			10	40.80499	74.04263
Marsh Resources Meadowlands Mitigation Bank	Tidal	Mudflat	1	40.81384	74.04163
			2	40.81271	74.04072
			3	40.81966	74.03467
			4	40.81917	74.03500

Appendix A Continued

Site	Macrohabitat	Microhabitat	Plot	Latitude	Longitude
			5	40.81883	74.03535
			6	40.81822	74.03562
			7	40.81926	74.03613
			8	40.81693	74.03775
			9	40.81062	74.04496
			10	40.81032	74.04536
		Edge	1	40.81323	74.04077
			2	40.81826	74.03282
			3	40.81707	74.03469
			4	40.81932	74.03661
			5	40.81621	74.03808
			6	40.81787	74.03512
			7	40.81641	74.03901
			8	40.81685	74.03976
			9	40.80990	74.04636
			10	40.80879	74.04758
		Cordgrass	1	40.81354	74.04113
			2	40.81333	74.04072
			3	40.81396	74.04225
			4	40.81308	74.04317
			5	40.81956	74.03559
			6	40.81802	74.03551
			7	40.81783	74.03591
			8	40.81691	74.03591
			9	40.81763	74.03507
			10	40.81764	74.03445

APPENDIX B

Collection dates for seasonal biomass estimates from tidal and restricted sample sites at the Hackensack Meadowlands, New Jersey, 2005-2006.

Site	Macrohabitat	Sample	Dates
Research Park	Restricted	Spring 2005	16-17 April 2005
		Fall 2005	1 September 2005
		Winter 2006	15 December 2005
		Spring 2006	30 March 2006
Mill Creek Impoundments	Restricted	Spring 2005	2 April 2005
		Fall 2005	23 August 2005
		Winter 2006	15 December 2005
		Spring 2006	7 April 2006
Kingsland Impoundment	Restricted	Spring 2005	8-9 April 2005
		Fall 2005	23 August 2005
		Winter 2006	14 December 2005
		Spring 2006	27 March 2006
Kearny Brackish Marsh	Restricted	Spring 2005	30 April, 1May 2005
		Fall 2005	24 August 2005
		Winter 2006	23 January 2006
		Spring 2006	31 March 2006
Harrier Meadows	Restricted	Spring 2005	8-9 April 2005
		Fall 2005	18-19 August 2005
		Winter 2006	15 December, 9 January 2006
		Spring 2006	31 March 2006
Saw Mill Wildlife Management Area	Tidal	Spring 2005	30 April, 1 May 2005
		Fall 2005	24, 26 August 2005
		Winter 2006	9-10 January 2006
		Spring 2006	30-31 March, 25 April 2006
Mill Creek Marsh	Tidal	Spring 2005	16-17 April 2005
		Fall 2005	18-19 August, 31 October 2005[a]

[a] Sample collection was conducted on 31 Oct 2005 to replace samples that were lost or destroyed.

Appendix B Continued

Site	Macrohabitat	Sample	Dates
		Winter 2006	29 December 2005, 04 February 2006
		Spring 2006	21, 23 April 2006
Marsh Resources Meadowlands Mitigation Bank	Tidal	Spring 2005	18 May 2005
		Fall 2005	31 August, 1 September 2005
		Winter 2006	12-13 January 2006
		Spring 2006	6-7 April 2006

[a] Sample collection was conducted on 31 Oct 2005 to replace samples that were lost or destroyed.

APPENDIX C

Percent composition of 2005-2006 seasonal biomass samples collected at samples sites in the Hackensack Meadowlands, New Jersey.

a) Spring 2005

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Inverts								
Annelida								
Oligochaeta	11.3	14.6	0.2	1.7	4.0	9.1	16.9	7.5
Polychaeta		29.0	4.4					29.2
Arachnida								
Crustacea								
Amphipoda		10.1	0.5	0.1	0.5		1.8	5.7
Cirripedia								
Decapoda			7.7	1.5				
Isopoda								10.2
Ostracoda	0.3							
Insecta								
Coleoptera						<0.1	0.5	1.1
Diptera	56.0	1.3	21.2	6.7	1.2	4.4	0.2	3.0
Hemiptera								
Hemiptera: Aphididae							0.1	0.2
Hemiptera: Diaspididae								
Hymenoptera								
Lepidoptera								
Odonata								
Tricoptera								
Mollusca								
Bivalvia								7.5
Bivalvia: Mytilidae								
Gastropoda			5.8	30.7	1.3	4.3	11.1	6.9

a HM = Harrier Meadows; KBM = Kearney Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Seeds								
Amaranthaceae: *Amaranthus*	1.2		0.5	0.2		<0.1	0.2	0.4
Anacardiaceae: *Rhus*				0.4			1.6	
Apiaceae (unknown)								
Asteraceae (unknown)						0.3	0.7	<0.1
Asteraceae: *Aster*	0.9	1.1			<0.1	1.1	0.9	
Asteraceae: *Pluchea*								
Betulaceae: *Betula*						<0.1		
Brassicaceae: *Brassica*		0.3				0.4	<0.1	
Brassicaceae: *Lepidium*		0.1		13.4	0.4	<0.1	11.2	
Brassicaceae: *Sinapis*								
Caprifoliaceae: *Lonicera*								
Caprifoliaceae: *Sambucus*					1.4		0.1	
Caprifoliaceae: *Viburnum*								
Caryophyllaceae (unknown)								
Chenopodiaceae: *Atriplex*		11.1	0.7	5.3	0.1	1.1	7.3	<0.1
Chenopodiaceae: *Chenopodium*			0.0	0.4			0.1	4.2
Cornaceae: *Nyssa*							0.8	
Cyperaceae: *Carex*		7.0			0.4	0.3	0.1	
Cyperaceae: *Cladium*	3.1	8.6	3.5	1.0	12.3	0.6	9.2	2.1
Cyperaceae: *Cyperus*	5.3	2.0				0.1	0.9	0.1
Cyperaceae: *Eleocharis*					0.2	2.6	0.6	
Cyperaceae: *Scirpus*	11.6	0.1	45.7	2.6	61.5	67.1	30.8	16.2
Ericaceae: *Vaccinium*								
Euphorbiaceae: *Acalypha*								
Fabaceae (unknown)						0.2		
Fabaceae: *Vicia*		0.7		7.4		0.1		
Hydrophyllaceae: *Hydrophyllum*								
Juncaceae: *Juncus*					0.3	3.0		0.2
Leguminosae (unknown)								
Najadaceae: *Potamogeton*					12.8			
Najadaceae: *Ruppia*		0.3						
Najadaceae: *Zannichellia*						<0.1		
Phytolaccaceae: *Phytolacca*			2.2	11.5	0.3	1.1	1.0	
Poaceae (unknown)	0.8					0.1	<0.1	<0.1
Poaceae: *Digitaria*								
Poaceae: *Oryzopsis*								
Poaceae: *Panicum*								
Poaceae: *Phragmites*	1.2	5.1	7.6	0.2	0.3	0.4	1.1	3.4
Poaceae: *Spartina*							0.1	<0.1

