FORAGING ECOLOGY OF BALD EAGLES IN A FRESHWATER TIDAL SYSTEM

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Abstract: We studied the summer foraging ecology of resident and migrant bald eagles (*Haliaeetus leucocephalus*) along the lower Hudson River, New York, from 1998 to 2001. In this area the Hudson is a freshwater tidal river with 1- to 2-m tidal ranges. Eagles foraged most often in the open channel (35%), where success was lowest (68% capture rate). When compared to landscape availability, eagles foraged in tidal mudflats devoid of aquatic vegetation more often than expected, and they avoided areas of deep water (>3 m). Eagles foraged more often during ebb tides with foraging activity peaking just before low tide. Eagles avoided areas of high human activity but also preferentially selected areas of low to moderate activity. Fish were the most important source of food and comprised 91% of prey identified. Over 50% of the observed prey captures consisted of 3 species: American eel (*Anguilla rostrata*), gizzard shad (*Dorosoma cepedianum*), and white catfish (*Ictalurus catus*). Our data indicate that unvegetated tidal mudflats that were isolated from intensive human activity provided the highest quality foraging habitat. Future loss of tidal mudflats through exotic plant invasions or shoreline development may limit eagle foraging opportunities and population growth.

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Bald eagles declined throughout the northeast United States during the early and mid-1900s due to a combination of habitat destruction, pollution, and direct persecution (Stalmaster 1987:149). Along the Hudson River, habitat destruction occurred with industrial development and shoreline manipulation (Young and Squires 1993). In 1890, the last pair of nesting eagles was observed along the southern Hudson River, and wintering eagles were observed until the early 1900s (Nye and Suring 1978). Beginning in the early 1970s, a number of northeast states began identifying and protecting eagle habitat. In particular, New York state began an aggressive reintroduction program aimed at the long- term reestablishment of breeding bald eagles. As of 2003 there were >70 active breeding pairs in New York, with additional pairs establishing territories every year (P. Nye, New York State Department of Environmental Conservation [NYSDEC], unpublished data).

Historically, the Hudson River Corridor (HRC) provided nesting habitat and wintering and summering areas for northern and southern eagle populations, respectively. As an estuarine system, the Hudson provides extensive tidal flat and intertidal marsh foraging habitat and numerous nest sites on isolated islands and peninsulas. As of 2003, the Hudson River supported 7 nesting pairs and 2 migrant populations of bald eagles (Thompson et al. 2003). The potential for conflicts between eagles and humans is particularly high in estuarine systems due to high recreational and development pressure (McGarigal et al. 1991).

The importance of surface visibility in terms of turbulence has been demonstrated for osprey (*Pandion haliaetus*; Machner and Ydenberg 1990) and bald eagles (Hunt et al. 1992*a*). Consequently, another potential threat to bald eagle use of estuarine systems is the invasion of exotic species such as the water chestnut (*Trapa natans*). Shallow native subaquatic vegetation beds in estuaries often function as nursery habitat for anadromous species (Rozas and Minello 1998) and may therefore provide high-quality foraging habitat for eagles. However, when compared to native tape grass (*Vallisneria americana*), water chestnut beds have 3 times the standing biomass and are characterized by a dense floating canopy (Feldman 2001). This increased density may inhibit eagle foraging by providing fish protection from aerial predation.

Between 1998 and 2001, we investigated many aspects of eagle ecology along the Hudson River. Our objective was to identify critical habitat and

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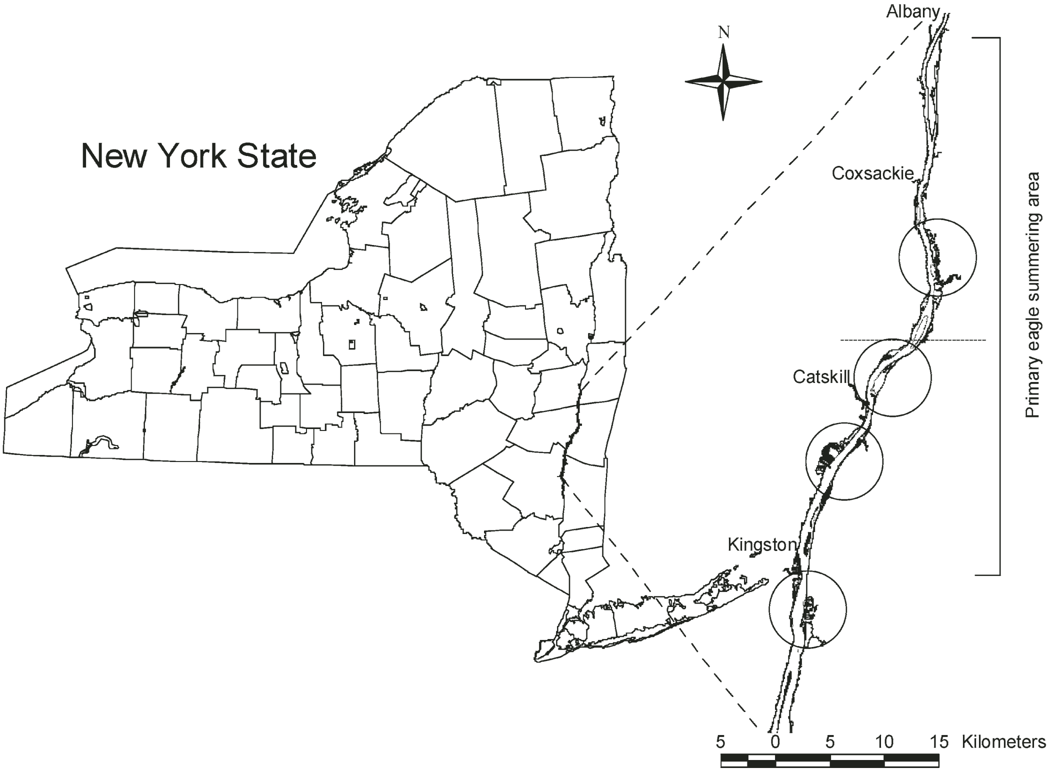

