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OSPREY DIET COMPOSITION AND QUALITY IN HIGH- AND LOW-SALINITY AREAS OF LOWER CHESAPEAKE BAY

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ABSTRACT.—Chesapeake Bay in the northeastern United States is believed to support the largest concentration of breeding Ospreys (*Pandion haliaetus*) in the world. Following the banning of DDT, this population exhibited significant spatial variation in growth rates, with the fastest and slowest rates occurring in the lowest and highest salinity areas, respectively. Because salinity can influence fish distributions, we quantitatively analyzed Osprey diet composition along the gradient in the Chesapeake Bay to determine if variation in foraging ecology contributed to this pattern of population recovery. We recorded >1800 hr of food-provisioning behavior for 25 pairs within nine study areas that were classified as either upper estuarine (<5 parts per thousand [ppt] salinity) or lower estuarine (>18 ppt). Atlantic menhaden (*Brevoortia tyrannus*) and seatrouts (*Cynoscion* spp.) were dominant dietary components for pairs within lower-estuarine reaches, whereas gizzard shad (*Dorosoma cepedianum*) and catfish (Ictaluridae) dominated upper-estuarine diets. Lower-estuarine prey fish averaged 6% shorter (Kolmogorov-Smirnov test: $D = 0.203$, $P = 0.004$), 34% lighter ($D = 0.305$, $P < 0.001$), and 40% lower in energy content ($D = 0.247$, $P < 0.001$) than their upper-estuarine counterparts. We conclude that diet quality may be contributing to spatial variation in the growth rate of the Chesapeake Bay Osprey population.

KEY WORDS: Osprey, *Pandion haliaetus*; Chesapeake Bay; diet; foraging ecology; population regulation; salinity.

COMPOSICIÓN Y CALIDAD DE LA DIETA DE *PANDION HALIAETUS* EN ÁREAS DE SALINIDAD ALTA Y BAJA EN LA PARTE BAJA DE LA BAHÍA DE CHESAPEAKE

RESUMEN.—Se cree que la bahía de Chesapeake, ubicada en el este de los Estados Unidos, sostiene la concentración más grande de individuos reproductivos de la especie *Pandion haliaetus* del mundo. Tras la prohibición del DDT, existió variación espacial sustancial en la tasa de crecimiento de esta población. Las tasas más altas y más bajas se presentaron en las áreas de salinidad máxima y mínima, respectivamente. Debido a que la salinidad puede influenciar las distribuciones de los peces, analizamos cuantitativamente la composición de la dieta de *P. haliaetus* a lo largo del gradiente en la bahía de Chesapeake para determinar si variaciones en la ecología de forrajeo habrían contribuido a este patrón de recuperación poblacional. Registramos más de 1800 horas de comportamiento de provisión de alimento para 25 parejas en nueve áreas de estudio que habían sido clasificadas ya sea, como estuarinas altas (menos de 5 partes por mil de salinidad) o estuarinas bajas (más de 18 partes por mil). Los peces *Brevoortia tyrannus* y *Cynoscion* spp. fueron componentes dominantes de la dieta de las parejas de las áreas estuarinas bajas, mientras que *Dorosoma cepedianum* y los de la familia Ictaluridae dominaron las dietas de las áreas estuarinas altas. Los peces depredados en las áreas estuarinas bajas fueron, en promedio, 6% más cortos (prueba de Kolmogorov-Smirnov: $D = 0.203$, $P = 0.004$), 34% más livianos ($D = 0.305$, $P < 0.001$) y presentaron un contenido de energía 40% menor ($D = 0.247$, $P < 0.001$) que sus contrapartes de las áreas estuarinas altas. Concluimos que la calidad de la dieta podría estar contribuyendo a la variación espacial en la tasa de crecimiento de la población de *P. haliaetus* de la bahía de Chesapeake.

[Traducción del equipo editorial]

Although restricted to a diet composed almost entirely of live fish, Ospreys (*Pandion haliaetus*) con-

sume a wide array of species and occur in a diversity of habitats (Poole et al. 2002). Fish populations of many coastlines, estuaries, marshes, lagoons, rivers, lakes, and reservoirs support Osprey populations. This dietary plasticity is one of the primary factors

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contributing to their worldwide distribution (Poole 1989). Ospreys are found on every continent except Antarctica (Poole et al. 2002).