[a] HM = Harrier Meadows; KBM = Kearney Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Poaceae: *Sporobolus*								
Polygonaceae: *Polygonum*	3.6	8.6		16.9	2.8	1.0	0.6	2.0
Polygonaceae: *Rumex*							0.8	
Rhamnaceae: *Frangula*								
Umbelliferae (Unknown)								
Verbenaceae: *Verbena*		0.1						
Vitaceae: *Vitis*						1.8		
Unknown Seed					0.1			
Roots & Tubers								
Cyperaceae: *Eleocharis* (root)						0.9	1.5	
Unknown Root								
Vegetation								
Lemnaceae: *Lemna* (algae)								
Unknown Algae	4.5							
Unknown Foliage								

[a] HM = Harrier Meadows; KBM = Kearney Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

b) Fall 2005

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Inverts								
Annelida								
Oligochaeta	<0.1	5.8	0.2	0.1	1.4	4.7	4.5	3.8
Polychaeta		19.6	0.9	<0.1		4.0	0.9	12.3
Arachnida	<0.1					<0.1	<0.1	<0.1
Crustacea								
Amphipoda				<0.1		<0.1		
Cirripedia		1.9						
Decapoda				0.6	0.3		<0.1	1.2
Isopoda								10.1
Ostracoda	20.3	2.0	30.7	0.1	0.2	0.4	2.2	3.1
Insecta								
Coleoptera	0.1	4.6	1.8	0.4	1.9	0.4	0.8	0.9
Diptera	6.2	0.4	0.3	0.1	1.5	0.3	1.3	2.8
Hemiptera							<0.1	0.0
Hemiptera: Aphididae						<0.1	<0.1	
Hemiptera: Diaspididae						0.3		0.8
Hymenoptera		<0.1				<0.1		
Lepidoptera							<0.1	
Odonata								
Tricoptera		0.4		<0.1	<0.1		<0.1	
Mollusca								
Bivalvia				2.4		5.6	<0.1	6.1
Bivalvia: Mytilidae								2.8
Gastropoda	1.9	1.3	2.7	56.6	0.8	21.1	31.5	2.5
Seeds								
Amaranthaceae: *Amaranthus*	1.4	0.1	0.1			<0.1	<0.1	
Anacardiaceae: *Rhus*								
Apiaceae (unknown)	0.1		<0.1	<0.1				
Asteraceae (unknown)	<0.1	1.2	0.1	0.1	0.7	0.4	4.0	0.2
Asteraceae: *Aster*	0.7			0.1	0.2	2.3	1.4	0.1
Asteraceae: *Pluchea*						1.6	2.1	
Betulaceae: *Betula*		<0.1	0.6	0.1	<0.1	0.3	<0.1	< 0.1
Brassicaceae: *Brassica*								
Brassicaceae: *Lepidium*	0.1	4.4	0.6	6.6	5.6	1.1	5.0	0.8
Brassicaceae: *Sinapis*							<0.1	
Caprifoliaceae: *Lonicera*					1.2	0.1		

[a] HM = Harrier Meadows; KBM = Kearney Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Caprifoliaceae: *Sambucus*					1.7		<0.1	0.1
Caprifoliaceae: *Viburnum*								
Caryophyllaceae (unknown)								
Chenopodiaceae: *Atriplex*	4.2	1.4	0.2	1.2	0.7	0.6	0.8	0.4
Chenopodiaceae: *Chenopodium*	<0.1						<0.1	
Cornaceae: *Nyssa*								
Cyperaceae: *Carex*	<0.1	0.2		<0.1	0.5	0.6	0.2	0.4
Cyperaceae: *Cladium*		2.9	6.0	1.0	21.2	0.6	4.2	1.8
Cyperaceae: *Cyperus*			0.2	0.3	0.4	0.2	1.0	0.1
Cyperaceae: *Eleocharis*	0.1	1.9	<0.1		0.1	1.4	0.3	0.6
Cyperaceae: *Scirpus*	0.8	1.3	15.9	3.1	33.5	26.8	14.1	26.8
Ericaceae: *Vaccinium*						0.1		
Euphorbiaceae: *Acalypha*					0.1			
Fabaceae (unknown)								
Fabaceae: *Vicia*			<0.1	7.4		<0.1	0.1	<0.1
Hydrophyllaceae: *Hydrophyllum*					0.2			
Juncaceae: *Juncus*			0.1		0.6	2.8	0.9	0.1
Leguminosae (unknown)							1.0	
Najadaceae: *Potamogeton*	<0.1		0.1		7.6			<0.1
Najadaceae: *Ruppia*	<0.1	<0.1						
Najadaceae: *Zannichellia*			<0.1	0.4		0.2	<0.1	0.1
Phytolaccaceae: *Phytolacca*			0.2	0.3	1.4	0.7	0.1	
Poaceae (unknown)			<0.1			0.1	<0.1	<0.1
Poaceae: *Digitaria*								
Poaceae: *Oryzopsis*						<0.1	<0.1	
Poaceae: *Panicum*	4.2	1.6	0.1		0.3	0.6	0.3	0.1
Poaceae: *Phragmites*	0.7	10.3	30.5	1.5	2.1	3.4	3.6	7.0
Poaceae: *Spartina*		2.6			1.6	4.4	8.5	12.9
Poaceae: *Sporobolus*								
Polygonaceae: *Polygonum*		4.3	0.1	6.7	13.8	1.3	0.8	1.2
Polygonaceae: *Rumex*				<0.1		<0.1	0.1	0.5
Rhamnaceae: *Frangula*						0.1		
Umbelliferae (unknown)								
Verbenaceae: *Verbena*								
Vitaceae: *Vitis*							0.9	
Unknown Seed		16.2	<0.1		0.2	<0.1	0.2	0.3
Roots & Tubers								
Cyperaceae: *Eleocharis* (root)	4.1		<0.1	<0.1	0.2	13.5	8.6	
Unknown Root		0.3	0.1	0.1	<0.1	0.1	0.5	<0.1

[a] HM = Harrier Meadows; KBM = Kearney Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Vegetation								
Lemnaceae: *Lemna* (algae)			1.0					0.2
Unknown Algae	54.0	9.1	7.6	1.5				
Unknown Foliage	1.0	6.1		9.2		<0.1	<0.1	

[a] HM = Harrier Meadows; KBM = Kearny Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

c) Winter 2006

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Inverts								
Annelida								
Oligochaeta	1.3	0.5	0.1	1.4	0.7	1.8	5.7	2.0
Polychaeta	0.2	35.7	0.4			2.5	1.0	16.9
Arachnida						<0.1	0.4	<0.1
Crustacea								
Amphipoda		1.4						0.3
Cirripedia								
Decapoda								
Isopoda								7.3
Ostracoda	42.0	9.6	27.5	<0.1	0.1	2.2	<0.1	3.3
Insecta								
Coleoptera	1.5	4.4	4.9	0.3	1.0	0.6	1.0	1.6
Diptera	43.9	1.0	5.3	2.5	0.1	1.9	1.5	0.8
Hemiptera						<0.1	<0.1	<0.1
Hemiptera: Aphididae						<0.1	<0.1	
Hemiptera: Diaspididae					<0.1	<0.1	<0.1	0.1
Hymenoptera						<0.1	<0.1	
Lepidoptera							0.1	
Odonata					<0.1			
Tricoptera								
Mollusca								
Bivalvia		1.6				7.6	<0.1	0.2
Bivalvia: Mytilidae								
Gastropoda			1.2	52.3	0.1	3.6	3.0	<0.1
Seeds								
Amaranthaceae: *Amaranthus*		0.6	0.2		<0.1	<0.1	<0.1	
Anacardiaceae: *Rhus*								
Apiaceae (unknown)				0.1		<0.1		
Asteraceae (unknown)	0.1	0.7	0.1	0.1	0.1	0.2	7.1	0.4
Asteraceae: *Aster*	0.1	0.1	0.1	1.5	0.1	1.9	5.7	<0.1
Asteraceae: *Pluchea*								
Betulaceae: *Betula*		1.7	<0.1	0.4	<0.1	0.7	<0.1	<0.1
Brassicaceae: *Brassica*								
Brassicaceae: *Lepidium*		1.5	0.3	4.9	3.5	1.4	8.1	0.2
Brassicaceae: *Sinapis*								
Caprifoliaceae: *Lonicera*								