Fig. 1. Study area along the Hudson River, New York, USA. Circles indicate approximate breeding territories of resident eagles. The dotted line indicates the northern extent of available bathymetry data. Darkened areas within the river indicate subaquatic vegetation beds.

potential limits to population growth. We report on the selection of aquatic foraging habitat and prey by eagles and on the influence of human activity, tide, and subaquatic vegetation on eagle foraging activities during summer months.

STUDY AREA

Our study area was approximately 80 km of the Hudson River between Albany and Kingston, New York, USA (Fig. 1). In this area, the Hudson was a freshwater tidal system, with tidal flows ranging from 10 to 100 times the total freshwater inflow, resulting in a tide range of 1–2 m. Numerous islands, peninsulas, dikes, and tributary inflows, combined with the strong tidal influence, created a complex system of mudflats, tidal wetlands, and side channels. This system provided spawning grounds for anadromous fish, including striped bass (*Morone saxatilis*), American shad (*Alosa sapidissima*), and blueback herring (*Alosa aestivalis*; USFWS 1996).

Human activity along the HRC included shoreline development, commercial shipping, and recreation. During the summer months, recreational fishing, boating, and camping were popular. Since 1910, the main channel of the river has been repeatedly dredged to maintain standard shipping depths, and commercial shipping continued year-round. The construction of dikes along much of the eastern shore for a rail line altered the shoreline significantly through straightening and the creation of impounded wetlands (Young and Squires 1993). The shoreline was a mix of urban, industrial, low-density residential, and forest land. Deciduous forests were dominated by Eastern cottonwood (*Populus deltoides*) and oaks (*Quercus* spp.); infrequent conifer stands were Eastern white pine *(Pinus strobus*) and Eastern hemlock (*Tsuga canadensis*).

In 1884, water chestnut was introduced to the Mohawk River and several New York lakes as an ornamental. Water chestnut requires full sunlight, a soft substrate, and minimal current (Kiviat 1987). It does particularly well in tidal mudflats and can reach dry weights of 1,575 g/m^2, virtually covering the water surface (Besha and Countryman 1980). By 1934, it spread to approximately 16 km of the Hudson River lock system, and by the late 1940s it was widespread throughout the Hudson River estuary. Between 1961 and 1976, an eradication effort by New York State reduced the distribution by 60%, but the effort was abandoned in 1977 (B. Blair, NYSDEC personal communication). Due to the dense surface coverage, water chestnut has been identified as a hazard to small boat operation and recreation (Kiviat 1987), but very little information is available regarding possible negative impacts on foraging by bald eagles. Water chestnut also excludes other aquatic vegetation through shading and may drastically alter aquatic communities.

METHODS

We captured eagles using several variations of the floating fish method (Cain and Hodges 1989, Jackman et al. 1993). We either placed sets upstream and allowed them to float past perched eagles, or anchored them in areas routinely used by resident eagles. We monitored sets continuously, and we retrieved captured eagles immediately. We banded captured eagles with U.S. Fish and Wildlife Service and New York State color visual identification (VID) aluminum rivet leg bands. We equipped adult eagles with a 65-g backpack transmitter (Communication Specialists Inc., California) and immature eagles with a 20-g tailmount transmitter following the methods described by McClelland et al. (1994). During handling, we secured the eagle to one researcher with a 4-m cord to ensure that no eagle with a hood or wrapped talons would escape. We initiated intensive telemetry monitoring on all captured birds immediately after release to monitor any adverse effects of handling or transmitter placement. We relocated eagles the following day for the same reason.