Chesapeake Bay is the largest estuary in North America and one of the most productive aquatic ecosystems in the world (Murdy et al. 1997). The bay's high productivity and 13 000-km shoreline make it an ideal waterbody for breeding Ospreys. Historically, Chesapeake Bay has supported the largest concentration of breeding Ospreys in the world (Henny et al. 1974, Spitzer and Poole 1980). Although this population suffered from the effects of DDT (Stinson and Byrd 1976), reproductive rates showed signs of recovery through the 1970s and 1980s (Watts and Paxton 2007). By the mid-1990s, the tidal reach of the bay supported an estimated 3473 breeding pairs (Watts et al. 2004). Not all areas of the bay have recovered at the same rate, however. The only bay-wide breeding survey conducted since 1973 revealed that mean doubling times of the within geographic subregions ranged from 4.3 yr to more than 40 yr. The slowest rates generally occurred in higher-salinity areas of the bay proper and the fastest rates along the lower-salinity reaches of upper tributaries (Watts et al. 2004).

Saturation of nesting substrate along the bay proper does not appear to be a primary factor contributing to the slower population growth rate there, because potential nesting sites are plentiful and some historic nest sites are no longer being occupied (M. Byrd pers. comm.). Neither are environmental contaminants likely responsible for the differential population growth rate, because studies have shown that recent contaminant levels have not affected Osprey reproductive success (Rattner et al. 2004). The potential effect of foraging ecology on population growth has not been assessed, however.

Salinity tolerance is an important factor contributing to the distribution of fish species within estuaries (Boesch 1977, Murdy et al. 1997, Jung 2002). Thus, prey availability, and ultimately Osprey foraging behavior, may differ markedly between higher- and lower-salinity areas in Chesapeake Bay. In 1985, McLean and Byrd (1991) documented provisioning behavior at seven nests located in high-saline waters of the bay. Here we compare the diet of Osprey pairs provisioning broods within defined higher- and lower-salinity subregions of Chesapeake Bay and its upper tributaries. We describe for the first time the diet of Ospreys nesting in lower-salinity reaches and discuss how differences across the salinity gradient may relate to the spatial differences

in population growth noted by Watts et al. (2004). Such information is important to Osprey conservation, as well as ecosystem-scale considerations such as fisheries management and contaminant monitoring.

METHODS

We investigated the influence of salinity on diet by observing nesting Ospreys during the 2006 and 2007 breeding seasons within the extremes of salinity found within Chesapeake Bay. For the purpose of this study, we considered "upper-estuarine" areas those ranging in salinity from 0 to 5 parts per thousand (ppt) and "lower-estuarine" areas those exceeding 18 ppt. We chose salinity replicates to study from a pool of areas delineated by the Chesapeake Bay Program analytical segmentation scheme (Data Analysis Work Group 1997). We chose five upper-estuarine and four lower-estuarine sites (Fig. 1), each of which contained an average of three nests on channel markers or duckblinds over open water that were accessible by boat. We attempted to randomize site locations over as broad an area as was feasible, but we were restricted by the availability of boat ramps. We sampled a total of 29 nests, three of which were sampled during both 2006 and 2007.

We used micro-video monitoring to record provisioning data. The camera unit consisted of a portable digital video recorder (Secumate Mini, Yoko Technology Corp., Taiwan) connected to a 10-cm bullet camera (CM25SH CCD Color Sunshield, MicroAmerica, U.S.A.), both of which were powered by a 12 V deep-cycle marine battery. To obtain the highest resolution image of provisioning behavior, we secured the bullet camera approximately 1 m from the nest. We attached the camera directly to either a channel marker railing or duckblind beam, and we stored the recording unit and battery inside a weather-proof container placed nearby. We mounted cameras after nestlings reached at least 2 wk old, and generally filmed during all daylight hours for 1–2 d/wk, until nestlings approached fledging age. Logistical difficulties, however, precluded us from collecting video footage equally at all nests and sites.