[a] HM = Harrier Meadows; KBM = Kearny Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Caprifoliaceae: *Sambucus*			1.6		1.3	0.1	0.1	<0.1
Caprifoliaceae: *Viburnum*								
Caryophyllaceae (unknown)					1.5			
Chenopodiaceae: *Atriplex*	0.3	0.6	0.8	3.1	0.9	1.7	0.7	0.4
Chenopodiaceae: *Chenopodium*								
Cornaceae: *Nyssa*								
Cyperaceae: *Carex*		1.7	0.2	0.1	0.4	0.8	0.3	0.5
Cyperaceae: *Cladium*		0.9	4.3		7.8	0.8	4.2	2.4
Cyperaceae: *Cyperus*		0.6	0.4	0.4	0.4	0.1	0.6	0.2
Cyperaceae: *Eleocharis*			0.6	0.2	0.3	0.8	0.4	0.5
Cyperaceae: *Scirpus*	2.2		31.9	1.8	56.5	44.0	28.6	19.2
Ericaceae: *Vaccinium*				0.2		0.1	<0.1	
Euphorbiaceae: *Acalypha*			<0.1		0.2			
Fabaceae (unknown)								
Fabaceae: *Vicia*		0.6		16.5	0.1	0.1	0.3	1.6
Hydrophyllaceae: *Hydrophyllum*						<0.1		
Juncaceae: *Juncus*			0.9	2.0	0.2	3.2	0.6	0.9
Leguminosae (unknown)		2.7						
Najadaceae: *Potamogeton*			0.2		5.4		0.1	
Najadaceae: *Ruppia*								
Najadaceae: *Zannichellia*			0.1	0.3		0.3	<0.1	0.7
Phytolaccaceae: *Phytolacca*		2.0	1.7	2.1	1.9	1.2	0.4	
Poaceae (unknown)	2.1						0.2	<0.1
Poaceae: *Digitaria*								
Poaceae: *Oryzopsis*								
Poaceae: *Panicum*	1.0	1.0			<0.1	0.3	<0.1	0.7
Poaceae: *Phragmites*	0.6	26.6	12.2	1.0	3.0	4.5	15.1	10.5
Poaceae: *Spartina*						7.0	7.6	27.8
Poaceae: *Sporobolus*								
Polygonaceae: *Polygonum*	4.7	4.3	3.4	5.7	13.6	1.9	0.5	0.7
Polygonaceae: *Rumex*						0.4	0.2	
Rhamnaceae: *Frangula*						1.1		
Umbelliferae (unknown)					0.6			
Verbenaceae: *Verbena*					<0.1	<0.1	<0.1	<0.1
Vitaceae: *Vitis*								
Unknown Seed			0.1	2.3	0.1			
Roots & Tubers								
Cyperaceae: *Eleocharis* (root)			0.1	<0.1	0.1	6.8	6.2	<0.1
Unknown Root			0.2	0.6	0.1	0.3	0.6	1.0

[a] HM = Harrier Meadows; KBM = Kearny Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Vegetation								
Lemnaceae: *Lemna* (algae)			1.2					
Unknown Algae								
Unknown Foliage								

[a] HM = Harrier Meadows; KBM = Kearny Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

d) Spring 2006

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Inverts								
Annelida								
Oligochaeta	6.9	2.6	0.8	1.6	5.3	6.4	6.5	2.2
Polychaeta		19.7	3.9	0.1		4.3	2.3	17.6
Arachnida	0.3					<0.1	0.1	
Crustacea								
Amphipoda	25.4	0.7				0.1	0.3	0.9
Cirripedia								
Decapoda								
Isopoda								5.6
Ostracoda	7.9	0.5	15.2	<0.1		0.2	<0.1	2.4
Insecta								
Coleoptera	0.6	3.4	0.8	<0.1	1.4	0.3	0.5	3.0
Diptera	30.0	0.9	7.8	11.5	1.4	1.3	2.0	1.5
Hemiptera						<0.1	<0.1	
Hemiptera: Aphididae							<0.1	
Hemiptera: Diaspididae		0.1				<0.1		0.2
Hymenoptera								
Lepidoptera								
Odonata								
Tricoptera					<0.1	<0.1		
Mollusca								
Bivalvia				1.0	<0.1	6.4	<0.1	
Bivalvia: Mytilidae								
Gastropoda		2.8	0.8	66.2		8.1	5.3	1.8
Seeds								
Amaranthaceae: *Amaranthus*		2.6	1.4	<0.1		<0.1		
Anacardiaceae: *Rhus*							0.2	
Apiaceae (unknown)								
Asteraceae (unknown)	0.1	0.4	0.4	0.2	<0.1	0.2	6.8	0.4
Asteraceae: *Aster*	0.2	0.5	0.1	0.2	0.3	0.9	4.6	
Asteraceae: *Pluchea*								
Betulaceae: *Betula*		0.1	0.1	<0.1	0.1	0.6	<0.1	
Brassicaceae: *Brassica*								
Brassicaceae: *Lepidium*		0.2	0.1	2.7	8.3	1.5	8.6	
Brassicaceae: *Sinapis*								
Caprifoliaceae: *Lonicera*								

[a] HM = Harrier Meadows; KBM = Kearny Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCM	MRI	SMWMA
Caprifoliaceae: *Sambucus*		0.3	0.6	0.2	2.2	0.8	<0.1	
Caprifoliaceae: *Viburnum*							0.5	
Caryophyllaceae (unknown)								
Chenopodiaceae: *Atriplex*	1.7	1.3	0.7	1.1	0.5	1.0	0.8	1.3
Chenopodiaceae: *Chenopodium*								
Cornaceae: *Nyssa*								
Cyperaceae: *Carex*		0.1		<0.1	0.3	0.8	0.2	0.9
Cyperaceae: *Cladium*			1.7	0.4	5.3	0.5	4.5	1.2
Cyperaceae: *Cyperus*	0.5	0.8	0.2	0.4	0.2	0.3	0.3	0.4
Cyperaceae: *Eleocharis*	0.3		0.5	<0.1	<0.1	1.7	0.3	1.2
Cyperaceae: *Scirpus*	2.8	6.0	27.0	3.5	49.8	38.8	20.9	16.0
Ericaceae: *Vaccinium*	1.8			0.1		<0.1		
Euphorbiaceae: *Acalypha*		0.2	0.4		0.2			<0.1
Fabaceae (unknown)								
Fabaceae: *Vicia*		0.2		4.3		0.2	0.2	< 0.1
Hydrophyllaceae: *Hydrophyllum*								
Juncaceae: *Juncus*		0.2			0.3	4.0	0.6	1.1
Leguminosae (unknown)						0.1		0.6
Najadaceae: *Potamogeton*					8.6			
Najadaceae: *Ruppia*	7.8		<0.1					
Najadaceae: *Zannichellia*				<0.1		0.1		0.1
Phytolaccaceae: *Phytolacca*				2.1	1.6	0.9	0.2	
Poaceae (unknown)	0.8					<0.1	<0.1	<0.1
Poaceae: *Digitaria*	0.1							
Poaceae: *Oryzopsis*								
Poaceae: *Panicum*		0.8			0.2	0.7	<0.1	<0.1
Poaceae: *Phragmites*	1.3	47.8	34.9	1.3	2.7	5.7	14.3	6.6
Poaceae: *Spartina*		2.2		0.5		4.5	10.7	34.6
Poaceae: *Sporobolus*							0.1	
Polygonaceae: *Polygonum*	11.2	0.4	1.5	2.3	10.4	1.5	1.8	<0.1
Polygonaceae: *Rumex*						0.2	0.1	
Rhamnaceae: *Frangula*		5.1						
Umbelliferae (unknown)					0.7			
Verbenaceae: *Verbena*		0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Vitaceae: *Vitis*								
Unknown Seed							0.2	
Roots & Tubers								
Cyperaceae: *Eleocharis* (root)				0.1	<0.1	7.3	7.0	0.1
Unknown Root			0.1	<0.1		0.2	0.1	