We recorded foraging observations by visually monitoring transmitter-equipped eagles and by collecting observations of other eagles opportunistically. We monitored each resident breeding pair once per week for 8–10 hr between April and September. We located migrant eagles equipped with transmitters 2–3 times each week, and we visually monitored them for 2–3 hr. We also monitored unmarked eagles located during weekly surveys for as long as visual contact could be maintained. We monitored by boat to enable an observer to maintain visual contact as a bird moved throughout its territory. Observations were continuous, lasting as long as visual contact could be maintained, and they were conducted at >300 m to reduce any impacts on eagle behavior. We began observations at sunrise to include peak foraging periods, though we collected opportunistic observations throughout the day.

We plotted the locations of all predation attempts, including scavenging and stealing prey from other predators, on enlarged 1:7,500 true-color, aerial photographs. Individual trees or other shoreline features were easily discernible on the photos, and we estimated that open water locations were accurate to within 20 m. We identified prey items to family, or species if possible, and we estimated prey size by comparison to eagle talon size. After an eagle finished feeding and left the area, we collected prey remains for further identification. We also collected prey remains from within and below nests twice each breeding season.

We collected locations of transitory human activities (e.g., recreational boating, hiking) during observation periods and mapped them on enlarged aerial photos. While this did not represent a standardized survey of recreational activities, 3 seasons of observations allowed us to identify the locations of commonly used fishing spots, boating areas, hiking trails, and campsites. We transferred the locations of predation attempts and human activity to an ArcView Geographic Information System (GIS; Environmental Systems Research Institute, Redlands, California, USA) point coverage for analysis.

We defined aquatic foraging habitat by depth, subaquatic vegetation (i.e., the presence and type of subaquatic vegetation) and as open channel, tidal mudflat, bay, or eddy. Areas where the substrate was exposed at low tide were defined as tidal mudflats regardless of other hydrology. We defined eddies as areas where a single obstruction created a disruption in current flow (i.e., jetties, sandbars, and downed trees). In contrast, we defined bays as indentations in the shoreline creating similar disruptions in current.

We obtained tidal information from the National Oceanic and Atmospheric Administration (NOAA) East Coast tide tables. The tidal cycle was broken into 6 periods based on current direction and velocity. Periods lasted approximately 2 hr and included slow flood, fast flood, second slow flood, slow ebb, fast ebb, and second slow ebb. The NYSDEC Ecological Research Station at Bard College, Annadale, NY, provided information on subaquatic vegetation beds, produced from stereoscopic aerial photo interpretation. Aerial photos were 1:14,400 resolution and were taken within 1 hr of low tide. The resulting grid resolution was approximately 0.016 ha. Dominant aquatic/upland marsh species that could be identified included tape grass, water chestnut, and *Phragmites.*

We obtained information on water depth using a NOAA sonar raster dataset at a 30-m resolution and 1-m categorization beginning at 1 m above mean low tide (NOAA, Rockville, Maryland, USA). We reclassified this dataset into a GIS coverage emphasizing shallow areas: 0–1 m above mean low tide (mlt, exposed tidal mudflats), between 0- and 3-m deep at mlt (shallows), and >3-m deep at mlt (deep water). This data was only available for the southern half of the study area, but it incorporated 3 of the 4 monitored nesting territories (Fig. 1).

We used chi-square analysis and Bonferroni confidence intervals (Neu 1974) to assess the influence of subaquatic vegetation, water depth, and the tidal cycle on eagle foraging activity as described by Watson et al. (1991). Hudson River eagles forage almost exclusively in aquatic habitat during the summer (Thompson et al. 2003). Therefore, we considered all aquatic areas within the boundaries of the study area available foraging habitat, and we considered all tidal periods equally available. We considered that an aquatic habitat type was used when a predation attempt was observed within that habitat type, and a tidal period was considered used when a predation attempt was observed during that period.

The influence of human activity on wildlife can extend beyond the point source; therefore, merely mapping sources of disturbance may be inappropriate. For example, eagles can be disturbed by activities over 500 m away (Stalmaster and Kaiser 1998) and may habitually avoid areas frequented by humans (McGarigal et al. 1991). To account for this, we created a landscape-level disturbance index representing the number and proximity of activities. Specifically, we created the index by first overlaying a fine resolution (5-m cell) raster grid over the point coverage of mapped human activities. For each cell, all activities within 400 m were selected using ArcInfo (ESRI, Redlands, California, USA). A degrading logistic function [Y = 100 – (A/(1 + exp (– (X – 200)/C)] was used to weight each selected activity based on the distance to the focal cell. These weighted values were then summed to generate an index value for each grid cell representing the overall amount and proximity of human activity for every point on the landscape. We categorized index values into areas of high, moderate–high, moderate, low–moderate, low, or no human activity. Habitat selection was evaluated by comparing use vs. availability (Neu et al. 1974). For a more detailed summary of this approach, see Thompson and McGarigal (2002).