The provisioning parameters we assessed included prey taxonomy, length, mass, and energy content. We identified prey items to the lowest taxonomic level possible and estimated prey size by comparing against Osprey morphological characters visible on images. We identified most prey to species; however, due to the lack of strong morpho-

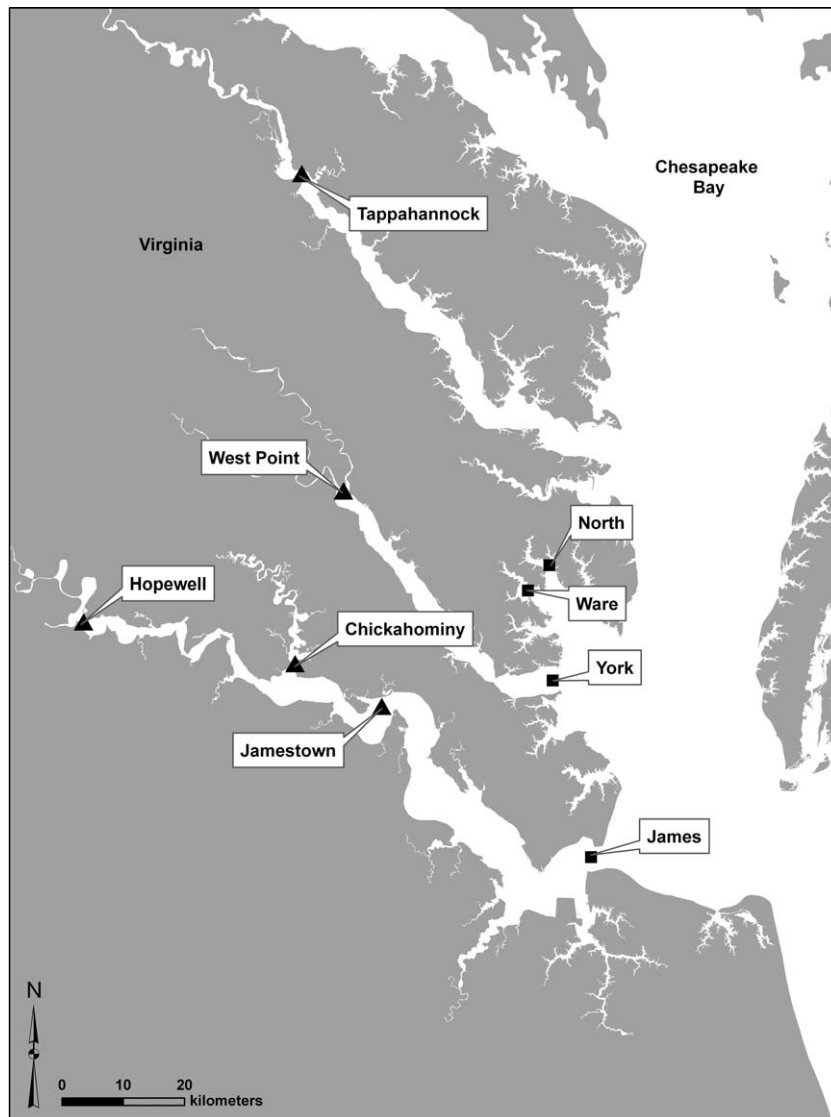


Figure 1. Osprey study sites within southwestern Chesapeake Bay during the 2006 and 2007 field seasons. Triangles indicate upper-estuarine, low-salinity sites and squares indicate lower-estuarine, high-salinity sites.

logical distinctions between some species (principally catfish [Ictaluridae] and shad [*Dorosoma* spp.]), we were able to identify some fish only to genus or family. We estimated fish length to the nearest cm using multiples of a typical adult Osprey's bill or talon length (values obtained from Poole et al. 2002). We minimized potential biases associated with these estimations by having a single individual conduct all video reviews. We used published morphometric data to extrapolate total fish length in

cases where prey were only partially visible, and ultimately estimated fish mass based on published length-mass conversion equations (Appendix 1). Finally, because energy content per unit mass varies among species, we calculated the total kilocalories delivered per prey item by using published energy-density data (Appendix 2). In the few cases where length-mass conversion equations or energy-density data were unavailable for identified taxa, we calculated values using data for closely related taxa. As in

previous Osprey diet studies, we considered most fish to be entirely edible and therefore wholly consumed (e.g., Stinson 1977, Poole 1982, Van Daele and Van Daele 1982, McLean and Byrd 1991, Steeger et al. 1992). Catfish >31 cm in total length were an exception; we assumed them to be only 90% consumable (Dykstra 1995, Markham 2004).

We summarized identified taxa by number of individuals, biomass, and energy content for upper- and lower-estuarine sites. We used chi-square tests to detect differences between habitats in the frequency of occurrence of each taxon. We calculated expected values by averaging the frequencies observed in the two salinity habitats and incorporating a correction factor that accounted for incidental unequal sampling effort. For example, because only 48% of the total sampling effort occurred in the lower-estuarine habitat, we calculated the expected frequency of a given taxon for this habitat by multiplying its cumulative observed frequency for both habitats by 0.48 rather than the usual 0.50.