[a] HM = Harrier Meadows; KBM = Kearny Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments; RP = Research Park; MCM = Mill Creek Marsh; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

Appendix C Continued.

Biomass Type	Site[a]							
	HM	KBM	KI	MCI	RP	MCT	MRI	SMWMA
Vegetation								
Lemnaceae: *Lemna* (algae)	0.1		1.0					
Unknown Algae								
Unknown Foliage						0.1		0.2

[a] HM = Harrier Meadows; KBM = Kearny Brackish Marsh; KI = Kingsland Impoundment; MCI = Mill Creek Impoundments;RP = Research Park; MCT = Mill Creek; MRI = Marsh Resources Meadowlands Mitigation Bank; SMWMA = Saw Mill Wildlife Management Areas.

APPENDIX D

Percent availability of shallow water microhabitat (water depth <30cm) in restricted sample sites at the Hackensack Meadowlands, New Jersey.

Site	Availability
Harrier Meadows	60%
Kearney Brackish Marsh	8%
Kingsland Impoundment	23%
Mill Creek Impoundments	79%
Research Park	70%

APPENDIX E

Percent availability of microhabitats in tidal sample sites at the Hackensack Meadowlands, New Jersey.

	Site		
Microhabitat	Mill Creek Marsh	Marsh Resources Meadowlands Mitigation Bank (MRI)	Saw Mill Wildlife Management Area
Cordgrass	10%	57%	38%
Edge	1%	2%	1%
Mudflat	45%	21%	41%
Other[a]	44%	20%	20%

[a] Other includes upland habitat, deepwater habitat, common reed and other vegetation.

APPENDIX F

A summary of published true metabolizable energy (TME) values (kcal/g) for waterfowl food items.

Food Item	TME	Test Species[a]	Source
Plant Foods[b]			
Alismaceae: *Sagittaria latifolia*	3.06	MALL	Hoffman and Bookhout 1985
Amaranthaceae: *Amaranthus* spp.	2.97	MALL	Checkett et al. 2002
Asteraceae: *Bidens cernua*	0.55	BWTE	Sherfy 1999
Brassicaceae: *Lepidium latifolium*	1.31	MALL	Dugger et al. 2006 (in review)
Chenopodiaceae: *Chenopodium album*	2.52	MALL	Dugger et al. 2006 (in review)
Cladophoraceae: *Cladophora* spp. (algae)	0.59	WPDU	Muztar et al. 1977
Cymodoceae: *Halodule wrightii* (foliage)	0.82	NOPI	Ballard et al. 2004
Cymodoceae: *Halodule wrightii* (rhizomes)	0.90	NOPI	Ballard et al. 2004
Cyperaceae: *Cyperus esculentus*	1.96	BWTE	Sherfy 1999
Cyperaceae: *Eleocharis palustris*	0.50	MALL	Dugger et al. 2006 (in review)
Cyperaceae: *Fimbristylis annua*	0.49	BWTE	Sherfy 1999
Cyperaceae: *Rhynchospora corniculata*	1.86	MALL	Checkett et al. 2002
Cyperaceae: *Scirpus americanus*	0.64	BWTE	Sherfy 1999
Cyperaceae: *Scirpus pungens*	0.50	BWTE	Sherfy 1999
Cyperaceae: *Scirpus robustus*	0.65	MALL	Dugger et al. 2006 (in review)
Cyperaceae: *Scirpus validus*	0.99	MALL	Hoffman and Bookhout 1985
Cyperaceae: *Scirpus validus*	0.85	NOPI	Hoffman and Bookhout 1985
Fagaceae: *Quercus nigra* (acorns)	2.38	MALL	Reinecke, unpublished data[c]
Fagaceae: *Quercus nutalli* (acorns)	2.35	MALL	Reinecke, unpublished data[c]
Fagaceae: *Quercus pagoda* (acorns)	2.85	WODU	Kaminski et al. 2003
Fagaceae: *Quercus palustris* (acorns)	2.65	WODU	Kaminski et al. 2003
Fagaceae: *Quercus palustris* (acorns)	2.72	CAGO	Petrie 1994
Fagaceae: *Quercus phellos* (acorns)	2.91	MALL	Reinecke, unpublished data[c]
Haloragaceae: *Myriophyllum spicatum* (foliage)	0.42	WPDU	Muztar et al. 1977

[a] Species abbreviations: AMBD = American black duck, BWTE = blue-winged teal, CAGO = Canada goose, DABB = unknown species of dabbling duck, LESC = lesser scaup, MALL = mallard, MUDU = Muscovy duck, NOPI = northern pintail, UNK = unknown species of waterfowl, WODU = wood duck, WPDU = white Peking duck