Table 1. Bald eagle predation attempts and capture success by river habitat type along the Hudson River, New York, USA, 1998–2001 (n = 187).

River habitat type	Predation attempts *n*	Predation attempts %	Success rate (%)
Open channel	66	35.3	68.2
Bay	59	31.6	92.9
Tidal mudflat	42	22.5	76.3
Eddy	16	8.6	87.5
Shore	4	2.1	100

[a] Success rate represents the proportion of observed predation attempts within that river habitat type where the eagle successfully captured prey.

RESULTS

Between 1998 and 2001, we captured 23 eagles (12 adults, 11 immatures). Six of the 12 adults were resident breeders. We documented 272 predation attempts. We recorded exact location for 243 of these attempts and identified 133 prey items to species.

Selection of Foraging Habitat

Eagles foraged most often in open channel, bay, and tidal flat areas (Table 1). There was variability in the selection of foraging habitat between breeding and nonbreeding eagles (χ^2 = 40.76, df = 4, P < 0.001). Predation attempts by breeding eagles occurred in bays and tidal flats 37% and 32% of the time, respectively. In contrast, 19% of nonbreeding eagle predation attempts occurred in bays, and only 2% occurred in tidal flats. Nonbreeding eagles foraged most often in the open channel (62%), while breeding eagles foraged in the open channel 23% of the time.

In the southern half of the study area where data on water depth and aquatic vegetation were available, eagles did not forage equally in all aquatic zones (Table 2). Instead, they selected for inter-tidal marsh and tidal mudflats that were devoid of aquatic vegetation (χ^2 = 113.4 and 39.6 respectively, df = 5, P < 0.001), and they avoided areas of deeper water (χ^2 = 22.90, df = 5, P < 0.001). There were no significant differences in eagle use vs. availability of other areas. The capture success rate varied between 77% and 98% for all aquatic zones except deep water where the capture success rate fell to 38%.

Influence of Tidal Cycles

Eagles did not forage equally across tidal periods (χ^2 = 34.75, df = 5, P < 0.001). Fifty percent of

Table 2. Bald eagle predation attempts in different aquatic habitat types along the Hudson River, New York, USA, 1998–2001 ($n = 95$).

	Capture success rate (%)	Predations					
		Observed		Expected			
		n	Proportion	*n*	Proportion[a]	*P*	95% CI[b]
Intertidal marsh	87	18	0.189	2	0.023	<0.001	0.111 – 0.268[c]
Tape grass	77	15	0.158	19	0.203	0.966	0.085 – 0.231
Water chestnut	98	8	0.084	3	0.035	0.244	0.028 – 0.140
Tidal mudflats	79	37	0.389	14	0.144	<0.001	0.291 – 0.488[c]
Shallows	97	3	0.032	1	0.013	0.451	0.000 – 0.067
Deep water	38	14	0.147	47	0.492	<0.001	0.076 – 0.219[d]

[a] Equal to the proportion of that habitat type within the study area.
[b] Bonferroni confidence interval (Zar 1984).
[c] More foraging attempts than expected.
[d] Less foraging attempts than expected.

Table 3. Bald eagle predation attempts during different tidal periods along the Hudson River, New York, USA, 1998–2001 ($n = 229$).

	Capture success rate (%)	Predations					
		Observed		Expected			
		n	Proportion	*n*	Proportion[a]	*P*	95% CI[b]
Slow flood	83	35	0.153	38	0.167	0.999	0.106 – 0.199
Fast flood	81	26	0.114	38	0.167	0.623	0.072 – 0.155 [b]
Second slow flood	76	29	0.127	38	0.167	0.899	0.084 – 0.170
Slow ebb	65	26	0.114	38	0.167	0.693	0.072 – 0.155 [b]
Fast ebb	77	45	0.197	38	0.167	0.957	0.145 – 0.248
Second slow ebb	87	68	0.297	38	0.167	<0.001	0.238 – 0.356[c]

[a] Bonferroni confidence interval (Zar 1984).
[b] Less foraging attempts than expected.
[c] More foraging attempts than expected.

predation attempts ($n = 243$) occurred within 2 hr of low tide, and we observed increased foraging during ebb tide ($\chi^2 = 23.3$, df = 5, $P < 0.001$; Table 3). The frequency of predation attempts increased during fast ebb (2–4 hr after high tide), peaked just before maximum low tide, and dropped off with the beginning of flood tide (Fig. 2). Eagle foraging in eddies and open channel habitat was relatively unaffected by tide. In contrast, foraging in bays and tidal mudflats was strongly influenced by tide; the number of predation attempts increased as low tide approached (Fig. 3).