We evaluated diet breadth and prey characteristics using a subset of nests where prey diversity reached an asymptote. We projected the asymptotic number of species consumed at each nest by fitting each distribution to the following negative exponential function: accumulated number of species = $b_0 * (1 - \exp(-b_1 * \text{accumulated number of observations}))$, where b_0 = asymptote (Miller and Wiegert 1989). Based on this subset of nests, we compared the frequency distributions of prey lengths, masses, and energy contents in the two salinity habitats using non-parametric Kolmogorov-Smirnov tests. We estimated diet breadth using Simpson's (1949) 1-D species-diversity index and evaluated differences in diet breadth between the habitats using a t -test.

We used chi-square analyses to assess the spatial and temporal uniformity of delivery rates (g/hr) for major fish taxa within each habitat. We used average site values for each habitat as the expected values for spatial comparisons and average annual values for each habitat as the expected values for temporal comparisons.

RESULTS

We recorded 667 hr and 748 hr of video footage in the lower- and upper-estuarine sites, respectively. On average, we recorded 177 hr of footage per site (range 50–308 hr, SD of 120 hr) and 59 hr of footage per nest (range 19–161 hr, SD of 38 hr). We pooled the prey data from the five upper-estuarine sites, and similarly pooled prey data from the four

lower-estuarine sites. We positively identified 589 prey items: 15 taxa to species, one taxon to genus, and two taxa to family.

The frequency of occurrence of species dominating the Osprey diet differed between the two salinity habitats for all species except the Atlantic croaker (*Micropogonias undulates*). Catfish and gizzard shad (*Dorosoma cepedianum*) represented the greatest percentage (80%) of total prey items provisioned in the upper-estuarine sites, whereas seatrouts (*Cynoscion* spp.), Atlantic menhaden (*Brevoortia tyrannus*), spot (*Leiostomus xanthurus*), and Atlantic croaker composed the major percentage (74%) of fish provisioned in the lower-estuarine sites (Table 1). Occurrences of less common species, including Atlantic thread herring (*Opisthonema oglimum*), unidentified Clupeidae, round herring (*Etrumeus teres*), and summer flounder (*Paralichthys dentatus*), also differed between salinity habitats (Table 1).

Prey species that dominated the Osprey diet by frequency of occurrence were similarly represented as percentages of total energy delivered to nests (Table 1). Catfish and gizzard shad made up 77% of the total energy provisioned to nestlings in upper-estuarine sites, whereas *Cynoscion* spp., Atlantic menhaden, and gizzard shad composed 76% of the total energy delivered to nestlings in lower-estuarine sites.

Fish length averaged 7% longer in upper-estuarine sites (range 10.2–42.9 cm, mean $23.7 \pm$ SD of 7.0 cm) than in lower-estuarine sites (range 12.7–42.0 cm, mean $22.2 \pm$ 5.0 cm; Kolmogorov-Smirnov test: $D = 0.203$, $P = 0.004$; Fig. 2). Fish biomass averaged 52% greater in upper-estuarine sites (range 10.2–850.0 g, mean $239.8 \pm$ 194.9 g) than in lower-estuarine sites (range 18.1–850.0 g, mean $157.8 \pm$ 112.8 g; $D = 0.305$, $P < 0.001$). Whole-fish energy content of fish averaged 66% higher in upper-estuarine sites (range 69.5–5904.5 kJ, mean $1491.6 \pm$ 1475.7 kJ) than in lower-estuarine sites (range 83.3–5899.4 kJ, mean $899.6 \pm$ 807.1 kJ; $D = 0.247$, $P < 0.001$). Taxonomic diet breadth, as measured by Simpson's 1-D diversity index, did not differ between the two habitats (upper-estuarine: range 0.236–0.823, mean $0.526 \pm$ 0.163; lower-estuarine: range 0.549–0.844, mean $0.696 \pm$ 0.119; $t = -0.981$, $P = 0.253$).

Significant spatial variation in prey delivery rates (g/hr) occurred among sites within each habitat for all major fish taxa (Table 2). Significant temporal (among year) differences in prey delivery rates occurred only for gizzard shad in the upper-estuarine sites (Table 2).

Table 1. Relative contributions of all prey taxa identified in the Osprey diet within lower- and upper-estuarine sites in lower Chesapeake Bay during the 2006 and 2007 breeding seasons. Chi-square tests were conducted to detect significant differences in frequencies of occurrence between habitats. Scientific names of species are in Appendix 1.