[b] Plant Foods are seeds unless otherwise indicated

[c] In Kaminski et al. 2003

[d] In Baldassarre and Bolen 2006

[e] Unpublished in Miller and Reinecke 1984

Appendix F Continued

Food Item	TME	Test Species[a]	Source
Hydrocharitaceae: *Vallisneria Americana* (foliage)	0.71	WPDU	Muztar et al. 1977
Juncaceae: *Juncus canadensis*	1.21	BWTE	Sherfy 1999
Lemnaceae: *Lemna minor* (algae)	1.07	BWTE	Fredrickson and Reid 1988
Najadaceae: *Potomegeton* spp. (foliage)	0.64	WPDU	Muztar et al. 1977
Najadaceae: *Potomegeton* spp.	5.94	NOPI	Ballard et al. 2004
Najadaceae: *Ruppia maritima*	5.94	NOPI	Ballard et al. 2004
Poaceae: *Digitaria ischaemum*	3.10	MALL	Checkett et al. 2002
Poaceae: *Digitaria sanguinalis*	3.09	MALL	Checkett et al. 2002
Poaceae: *Echinochloa* spp.	2.63	UNK (♂)	Fredrickson and Reid 1988
Poaceae: *Echinochloa* spp.	2.99	UNK (♀)	Fredrickson and Reid 1988
Poaceae: *Echinochloa colonum*	2.54	MALL	Reinecke et al. 1989
Poaceae: *Echinochloa crusgalli*	2.65	BWTE	Sherfy 1999
Poaceae: *Echinochloa crusgalli*	2.67	BWTE	Sherfy et al. 2001
Poaceae: *Echinochloa crusgalli*	2.61	MALL	Checkett et al. 2002
Poaceae: *Echinochloa crusgalli*	3.29	CAGO	Petrie et al. 1998
Poaceae: *Echinochloa walteri*	2.86	MALL	Hoffman and Bookhout 1985
Poaceae: *Echinochloa walteri*	2.82	NOPI	Hoffman and Bookhout 1985
Poaceae: *Leersia oryzoides*	3.00	MALL	Hoffman and Bookhout 1985
Poaceae: *Leersia oryzoides*	2.82	NOPI	Hoffman and Bookhout 1985
Poaceae: *Leersia oryzoides*	3.00	UNK (♂)	Fredrickson and Reid 1988
Poaceae: *Panicum dichotomiflorum*	2.54	BWTE	Sherfy 1999
Poaceae: *Panicum dichotomiflorum*	2.75	MALL	Checkett et al. 2002
Poaceae: *Panicum virgatum*	2.05	BWTE	Sherfy 1999
Poaceae: *Paspalum leave*	1.57	MALL	Checkett et al. 2002
Poaceae: *Setaria lutescens*	2.88	MALL	Checkett et al. 2002
Poaceae: *Spartina patens*	0.05	BWTE	Sherfy 1999
Poaceae: *Zizania aquatica*	3.47	BWTE	Sherfy 1999
Polygonaceae: *Polygonum lapthifolium*	1.52	MALL	Checkett et al. 2002
Polygonaceae: *Polygonum pensylvanicum*	1.08	MALL	Hoffman and Bookhout 1985
Polygonaceae: *Polygonum pensylvanicum*	1.25	NOPI	Hoffman and Bookhout 1985
Polygonaceae: *Polygonum pensylvanicum*	1.12	DABB (♂)	Fredrickson and Reid 1988
Polygonaceae: *Polygonum pensylvanicum*	1.10	DABB (♀)	Fredrickson and Reid 1988
Polygonaceae: *Polygonum pensylvanicum*	1.59	CAGO	Petrie et al. 1998
Polygonaceae: *Polygonum pensylvanicum*	1.30	BWTE	Sherfy et al. 2001
Polygonaceae: *Rumex crispus*	2.68	MALL	Checkett et al. 2002

[a] Species abbreviations: AMBD = American black duck, BWTE = blue-winged teal, CAGO = Canada goose, DABB = unknown species of dabbling duck, LESC = lesser scaup, MALL = mallard, MUDU = Muscovy duck, NOPI = northern pintail, UNK = unknown species of waterfowl, WODU = wood duck, WPDU = white Peking duck
[b] Plant Foods are seeds unless otherwise indicated
[c] In Kaminski et al. 2003
[d] Unpublished in Miller and Reinecke 1984

Appendix F Continued

Food Item	TME	Test Species[a]	Source
Invertebrates			
Amphipoda: Gammaridae: *Gammarus* spp.	2.29	LESC	Sudgen 1973
Amphipoda: Gammaridae: *Gammarus* spp.	2.32	BWTE	Frederickson and Reid 1988
Amphipoda: Gammaridae: *Gammarus* spp.	2.21	AMBD	Jorde and Owen 1988
Amphipoda: Gammaridae: *Gammarus* spp.	2.39	NOPI	Ballard et al. 2004
Bivalvia: Mytilidae: *Mytilis edulis*	0.76	AMBD	Jorde and Owen 1988
Bivalvia: Myidae: *Mya arenaria*	0.52	AMBD	Jorde and Owen 1988
Bivalvia: Mactridae: *Mulinia lateralis*	0.00	NOPI	Ballard et al. 2004
Cladocera: Daphnidae	0.82	BWTE	Frederickson and Reid 1988
Diptera: Chironomidae	0.27	BWTE	Sherfy 1999
Gastropoda: Lymnaeidae	0.59	BWTE	Frederickson and Reid 1988
Gastropoda: Littorinidae: *Littorina spp.*	0.39	AMBD	Jorde and Owen 1988
Hemiptera: Corixidae	0.48	BWTE	Sherfy 1999
Isopoda	0.08	BWTE	Sherfy 1999
Crops			
Fabaceae: *Glycine max*	2.65	MALL	Reinecke et al. 1989
Fabaceae: *Glycine max*	3.55	CAGO	Petrie et al. 1998
Fabaceae: *Medicago sativa* (foliage)	1.34	WPDU	Muztar et al. 1977
Poaceae: *Avena* spp. (hull-less)	3.64	WPDU	King et al. 1997
Poaceae: *Hordeum* spp.	2.86	WPDU	Ragland et al. 1997
Poaceae: *Hordeum* spp.	3.17	MUDU	Penkov and Gerzilov 2004
Poaceae: *Oryza sativa*	2.81	CAGO	Petrie et al. 1998
Poaceae: *Oryza sativa*	3.34	MALL	Reinecke et al. 1989
Poaceae: *Oryza* spp.	3.61	WPDU	King et al. 1997
Poaceae: *Pennisetum glaucum*	3.48	WPDU	Ragland et al. 1997
Poaceae: *Secale cereale*	2.85	WPDU	King et al. 1997
Poaceae: *Sorghum vulgare*	3.57	WPDU	Ragland et al. 1997
Poaceae: *Sorghum vulgare*	3.78	CAGO	Petrie et al. 1998
Poaceae: *Sorghum vulgare*	3.49	BWTE	Sherfy et al. 2001
Poaceae: *Triticosecale rimpaui*	3.07	WPDU	Ragland et al. 1997
Poaceae: *Triticum aestivum* (foliage)	2.40	CAGO	Petrie et al. 1998
Poaceae: *Triticum* spp.	3.43	MALL	Reinecke and Kirk[e]
Poaceae: *Triticum* spp.	3.38	CAGO	Petrie et al. 1998
Poaceae: *Triticum* spp.	3.30	WPDU	King et al. 1997
Poaceae: *Zea mays*	3.90	CAGO	Petrie et al. 1998

[a] Species abbreviations: AMBD = American black duck, BWTE = blue-winged teal, CAGO = Canada goose, DABB = unknown species of dabbling duck, LESC = lesser scaup, MALL = mallard, MUDU = Muscovy duck, NOPI = northern pintail, UNK = unknown species of waterfowl, WODU = wood duck, WPDU = white Peking duck

[b] Food items are seeds unless otherwise indicated

[c] In Kaminski et al. 2003

[d] Unpublished in Miller and Reinecke 1984

Appendix F Continued

Food Item	TME	Test Species[a]	Source
Poaceae: *Zea* spp.	3.76	MALL	Reinecke and Kirk[d]
Poaceae: *Zea* spp.	3.67	MALL	Reinecke et al. 1989
Poaceae: *Zea* spp.	3.27	WPDU	King et al. 1997
Poaceae: *Zea* spp.	3.40	WPDU	King et al. 1997
Poaceae: Zea spp.	3.34	WPDU	Ragland et al. 1997
Poaceae: Zea spp.	3.46	WPDU	Ragland et al. 1997