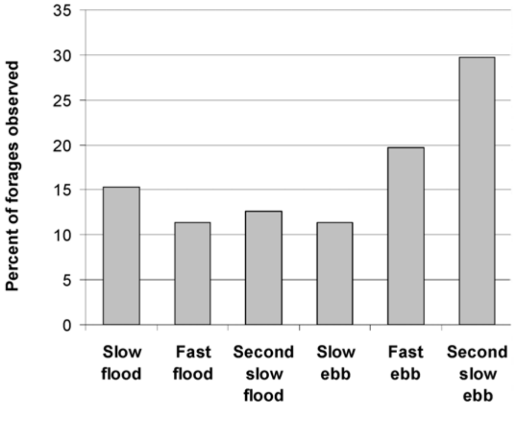

Fig. 2. Timing of foraging attempts by bald eagles along the Hudson River, New York, USA. Observations were collected during summer months, 1998–2000 ($n = 243$).

Human Activity

Eagle selection of foraging areas was related to the intensity of human activity along the river but not in the classic pattern of avoidance. As expected, eagles foraged in areas of high human activity less than would be expected under a random distribution ($\chi^2 = 28.0$, df = 4, $P < 0.001$). However, eagles foraged in areas of no human activity less than expected ($\chi^2 = 42.4$, df = 4, $P < 0.001$) and in areas of low or low–moderate human activity more than expected ($\chi^2 = 13.5$ and 199.7, respectively; df = 4, $P < 0.01$). In areas of moderate or moderate–high activity, we were unable to reject the hypothesis that eagle foraging was distributed randomly ($\chi^2 = 2.7$ and 0.75, respectively; df = 4, $P = 0.61$ and 0.94).

Prey Selection

Fifty-one percent of the prey taken by eagles during the summer season came from 3 species:

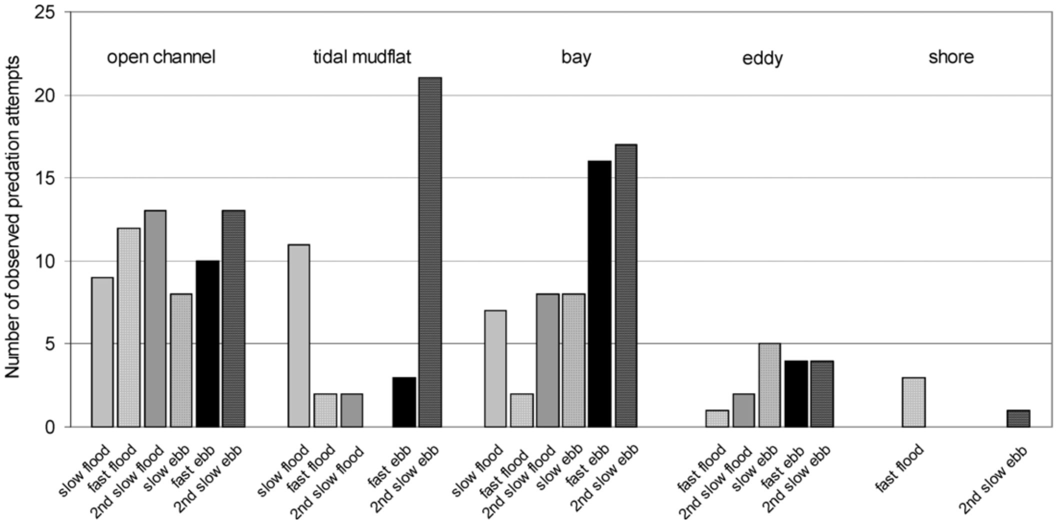

Fig. 3. Number of foraging attempts by summering bald eagles, 1998–2000, along the Hudson River, New York, USA, by foraging habitat and tidal cycle (n = 182). Low tide occurs between second fast ebb and slow flood; high tide occurs between second slow flood and slow ebb.

American eel, gizzard shad, and catfish (*Ictalurus* spp.; Table 4). Most of the catfish captured were believed to be white catfish (*I. catus*), though at least 1 was a channel catfish (*I. punctatus*). Mammals, waterfowl, and reptiles constituted only a small portion (9%) of the eagles' diet. We never observed eagles taking mammalian prey, though we found mammalian remains during nest visits.

DISCUSSION

Hudson River eagles hunted in a variety of aquatic landscapes, but analysis of use vs. availability for particular river features indicated that selection was related to water depth and vegetative cover. Eagles favored inter-tidal marsh and nonvegetated tidal mudflats that were exposed at low tide. These patterns were similar to those

Table 4. Bald eagle prey items identified along the Hudson River, New York, USA, 1998–2000.