SPECIES	LOWER		UPPER		OBSERVED vs. EXPECTED FREQUENCY		LOWER		UPPER	
	N	% TOTAL	N	% TOTAL	χ^2	P	kJ	% TOTAL	kJ	% TOTAL
	Alewife	0	0.0	1	0.3	1.0	0.330	0.0	0.0	3211.6
Atlantic croaker	27	12.3	26	6.6	0.1	0.745	15238.1	5.5	28875.5	3.9
Atlantic menhaden	53	24.2	6	1.5	39.9	<0.001	123901.2	44.7	33051.1	4.5
Atlantic thread herring	5	2.3	0	0.0	5.3	0.022	2630.1	1.0	0.0	0.0
Bluefish	1	0.5	0	0.0	1.0	0.330	560.2	0.2	0.0	0.0
Clupeidae	0	0.0	15	3.8	14.3	<0.001	0.0	0.0	29870.8	4.0
Gizzard shad	9	4.1	110	28.0	80.7	<0.001	36868.2	13.3	341197.7	46.0
Hickory shad	0	0.0	3	0.8	2.9	0.091	0.0	0.0	21381.5	2.9
Hogchoker	1	0.5	0	0.0	1.0	0.330	394.1	0.1	0.0	0.0
Ictaluridae	0	0.0	203	51.7	192.8	<0.001	0.0	0.0	245045.6	33.0
Largemouth bass	0	0.0	1	0.3	1.0	0.330	0.0	0.0	1595.8	0.2
Round herring	4	1.8	0	0.0	4.2	0.040	5516.6	2.0	0.0	0.0
Spot	19	8.7	0	0.0	20.0	<0.001	10132.8	3.7	0.0	0.0
Spotted seatrout	63	28.8	0	0.0	66.3	<0.001	50187.5	18.1	0.0	0.0
Striped bass	10	4.6	5	1.3	1.9	0.164	12156.2	4.4	13399.7	1.8
Summer flounder	12	5.5	0	0.0	12.6	<0.001	5403.2	2.0	0.0	0.0
Threadfin shad	1	0.5	4	1.0	1.7	0.199	151.0	0.1	2669.8	0.4
White perch	2	0.9	8	2.0	3.3	0.069	2294.9	0.9	4842.6	0.7
Unknown	12	5.5	11	2.8			11913.1	4.3	16586.2	2.2
TOTAL	219		393				277347.2		741727.1	

DISCUSSION

Our characterization of Osprey diet during the 2006 and 2007 breeding seasons elucidated marked differences between upper- and lower-estuarine

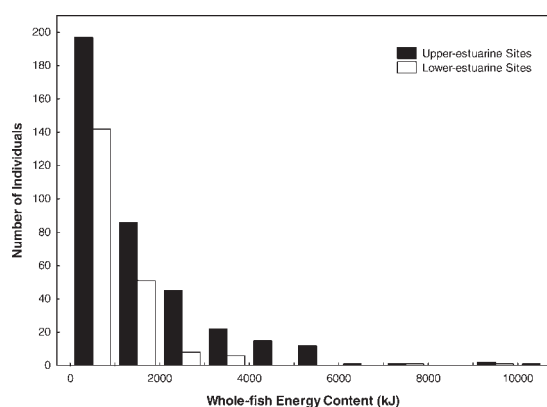


Figure 2. Comparisons of the frequency of occurrence and energy content of individual fish identified in Osprey diets within upper- and lower-estuarine sites during the 2006 and 2007 breeding seasons in lower Chesapeake Bay.

habitats. Fish taxa targeted by Ospreys varied significantly along the salinity gradient in both frequency of occurrence and percentage of total energy content delivered to broods. In the lower-estuarine sites, Atlantic menhaden and *Cynoscion* spp. were the dominant prey items provisioned. Although constituting only 24% of the diet by frequency of occurrence, Atlantic menhaden provided 44% of the total energy provided to broods in the lower-estuarine sites. Due in large part to its high lipid content relative to other species, Atlantic menhaden historically has been shown to be an important prey item for Ospreys breeding throughout the coastal waters of the mid-Atlantic and northeastern United States (Spitzer and Poole 1980, Poole 1989, McLean and Byrd 1991, Steidl et al. 1991). Atlantic menhaden also form large compact schools very near the water surface, making them relatively easy for Ospreys to locate and capture (Munroe and Smith 2000).