[a] Species abbreviations: AMBD = American black duck, BWTE = blue-winged teal, CAGO = Canada goose, DABB = unknown species of dabbling duck, LESC = lesser scaup, MALL = mallard, MUDU = Muscovy duck, NOPI = northern pintail, UNK = unknown species of waterfowl, WODU = wood duck, WPDU = white Peking duck
[b] Food items are seeds unless otherwise indicated
[c] In Kaminski et al. 2003
[d] Unpublished in Miller and Reinecke 1984

APPENDIX G

Assignment of TME values (kcal/g) used in the calculation of Duck Use-Days (DUDs) based on published TME values (Appendix A) and food items found in 2005-2006 seasonal biomass samples taken from the Hackensack Meadowlands, New Jersey**.**

Food Item	TME	Calculation
Invertebrates		
Arachnida	0.7	average of published invertebrate TME values
Crustacea		
Amphipoda	2.30	average of published Amphipoda TME values
Decapoda	1.19	average of TME values for Amphipoda (avg) + Isopoda
Isopoda	0.08	TME value for Isopoda
Ostracoda	1.01	avg of Brachiopoda (Cladocera) + Malacostraca (Isopoda + Amphipoda)
Insecta		
Coleoptera	0.48	TME for Hemiptera: Corixidae
Diptera	0.27	TME for Diptera: Chironomidae (larvae)
Hemiptera (unknown)	0.48	TME for Hemiptera: Corixidae
Hemiptera: Aphididae	0.48	TME for Hemiptera: Corixidae
Hemiptera: Diaspididae	0.48	TME for Hemiptera: Corixidae
Hymenoptera (unknown)	0.38	average of published TME values for Class Insecta
Lepidoptera (unknown)	0.38	average of published TME values for Class Insecta
Odonata (unknown)	0.38	average of published TME values for Class Insecta
Tricoptera	0.38	average of published TME values for Class Insecta
Mollusca		
Bivalvia	0.43	average of published TME values for genera of Bivalvia
Bivalvia: Mytilidae	0.76	TME for Bivalvia: Mytilidae: Mytilis edulis
Gastropoda	0.49	average of TME values for Gastropoda (Lymnaeidae + Littorinidae)
Seeds		
Amaranthaceae: *Amaranthus* spp.	2.97	TME for Amaranthaceae: *Amaranthus* spp.
Anacardiaceae: *Rhus* spp.	1.93	average of published seed TME values
Apiaceae (unknown)	1.93	average of published seed TME values
Asteraceae (unknown)	0.55	TME for Asteraceae: *Bidens cernua*
Asteraceae: *Aster* spp.	0.55	TME for Asteraceae: *Bidens cernua*
Asteraceae: *Pluchea* spp.	0.55	TME for Asteraceae: *Bidens cernua*

Appendix G Continued

Food Item	TME	Derivation
Betulaceae: *Betula* spp.	1.93	average of published seed TME values
Brassicaceae: *Brassica* spp.	1.31	TME for Brassicaceae: *Lepidium latifolium*
Brassicaceae: *Lepidium* spp.	1.31	TME for Brassicaceae: *Lepidium latifolium*
Brassicaceae: *Sinapis* spp.	1.31	TME for Brassicaceae: *Lepidium latifolium*
Caprifoliaceae: *Lonicera* spp.	1.93	average of published seed TME values
Caprifoliaceae: *Sambucus* spp.	1.93	average of published seed TME values
Caprifoliaceae: *Viburnum* spp.	1.93	average of published seed TME values
Caryophyllaceae:	1.93	average of published seed TME values
Chenopodiaceae: *Atriplex* spp.	2.52	TME for Chenopodiaceae: *Chenopodium album*
Chenopodiaceae: *Chenopodium* spp.	2.52	TME for Chenopodiaceae: *Chenopodium album*
Cornaceae: *Nyssa* spp.	1.93	average of published seed TME values
Cyperaceae: *Carex* spp.	1.11	average of published TME values for genera of Cyperaceae
Cyperaceae: *Cladium* spp.	1.11	average of published TME values for genera of Cyperaceae
Cyperaceae: *Cyperus* spp.	1.96	TME value for Cyperaceae: *Cyperus esculentus*
Cyperaceae: *Eleocharis* spp.	0.50	TME value for Cyperaceae: *Eleocharis palustris*
Cyperaceae: *Scirpus* spp.	0.73	average of TME values for Cyperaceae: *Scirpus* spp.
Ericaceae: *Vaccinium* spp.	1.93	average of published TME seed values
Euphorbiaceae: *Acalypha* spp.	1.93	average of published TME seed values
Fabaceae (unknown)	3.1	average of TME values for Fabaceae: *Glycine max*
Fabaceae: *Vicia* spp.	3.1	average of TME values for Fabaceae: *Glycine max*
Hydrophyllaceae: *Hydrophyllum* spp.	1.93	average of published TME seed values
Juncaceae: *Juncus* spp.	1.21	TME value for Juncaceae: *Juncus canadensis*
Leguminosae (unknown)	3.1	average of TME values for Fabaceae: *Glycine max*
Najadaceae: *Potamogeton* spp.	1.42	TME value for Najadaceae: *Potamogeton* spp. (seeds)
Najadaceae: *Ruppia* spp.	1.42	TME value for Najadaceae: *Potamogeton* spp. (seeds)
Najadaceae: *Zannichellia*	1.42	TME value for Najadaceae: *Potamogeton* spp. (seeds)
Phytolaccaceae: *Phytolacca* spp.	1.93	average of published TME seed values
Poaceae (unknown)	2.39	average of TME values (non-crop) for genera of Poaceae
Poaceae: *Digitaria* spp.	3.1	average of TME values for Poaceae: *Digitaria* spp.
Poaceae: *Oryzopsis* spp.	2.39	average of TME values (non-crop) for genera of Poaceae
Poaceae: *Panicum* spp.	2.05	average of TME values for Poaceae: *Panicum* spp.
Poaceae: *Phragmites* spp.	2.39	average of TME values (non-crop) for genera of Poaceae
Poaceae: *Spartina* spp.	0.05	TME value for Poaceae: *Spartina patens*
Poaceae: *Sporobolus* spp.	2.39	average of TME values (non-crop) for genera of Poaceae
Polygonaceae: *Polygonum* spp.	1.38	average of TME values for species of Polygonaceae: *Polygonum*

Appendix G Continued

Food Item	TME	Derivation
Polygonaceeae: *Rumex* spp.	2.68	TME value for Polygonaceae: *Rumex crispus*
Rhamnaceae: *Frangula* spp.	1.93	average of published TME seed values
Umbelliferae (unknown)	1.93	average of published TME seed values
Verbenaceae: *Verbena* spp.	1.93	average of published TME seed values
Vitaceae: *Vitis* spp.	1.93	average of published TME seed values
Unknown Seed	1.93	average of published TME seed values
Roots & Tubers		
Cyperaceae: *Eleocharis* (root)	2.47	average of TME values for Cyperaceae: *Cyperus esculentus* (tubers) + Cymodoceae: *Halodule wrightii* (rhizomes)
Unknown Root	2.47	average of TME values for Cyperaceae: *Cyperus esculentus* (tubers) + Cymodoceae: *Halodule wrightii* (rhizomes)
Vegetation		
Lemnaceae: *Lemna* spp. (algae)	0.86	average of TME values for Lemnaceae: *Lemna minor*
Unknown Algae	0.72	average of TME values for Cladophoraceae: *Cladocera* spp. (algae) + Lemnaceae: *Lemna minor* (algae)
Unknown Foliage	0.65	average of TME values for Cymodoceae: *Halodule wrightii* (foliage) + Haloragaceae: *Myriophyllum spicatum* (foliage) + Hydrocharitaceae: *Vallisneria americana* (foliage)

APPENDIX H

Mid-Winter Inventory Survey data from 2001-2005 for the Hackensack Meadowlands, New Jersey was used to model available duck use-days (DUDs) against potential waterfowl use during the wintering period 15 December – 31 January (Source USFWS 2007a).