Classification	Individuals: Observations	Individuals: Nest visits	Class (%)	Total (%)
Fish				
American eel (*Anguilla rostrata*)	10	18	23	21
Catfish (*Ictalurus* sp.)	18	5	19	17
Gizzard shad (*Dorosoma cepedianum*)	16	2	15	13
White perch (*Morone americana*)	12	0	10	9
White sucker (*Catostomus commersoni*)	2	6	7	6
Brown bullhead (*Ictalurus nebulosus*)	1	5	5	5
Blueback herring (*Alosa aestivalis*)	3	2	4	4
Bass (*Micropterus* sp.)	4	1	4	4
Common carp (*Cyprinus carpio*)	1	3	3	3
Chain pickerel (*Esox niger*)	1	3	3	3
Redbreast sunfish (*Lepomis auritus*)	3	0	2	2
Golden shiner (*Notemigonus crysoleucas*)	1	1	2	2
Sturgeon (*Acipenser* sp.)	0	1	1	1
Goldfish (*Carassius auratus*)	0	1	1	1
Alewife (*Alosa pseudoharengus*)	1	0	1	1
Subtotal	73	48		92
Birds				
Mallard (*Anas platyrhynchos*)	2	1	43	2
Canada goose (*Branta canadensis*)	1	0	14	1
Grebe (*Podiceps* sp.)	0	1	14	1
Blue-winged teal (*Anas discors*)	0	1	14	1
Common merganser (*Mergus merganser*)	1	0	14	1
Subtotal	*4*	*3*		*5*
Mammals				
Grey squirrel (*Sciurus carolinensis*)	0	2	50	2
Eastern cottontail (*Sylvilagus floridanus*)	0	1	25	1
Muskrat (*Ondatra zibethicus*)	0	1	25	1
Subtotal	0	4		*3*
Reptiles				
Northern water snake (*Colubridae* sp.)	1	0	100	1
Subtotal	1	0		*1*

reported for eagles in other systems (Watson et al. 1991, Gende et al. 1997). The breeding territories we monitored encompassed the largest tidal mudflats along the river. This explains the dominance of breeding eagles foraging in this habitat and supports the idea that tidal mudflats represent high quality foraging habitat. Bays and eddies were also favored, probably because eagles were scavenging floating carrion.

In estuarine systems, subaquatic vegetation beds often function as nursery habitat for anadromous species and consequently attract larger, predatory fish. As a result, these areas may provide high quality foraging opportunities for raptors that hunt aquatic prey such as bald eagles and osprey. However, the beds also provide cover from aerial predation, thereby limiting such foraging. The link between surface visibility and foraging success for raptors is well documented, including such aspects as water clarity and surface turbulence (Watson et al. 1991, Hunt et al. 1992*b*). However, few researchers have examined the relationship between subaquatic vegetation beds and raptor foraging. We found no indication of a direct relationship; subaquatic vegetation beds were used in proportion to their availability, and eagles foraged preferentially in nonvegetated tidal flats. However, we did not examine the spatial relationship between subaquatic vegetation and eagle foraging behavior beyond the discrete boundaries of the vegetation beds. One testable hypothesis is that the quality of foraging habitat may increase in areas adjacent to vegetation beds, where prey density and visibility may be increased.

We did not differentiate between eagles capturing live or dead prey. The high capture success rate in bays and eddies may have been associated with dead fish being carried to those areas on river currents. On tidal mudflats, eagles appeared to be focusing on live fish trapped in pools as the tide receded. The 100% capture success rate associated with shoreline forages represented eagles scavenging dead fish from beaches or rocky sections of the shoreline.

Several studies have indicated eagles' preference for foraging at low tide and related this behavior to decreased human activity or exposed carrion (Todd 1979, McGarigal et al. 1991, Watson et al. 1991). Hudson River eagles showed a similar pattern: 50% of foraging attempts (n = 243) occurred within 2 hr before or after low tide. Hudson River eagles also showed increased foraging as the tide was dropping: almost a third of all predation attempts occurred in the 2 hr prior to low tide. There was an increase in foraging activity prior to low tide, a decrease in frequency after low tide, and a lull in foraging around high tide (Fig. 2). This argues against an influence of human activity and carrion in tide-related foraging behavior because these factors probably remain constant immediately before and after low tide. The increase in foraging activity 2–3 hr after high tide may indicate a point at which the water level was low enough to expose fish on tidal flats to aerial predation. The decrease in activity after peak, low tide may have been due to satiation. Watson et al. (1991) suggested that carrion may be depleted throughout the tidal cycle resulting in decreased foraging activity after peak low tide. However, Hudson River eagles appeared to prey heavily on fish that were either leaving exposed tidal flats prior to peak, low tide or caught in pools by the dropping tide. After peak, low tide passed, those opportunities may have declined, resulting in decreased foraging activity, or more likely, the returning tide allowed fish to escape to deeper water. This hypothesis is supported by the tendency of HRC eagles to focus their foraging activity in areas of fine-scale depth variation within large tidal mudflats, such as pools or drainage channels (Thompson and McGarigal 2002). Brown et al. (1998) found similar behavior on the Colorado River, where eagles foraged heavily on trout stranded in pools by fluctuating river flows.