Although we were not able to identify to species all individuals in the important group *Cynoscion* spp., it appeared that this group was composed pri-

Table 2. Spatial and temporal comparisons of provisioning rates (g/hr) for major taxa identified in the Osprey diet during the 2006 and 2007 breeding seasons in lower Chesapeake Bay. Site means were calculated by averaging all site values for both years. Annual means were calculated by averaging all site values within each year. These means were used as expected values in chi-square analyses.

ZONE AND SPECIES	SITE		OBSERVED VS. EXPECTED FREQUENCY		ANNUAL		OBSERVED VS. EXPECTED FREQUENCY	
	MEAN	SD	χ^2	<i>P</i>	MEAN	SD	χ^2	<i>P</i>
Upper-estuarine zone								
Atlantic croaker (<i>Micropogonias undulatus</i>)	12.1	14	64.5	<0.001	1.4	1.5	1.6	0.201
Gizzard shad (<i>Dorosoma cepedianum</i>)	78.5	41.8	89.0	<0.001	93.9	57.1	34.7	<0.001
Ictaluridae	55.6	26.1	48.8	<0.001	66.2	7.0	0.7	0.389
Lower-estuarine zone								
Atlantic croaker (<i>Micropogonias undulatus</i>)	7.9	5.6	13.1	0.001	4.1	1.8	0.8	0.381
Atlantic menhaden (<i>Brevoortia tyrannus</i>)	25.1	30.5	63.0	<0.001	9.1	4.5	2.2	0.138
Spotted seatrout/weakfish (<i>Cynoscion</i> spp.)	11	10.6	20.3	<0.001	23.0	5.7	1.4	0.236

marily of spotted seatrout (*Cynoscion nebulosus*). This concurs with McLean and Byrd's (1991) study as well as with the opinions of local recreational anglers (K. Glass unpubl. data) who routinely fished for this species throughout the lower-estuarine sites. By biomass, spotted seatrout are the second largest catch annually landed by the saltwater fishing industry in the southeast United States, and the recreational catch is believed to be greater than the commercial catch (Murdy et al. 1997). Although found throughout the Chesapeake Bay in a wide range of salinities, spotted seatrout occur predominantly in higher-salinity waters and frequent shallow waters with sandy bottoms, making them accessible to Ospreys (Murdy et al. 1997).

In the upper-estuarine sites, gizzard shad and catfish dominated the diet. Although gizzard shad occurred only half as frequently as catfish, which comprised 52% of the diet by frequency of occurrence, gizzard shad constituted 46% of the total energy delivered to broods, whereas catfish constituted only 33%. The dominance of these taxa in the upper-estuarine diet is not surprising because they are abundant in these waters (Murdy et al. 1997). Gizzard shad can occur in salinities as high as 22 ppt within Chesapeake Bay, but they are not anadromous and primarily occur in the tidal fresh and oligohaline waters where they spawn from March to August (Murdy et al. 1997, Munroe 2000). This species is therefore an ideal prey item because it is available throughout the Osprey breeding season (April–August). Its availability to Ospreys is further increased by both a rapid growth rate, which quickly

precludes consumption by most piscivorous fish, and the schooling behavior it typically exhibits between 0.3–1.6 m below the surface (Jenkins and Burkhead 1994). Furthermore, a large size associated with a very high energy density guarantees that gizzard shad provide a substantial energy return for foraging Ospreys. Previously, gizzard shad had been documented in the Osprey diet only within the resident population of southern Florida (Collopy 1984, Edwards 1988).

Like gizzard shad, catfish also can be found in a wide range of salinities, but occur most frequently in fresher water (Murdy et al. 1997, Virginia Institute of Marine Science unpubl. data). Several species of catfish are well established throughout the lower-saline reaches of Chesapeake Bay (Murdy et al. 1997) and localized spawning ensures their presence throughout the Osprey breeding season (Jenkins and Burkhead 1994). The foraging ecology of catfish likely also contributes to their large presence in the Osprey diet. Catfish primarily feed on benthic organisms (Murdy et al. 1997) and bottom-feeders are more vulnerable to Osprey attacks than limnetic-feeders; presumably because they have their eyes focused predominantly on the underlying substrate (Swenson 1979). Benthic fish are also often drawn to shallower waters to forage (Haywood and Ohmart 1986), thereby further increasing their vulnerability to depredation because they have no downward escape route. We believe that Ictaluridae brought to nests were primarily channel catfish (*Ictalurus punctatus*), blue catfish (*Ictalurus furcatus*), and white catfish (*Ameiurus catus*), as suggested by regular obser-

vation of deeply forked caudal fins. Previously, only bullhead catfish (*Ameiurus* spp.) had been documented in the Osprey diet (Van Daele and Van Daele 1982, Collopy 1984, Vana-Miller 1987, Poole 1989, Steeger et al. 1992).