			Year			
Species	2001	2002	2003	2004	2005	$\overline{x}$
American black duck	0	760	185	10	30	197
American widgeon	0	180	0	0	0	36
Blue-winged teal	0	0	0	0	0	0
Gadwall	0	345	30	0	140	103
Green-winged teal	0	125	695	0	695	303
Mallard	85	1,405	420	50	570	506
Northern Pintail	0	100	150	0	0	50
Northern Shoveler	0	0	0	0	0	0
Total						1,195
Total # of DUDs required during the wintering period						57,360

APPENDIX I

Weekly waterfowl survey data collected in 2005 at Edwin B. Forsythe National Wildlife Refuge, New Jersey, was used to model available duck use-days (DUDs) in the Hackensack Meadowlands, New Jersey, against potential waterfowl use during the fall migration period 15 September – 14 December. DUDs/wk is the number of duck use-days required per week to meet expected waterfowl use based on the number of waterfowl recorded on each survey date (Source USFWS 2007b).

	Survey Date[a]												
Species	15-Sep	21-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec
American black duck	387	325	475	487	487	861	1,206	625	1,922	743	743	3,284	5,123
American widgeon	0	0	0	0	0	31	20	2	40	0	0	0	4
Blue-winged teal	0	0	0	15	15	0	5	2	0	0	0	0	0
Gadwall	0	218	0	4	4	21	2	4	16	0	0	8	0
Green-winged teal	568	403	500	900	900	12,506	4,856	2,010	7,220	2,440	2,440	262	4
Mallard	301	11	241	70	70	188	202	301	517	604	604	222	173
Northern pintail	0	0	2,000	8	8	8,802	3,961	1,531	3,774	2,246	2,246	501	124
Northern shoveler	0	0	0	0	0	7	0	2	159	10	10	42	0
Total	1,256	957	3,216	1,484	1,484	22,416	10,252	4,477	13,648	6,043	6,043	4,319	5,428
DUDs/wk	7,536	7,656	22,512	10,388	10,388	156,912	71,764	31,339	95,536	42,301	42,301	30,233	37,996

Total # of DUDs required during fall migration period: 566,862

[a] Survey data were unavailable for 13 Oct and 24 Nov; data from the previous dates were substituted.

APPENDIX J

Weekly waterfowl survey data collected in 2005 at Edwin B. Forsythe National Wildlife Refuge, New Jersey, was used to model available duck use-days (DUDs) in the Hackensack Meadowlands, New Jersey, against potential waterfowl use during the spring migration period 1 February – 1 May. DUDs/wk is the number of duck use-days required per week to meet expected waterfowl use based on the number of waterfowl recorded on each survey date (Source: USFWS 2007b).

	Survey Date[a]												
Species	3-Feb	10-Feb	17-Feb	24-Feb	3-Mar	10-Mar	17-Mar	24-Mar	31-Mar	7-Apr	14-Apr	21-Apr	28-Apr
American black duck	737	417	1,503	1,052	765	905	837	170	356	834	834	598	515
American widgeon	2	17	4	72	10	4	36	4	6	0	0	0	0
Blue-winged teal	0	0	0	0	0	0	0	76	0	2	2	0	0
Gadwall	6	15	86	11	6	0	43	23	10	17	17	0	14
Green-winged teal	36	0	80	248	38	175	271	320	575	992	992	162	163
Mallard	116	74	103	67	157	165	113	5	29	24	24	14	16
Northern Pintail	217	6	174	179	31	84	73	180	200	0	0	175	0
Northern Shoveler	0	2	0	0	0	0	26	0	0	0	0	4	0
Total	1,114	531	1,950	1,629	1,007	1,333	1,399	778	1,176	1,869	1,869	953	708
DUDs/wk	10,026	3,717	13,650	11,403	7,049	9,331	9,793	5,446	8,232	13,083	13,083	6,671	2,832

Total # of DUDs required during the spring migration period: 114,316

[a] Survey data were unavailable for 3 Feb; data from the previous date were substituted.

APPENDIX K

County-level wintering waterfowl population objectives for Bergen and Hudson counties used to model the ability of the Hackensack Meadowlands, New Jersey, to support target waterfowl population objectives. County-level population objectives were calculated from continental population objectives specified in the North American Waterfowl Management Plan. Continental objectives were scaled down to the county-level using Mid-Winter Inventory survey data for New Jersey and county-level harvest data for Bergen and Hudson counties during two time periods: 1970-1979 and from 1990-2002 (harvest data 1990-1999 only). The DUDs required to support wintering population objectives were calculated assuming a wintering period of 15 December – 31 January (Source: Koneff, unpublished data).

	Bergen		Hudson		Total	
Species	1970's	1990's	1970's	1990's	1970's	1990's
Northern Shoveler	63	7	0	15	63	22
Northern Pintail	38	210	60	246	98	456
Mallard	177	281	260	1,136	437	1,417
Gadwall	16	142	84	112	100	254
Blue-winged teal	0	0	0	0	0	0
American widgeon	0	0	703	0	703	0
Green-winged teal	193	40	78	142	271	182
American black duck	1,979	2,525	1,069	5,892	3,048	8,417
Total dabbling ducks					4,720	10,748
# of DUDs required to support population objectives					226,560	515,904

APPENDIX L

Seasonal biomass estimates (kg/ha) of food availability at sample sites in the Hackensack Meadowlands, New Jersey, 2005-2006.

Site	Macrohabitat	Food	Season	n[a]	$\overline{x}$	SE
Research Park	Restricted	Invertebrates	Fall	10	11.24	2.11
			Winter	10	4.03	1.26
			Spring	20	4.43	1.22
		Seeds	Fall	10	352.49	79.55
			Winter	10	582.24	159.03
			Spring	20	224.43	50.35
		Roots/Tubers	Fall	10	0.48	0.27
			Winter	10	0.15	0.15
			Spring	20	0.03	0.03
		Vegetation	Fall	10	0.00	0.00
			Winter	10	0.00	0.00
			Spring	20	0.00	0.00
Mill Creek Impoundments	Restricted	Invertebrates	Fall	10	350.48	149.51
			Winter	10	125.98	59.63
			Spring	20	93.58	23.42
		Seeds	Fall	10	77.58	21.75
			Winter	10	62.49	15.02
			Spring	20	30.25	5.80
		Roots/Tubers	Fall	10	0.35	0.21
			Winter	10	0.70	0.32
			Spring	20	0.14	0.08
		Vegetation	Fall	10	41.97	14.87
			Winter	10	0.00	0.00
			Spring	20	0.00	0.00
Kingsland Impoundment	Restricted	Invertebrates	Fall	10	76.07	38.05
			Winter	10	51.24	40.21
			Spring	19	7.24	3.21
		Seeds	Fall	10	53.88	26.21
			Winter	10	40.69	12.63
			Spring	19	23.59	9.37

[a] n=number of samples; microhabitat samples at Tidal sample site were averaged together for each corresponding sample plot number.