Along the HRC, areas of high human activity were typically marinas or popular campsites. Foraging eagles appeared to avoid these areas. However, the dominant human activity along the river was recreational fishing that was generally focused in productive areas (e.g., subaquatic vegetation beds, areas of submerged debris). Areas of no human activity corresponded to unproductive fish areas such as deeper water or faster current that were avoided by eagles and fishermen alike. Hudson River eagles appeared to tolerate low levels of human activity in order to access productive foraging areas. They did not tolerate human activity within 150–200 m but tolerated low levels of activity at larger spatial scales, resulting in increased foraging success (for a more detailed analysis of this result, see Thompson and McGarigal 2002). This is similar to a response reported by McGarigal et al. (1991) along the Columbia River where eagles approached boats only when the probability of successful foraging was high. Stalmaster and Newman (1978) and

Wood (1999) found that eagles developed tolerances to certain repeated human activities, although Fraser et al. (1985) reported the opposite.

The HRC eagles' preference for fish is similar to results reported in many previous bald eagle studies (Hunt et al. 1992*a*, Bowerman 1993, Grubb 1995). Due to the small number of mammalian prey remains collected and the thick vegetation along most of the Hudson shoreline, we hypothesize that most mammalian prey taken by HRC eagles consisted of scavenged roadkill with the possible exception of muskrat (*Ondatra zibethicus*).

Several factors may have influenced our representation of the HRC eagles' summer diet. First, we obtained many prey identifications by observing feeding eagles and collecting remains after the eagle departed. Smaller species of fish such as herring or shiners may be underrepresented as they generally are consumed entirely. Second, eagles along the HRC exploited seasonal spawning runs of several anadromous fish species, including gizzard shad, blueback herring, and alewife (*Alosa pseudoharengus*) that typically occur in the spring and early summer (T. Lake, Hudson River Almanac, personal communication). We collected most samples in June and July, and that may have resulted in an under-representation of species such as the alewife that typically spawn earlier in the spring. Finally, prey samples collected from nests may be biased toward taxa with more durable or less digestible body parts (i.e., birds or catfish). This concern has been validated through feeding trials of captive eagles (Hunt et al. 1992*a*), though Bowerman (1993) found no difference between observational and prey-remains collection methods for evaluating prey composition in an eagle population preying primarily on fish.

MANAGEMENT IMPLICATIONS

The foraging habitat selection of summering HRC bald eagles was well documented. Unvegetated tidal mudflats, isolated from intensive human activity, provided the highest-quality foraging habitat. While HRC eagles currently do not appear to be adversely affected by the invasion of water chestnut, the future loss of unvegetated tidal flats due to the continued spread of this species could restrict foraging opportunities. In other areas, invasions by nonnative aquatic vegetation have been shown to threaten the ability of aquatic foraging raptors to forage successfully (Rodgers et al. 2001).

In addition, increases in human activity reduce the likelihood of eagles foraging in an area (Stalmaster and Kaiser 1998, McGarigal et al. 1991). Temporal control of human activity around eagle use areas has been recommended as a potentially effective management strategy (Steidl and Anthony 1996). We recommend that land managers along the HRC identify, delineate, and protect foraging habitat, then manage human activity in and adjacent to those areas to reduce the impact during peak foraging times.

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LITERATURE CITED

BESHA, J. A., AND W. D. COUNTRYMAN. 1980. Feasibility assessment of anaerobic digestion of European water chestnuts (*Trapa natans* L.). New York State Energy Research and Development Authority ERDA 80-13. Albany, New York, USA.

BOWERMAN, W. W. 1993. Regulation of bald eagle (*Halieatus leucocephalus*) productivity in the Great Lakes Basin: an ecological and toxicological approach. Thesis, Department of Fisheries and Wildlife, Michigan State University, East Lansing, USA.

BROWN, B. T., L. E. STEVENS, AND T. A. YATES. 1998. Influences of fluctuating river flows on bald eagle foraging behavior. Condor 100:745–748.

CAIN, S. L., AND J. I. HODGES. 1989. A floating fish snare for capturing bald eagles. Journal of Raptor Research 23:10–13.

FELDMAN, R.S. 2001. Taxonomic and size structures of phytophilous macroinvertebrate communities in *Vallisneria* and *Trapa* beds of the Hudson River, New York. Hydrobiologia 452:233–245.

FRASER, J. D., L. D. FRENZEL, AND J. E. MATHISEN. 1985. The impacts of human activities on breeding bald eagles in north-central Minnesota. Journal of Wildlife Management 49:585–592.

GENDE, S. M., M. F. WILSON, AND M. JACOBSEN. 1997. Reproductive success of bald eagles (*Haliaeetus leucocephalus*) and its association with habitat or landscape features and weather in southeast Alaska. Canadian Journal of Zoology 75:1595–1604.