Breeding Bald Eagles (*Haliaeetus leucocephalus*) also have been shown to rely predominantly on catfish and shad species in the upper-estuarine areas of Chesapeake Bay (Markham 2004). As Osprey and Bald Eagle populations both continue to expand in this region, competition for these prey resources will likely escalate. Exploitive or interference competition may subsequently affect population dynamics. Although Bald Eagles may displace Ospreys when territories overlap to a large extent, some researchers have suggested that the dominance may be reversed if Ospreys greatly outnumber Bald Eagles (Ogden 1975).

In other populations, Ospreys have been shown to target fish within a narrow size range (Swenson 1978, Van Daele and Van Daele 1982, Poole 1989). We found that the average lengths, biomasses, and energy contents of consumed fish all differed between upper- and lower-estuarine sites. Differing by 1.5 cm, 82 g, and 592.4 kJ per fish on average, the provisioned lower-estuarine fish were 6% shorter, 34% lighter, and 40% less energy-rich than their upper-estuarine counterparts. The differences in fish biomass and energy content appeared to be primarily due to a variation in diet composition rather than fish length, because each species has unique length-mass and mass-energy conversion factors.

Although spatial differences in diet composition within habitats existed, our results indicate that Ospreys breeding in the upper-estuarine sites enjoy a higher quality diet than those in the lower-estuarine sites. Given the broad spatial scale of our study, extrapolation of our findings to the broader region seems valid. Because diet quality directly influences the reproductive success of breeding Ospreys, spatial differences in diet quality may be influencing the dynamics of the Chesapeake Bay Osprey population. Given that Ospreys rarely breed farther than 50 km from their natal sites and exhibit extreme site fidelity in annual breeding, Osprey population growth and decline are predominantly influenced by local survival and reproductive rates (Poole et al. 2002). Consequently, if Ospreys produce fewer young per breeding attempt in the lower-estuarine sites than in the upper-estuarine sites due to lower diet quality, overall population growth would likely reflect this. Spatial variation in growth rates of the

Chesapeake Bay population may therefore ultimately be due to the spatial differences in diet quality elucidated in our study. This has important implications for the long-term stability of this population, as well as for fisheries management and overall ecosystem health. We encourage further studies that characterize both parental provisioning rates and reproductive success to more conclusively assess the influence diet quality may be having on the growth trend of the Chesapeake Bay Osprey population.

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Appendix 1. Length-mass conversions used for fish identified in the diet of Ospreys nesting in lower Chesapeake Bay during the 2006 and 2007 breeding seasons. In conversion equations, mass (M) is in grams and length (L) is in centimeters.