Site	Macrohabitat	Food	Season	n[a]	$\overline{X}$	SE
		Roots/Tubers	Fall	10	0.15	0.15
			Winter	10	0.13	0.07
			Spring	19	0.02	0.02
		Vegetation	Fall	10	3.61	2.88
			Winter	10	2.04	1.81
			Spring	19	0.36	0.28
Kearny Brackish Marsh	Restricted	Invertebrates	Fall	10	0.59	0.32
			Winter	10	2.37	1.12
			Spring	19	0.59	0.23
		Seeds	Fall	10	1.81	0.59
			Winter	10	3.47	0.60
			Spring	19	4.32	1.55
		Roots/Tubers	Fall	10	0.05	0.05
			Winter	10	0.00	0.00
			Spring	19	0.00	0.00
		Vegetation	Fall	10	1.98	1.16
			Winter	10	0.00	0.00
			Spring	19	0.00	0.00
Harrier Meadows	Restricted	Invertebrates	Fall	10	20.91	11.02
			Winter	9	22.57	6.10
			Spring	20	11.30	3.06
		Seeds	Fall	10	4.46	1.61
			Winter	9	3.32	1.27
			Spring	20	4.20	1.53
		Roots/Tubers	Fall	10	0.22	0.19
			Winter	9	0.00	0.00
			Spring	20	0.00	0.00
		Vegetation	Fall	10	501.84	180.56
			Winter	9	0.00	0.00
			Spring	20	1.15	1.14
Saw Mill Wildlife Management Area	Tidal	Invertebrates	Fall	9	122.93	78.24
			Winter	10	16.39	3.30
			Spring	14	11.82	3.25
		Seeds	Fall	9	196.70	80.67
			Winter	10	201.06	47.58
			Spring	14	118.09	38.58
		Roots/Tubers	Fall	9	0.12	0.12
			Winter	10	0.47	0.18

[a] n=number of samples; microhabitat samples at Tidal sample site were averaged together for each corresponding sample plot number.

Site	Macrohabitat	Food	Season	n[a]	$\bar{x}$	SE
			Spring	14	0.04	0.02
		Vegetation	Fall	9	0.02	0.02
			Winter	10	0.00	0.00
			Spring	14	0.34	0.34
Mill Creek Marsh	Tidal	Invertebrates	Fall	10	331.97	169.79
			Winter	10	538.46	412.76
			Spring	15	483.32	407.87
		Seeds	Fall	10	271.89	71.43
			Winter	10	317.15	55.08
			Spring	15	250.05	61.68
		Roots/Tubers	Fall	10	45.68	7.75
			Winter	10	15.03	1.87
			Spring	15	10.06	2.33
		Vegetation	Fall	10	2.78	2.78
			Winter	10	0.00	0.00
			Spring	15	1.85	1.85
Marsh Resources Meadowlands Mitigation Bank	Tidal	Invertebrates	Fall	8	132.76	31.08
			Winter	10	22.03	4.95
			Spring	14	27.41	12.19
		Seeds	Fall	8	639.44	328.61
			Winter	10	393.68	126.65
			Spring	14	231.97	46.90
		Roots/Tubers	Fall	8	31.12	10.62
			Winter	10	29.78	10.30
			Spring	14	15.87	6.87
		Vegetation	Fall	8	0.00	0.00
			Winter	10	0.00	0.00
			Spring	14	0.00	0.00

[a] n=number of samples; microhabitat samples at Tidal sample site were averaged together for each corresponding sample plot number.

APPENDIX M

Seasonal estimates of duck use-days/ha (DUDs/ha) at sample sites in the Hackensack Meadowlands, New Jersey, 2005-2006.

Site	Macrohabitat	Model	Season	n[a]	$\overline{x}$	SE
Research Park	Restricted	DUD_{raw}[b]				
			Fall	10	1348.5	295.7
			Winter	10	1960.7	485.0
			Spring	20	733.4	147.5
		DUD_{adj}[c]				
			Fall	10	1218.1	295.5
			Winter	10	1834.8	487.9
			Spring	20	614.5	148.7
Mill Creek Impoundments	Restricted	DUD_{raw}				
			Fall	10	1142.1	248.2
			Winter	10	677.5	147.3
			Spring	20	328.9	57.7
		DUD_{adj}				
			Fall	10	1019.4	255.2
			Winter	10	512.5	141.1
			Spring	20	193.8	62.3
Kingsland Impoundment	Restricted	DUD_{raw}				
			Fall	10	464.6	127.9
			Winter	10	325.8	155.9
			Spring	19	121.2	32.5
		DUD_{adj}				
			Fall	10	411.8	132.5
			Winter	10	283.6	156.5
			Spring	19	78.2	31.4
Kearny Brackish Marsh	Restricted	DUD_{raw}				
			Fall	10	16.9	5.6

[a] n=number of samples; microhabitat samples at Tidal sample site were averaged together for each corresponding sample plot number.
[b] DUD_{raw} excludes a food density threshold
[c] DUD_{adj} assumes a food density threshold of 50 kg/ha, below which waterfowl will not exploit available food resources

Site	Macrohabitat	Model	Season	n[a]	$\overline{x}$	SE
			Winter	10	34.4	7.3
			Spring	19	30.0	9.9
		DUD_{adj}				
			Fall	10	0.0	0.0
			Winter	10	7.3	7.9
			Spring	19	4.3	10.0
Harrier Meadows	Restricted	DUD_{raw}				
			Fall	10	1323.6	438.8
			Winter	9	45.3	8.0
			Spring	20	51.0	11.0
		DUD_{adj}				
			Fall	10	1221.6	447.7
			Winter	9	0.0	0.0
			Spring	20	0.0	0.0
Saw Mill Wildlife Management Area	Tidal	DUD_{raw}				
			Fall	9	699.6	268.0
			Winter	10	396.8	124.7
			Spring	14	235.1	90.5
		DUD_{adj}				
			Fall	9	575.3	268.1
			Winter	10	275.9	117.5
			Spring	14	121.8	90.8
Mill Creek Marsh	Tidal	DUD_{raw}				
			Fall	10	1729.4	271.3
			Winter	10	1834.3	611.0
			Spring	15	1532.6	614.1
		DUD_{adj}				
			Fall	10	1615.9	273.4
			Winter	10	1723.4	615.4
			Spring	15	1417.1	616.6
Marsh Resources MeadowlandsMitigation Bank	Tidal	DUD_{raw}				
			Fall	8	1116.7	183.4
			Winter	10	1534.9	357.1

[a] n=number of samples; microhabitat samples at Tidal sample site were averaged together for each corresponding sample plot number.
[b] DUD_{raw} excludes a food density threshold
[c] DUD_{adj} assumes a food density threshold of 50 kg/ha, below which waterfowl will not exploit available food resources

Appendix M Continued

Site	Macrohabitat	Model	Season	n[a]	$\bar{x}$	SE
			Spring	14	1144.4	300.1
		DUD_{adj}				
			Fall	8	990.1	191.2
			Winter	10	1369.2	357.6
			Spring	14	978.9	290.9

[a] n=number of samples; microhabitat samples at Tidal sample site were averaged together for each corresponding sample plot number.
[b] DUD_{raw} excludes a food density threshold
[c] DUD_{adj} assumes a food density threshold of 50 kg/ha, below which waterfowl will not exploit available food resources