GRUBB, T. G. 1995. Food habits of bald eagles breeding in the Arizona desert. Wilson Bulletin 107:258–274.

HUNT, W. G., D. E. DRISCOLL, E. W. BIANCHI, AND R. E. JACKMAN. 1992*a*. Ecology of bald eagles in Arizona, Volume 1-5. Report to the U.S. Bureau of Reclamation, Contract 6-CS-30-04470. BioSystems Analysis, Santa Cruz, California, USA.

———, J. M. JENKINS, R. E. JACKMAN, C. G. THELANDER, AND A. T. GERSTELL. 1992*b*. Foraging ecology of bald eagles on a regulated river. Journal of Raptor Research 26:243–256.

JACKMAN, R. E., W. G. HUNT, D. E. DRISCOLL, AND J. M. JENKINS. 1993. A modified floating fish snare for capture of inland bald eagles. North American Bird Bander 18:98–101.

KIVIAT, E. 1987. Water chestnut (*Trapa natans*). Pages 31–38 *in* D. J. Decker and J. W. Enck, editors. Exotic plants with identified detrimental impacts on wildlife habitats in New York state. The Wildlife Society, New York Chapter. Cornell University, Ithaca, New York, USA.

MACHNER, M. M., AND R. C. YDENBERG. 1990. Weather and osprey foraging energetics. Canadian Journal of Zoology 68:40–43.

MCCLELLAND, B. R., L. S. YOUNG, P. T. MCCLELLAND, J. G. CRENSHAW, H. L. ALLEN, AND D. S. SHEA. 1994. Migration ecology of bald eagles from autumn concentrations in Glacier National Park, Montana. Wildlife Monographs 125.

MCGARIGAL, K., R. G. ANTHONY, AND F. B. ISAACS. 1991. Interactions of humans and bald eagles on the Columbia River Estuary. Wildlife Monographs 115.

NEU, C. W., C. R. BYERS, AND J. M. PEEK. 1974. Technique for analysis of utilization-availability data. Journal of Wildlife Management 38:541–545.

NYE, P. E., AND L. H. SURING. 1978. Observations concerning a wintering population of bald eagles on an area in southeastern New York. New York Fish and Game Journal 25:91–107.

RODGERS, J. A., H. T. SMITH, AND D. D. THAYER. 2001. Integrating nonindigenous aquatic plant control with protection of snail kite nests in Florida. Environmental Management 28:31–37.

ROZAS, L. P., AND T. J. MINELLO. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a south Texas (USA) estuary. Bulletin of Marine Science 63:481–501.

STALMASTER, M. V., AND J. L. KAISER. 1998. Effects of recreation activity on wintering bald eagles. Wildlife Monographs 137.

———. 1987. The bald eagle. Universe Books, New York, USA.

———, AND J. R. NEWMAN. 1978. Behavioral responses of wintering bald eagles to human activity. Journal of Wildlife Management 42:506–513.

STEIDL, R. J., AND R. G. ANTHONY. 1996. Responses of bald eagles to human activity during the summer in interior Alaska. Ecological Applications 6:482–491.

THOMPSON, C. M., S. G. KOHLMAN, G. A. SCHMIDT, AND D. K. GARCELON. 2003. Status and movements of bald eagles along the Hudson River Corridor. Final report to the New York State Department of Environmental Conservation, Endangered Species Unit. Institute for Wildlife Studies, Arcata, California, USA.

———, AND K. MCGARIGAL. 2002. The influence of research scale on bald eagle habitat selection along the Lower Hudson River, New York (USA). Journal of Landscape Ecology 17:569–586.

TODD, C. S. 1979. The ecology of the bald eagle in Maine. Thesis, University of Maine, Orono, USA.

U.S. FISH AND WILDLIFE SERVICE. 1996. Regionally significant habitats and habitat complexes of the New York Bight Watershed. Southern New England–New York Bight Coastal Ecosystems Program final report. U.S. Fish and Wildlife Service, Charlestown, Rhode Island, USA.

WATSON, J. W., R. G. ANTHONY, AND M. GARRETT. 1991. Foraging ecology of bald eagles in the Columbia River estuary. Journal of Wildlife Management 55:492–499.

WOOD, P. B. 1999. Bald eagle response to boating activity in northcentral Florida. Journal of Raptor Research 33:97–101.

YOUNG, J. A., AND D. F. SQUIRES. 1993. Human manipulation of the historical Hudson shoreline, a geographical approach. Pages 1–22 *in* J. R. Waldman and W. C. Nieder, editors. Final reports of the Tibor T. Polgar Fellowship Program. Hudson River Foundation, New York, USA.

ZAR, J. H. 1984. Biostatistical analysis. Second edition. Prentice Hall, Englewood Cliffs, New Jersey, USA.

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