SPECIES	BIOMASS CONVERSION	REFERENCE
Alewife (<i>Alosa pseudoharengus</i>)	$M = 0.0085 * L^{3.000}$	Madenjian et al. 2003
American shad (<i>Alosa sapidissima</i>)	$M = 0.0065 * L^{2.959}$	Muncy 1960
Atlantic croaker (<i>Micropogonias undulatus</i>)	$M = 0.0052 * L^{3.148}$	Wilk et al. 1978
Atlantic herring (<i>Clupea harengus</i>)	$M = 0.0075 * L^{3.030}$	Muncy 1960
Atlantic menhaden (<i>Brevoortia tyrannus</i>)	$M = 0.0161 * L^{3.000}$	June and Nicholson 1964
Atlantic thread herring (<i>Opisthonema oglimum</i>)	$M = 0.0186 * L^{2.920}$	Claro and Garcia-Arteaga 1994
Banded rudderfish (<i>Seriola zonata</i>)	$M = 0.0259 * L^{2.908}$	Bohnsack and Harper 1988
Black crappie (<i>Pomoxis nigromaculatus</i>)	$M = 0.0096 * L^{3.075}$	Vanderpuye and Carlander 1971
Blue catfish (<i>Ictalurus furcatus</i>)	$M = 0.0185 * L^{3.000}$	Crawford 1993
Channel catfish (<i>Ictalurus punctatus</i>)	$M = 0.0041 * L^{3.407}$	Muncy 1959
Clearnose skate (<i>Raja eglanteria</i>)	$M = 0.0022 * L^{3.295}$	Sulikowski et al. 2003
Gizzard shad (<i>Dorosoma cepedianum</i>)	$M = 0.0182 * L^{2.890}$	Lagler and Van Meter 1951
Hickory shad (<i>Alosa mediocris</i>)	used American shad	
Hogchoker (<i>Trinectes maculatus</i>)	$M = 0.0199 * L^{3.001}$	Dawson 1965
Largemouth bass (<i>Micropterus salmoides</i>)	$M = 0.0158 * L^{2.960}$	Swingle 1965
Round herring (<i>Etrumeus teres</i>)	$M = 0.0059 * L^{3.158}$	Dawson 1965
Spot (<i>Leiostomus xanthurus</i>)	$M = 0.0092 * L^{3.072}$	Dawson 1965
Spotted seatrout (<i>Cynoscion nebulosus</i>)	$M = 0.0131 * L^{3.000}$	Crawford 1993
Striped bass (<i>Morone saxatilis</i>)	$M = 0.0061 * L^{3.153}$	Mansueti 1961
Summer flounder (<i>Paralichthys dentatus</i>)	$M = 0.0102 * L^{2.994}$	Smith and Daiber 1977
Threadfin shad (<i>Dorosoma petenense</i>)	$M = 0.0035 * L^{3.774}$	Carlander 1969
Weakfish (<i>Cynoscion regalis</i>)	$M = 0.0088 * L^{3.000}$	Crozier and Hecht 1913
White perch (<i>Morone Americana</i>)	$M = 0.0125 * L^{3.020}$	St. Pierre and Davis 1972

Appendix 2. Mass-energy conversion equations used for fish identified in the diet of Ospreys nesting in lower Chesapeake Bay during the 2006 and 2007 breeding seasons. In conversion equations, energy (E) is in kJ and mass (M) is in grams.

SPECIES	ENERGY CONVERSION	REFERENCE
Alewife (<i>Alosa pseudoharengus</i>)	$E = 185*(M/100)$	Frimodt 1995
American shad (<i>Alosa sapidissima</i>)	$E = 192*(M/100)$	Watt and Merrill 1975
Atlantic croaker (<i>Micropogonias undulatus</i>)	$E = 100*(M/100)$	Frimodt 1995
Atlantic herring (<i>Clupea harengus</i>)	$E = 190*(M/190)$	Frimodt 1995
Atlantic menhaden (<i>Brevoortia tyrannus</i>)	$E = 189*(M/100)$	Frimodt 1995
Atlantic thread herring (<i>Opisthonema oglimum</i>)	used Atlantic herring	
Banded rudderfish (<i>Seriola zonata</i>)	used white perch	
Black crappie (<i>Pomoxis nigromaculatus</i>)	used white perch	
Blue catfish (<i>Ictalurus furcatus</i>)	$E = 103*(M/100)$	Frimodt 1995
Channel catfish (<i>Ictalurus punctatus</i>)	$E = 112*(M/100)$	Frimodt 1995
Clearnose skate (<i>Raja eglanteria</i>)	used summer flounder	
Gizzard shad (<i>Dorosoma cepedianum</i>)	$E = 200*(M/100)$	Watt and Merrill 1975
Hickory shad (<i>Alosa mediocris</i>)	used American shad	
Hogchoker (<i>Trinectes maculatus</i>)	used summer flounder	
Largemouth bass (<i>Micropterus salmoides</i>)	used white perch	
Round herring (<i>Etrumeus teres</i>)	used Atlantic herring	
Spot (<i>Leiostomus xanthurus</i>)	used Atlantic croaker	
Spotted seatrout (<i>Cynoscion nebulosus</i>)	$E = 99*(M/100)$	Frimodt 1995
Striped bass (<i>Morone saxatilis</i>)	$E = 92*(M/100)$	Frimodt 1995
Summer flounder (<i>Paralichthys dentatus</i>)	$E = 84*(M/100)$	Frimodt 1995
Threadfin shad (<i>Dorosoma petenense</i>)	used gizzard shad	
Weakfish (<i>Cynoscion regalis</i>)	$E = 99*(M/100)$	Frimodt 1995
White perch (<i>Morone Americana</i>)	$E = 118*(M/100)$	Watt and Merrill 1975