Branden L. Johnson[1], **James L. Kaiser, Charles J. Henny,** and **Robert A. Grove,** U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 3200 SW Jefferson Way, Corvallis, Oregon 97331

Prey of Nesting Ospreys on the Willamette and Columbia Rivers, Oregon and Washington

Abstract

To more effectively use ospreys as a biomonitoring tool and to better assess contaminant pathways, the diet of nesting ospreys (*Pandion haliaetus*) was studied along the lower Columbia and upper mainstem Willamette rivers by evaluating prey remains collected from wire baskets constructed under artificial feeding perches installed near nest sites and from the ground beneath natural feeding perches and nests. Prey remains from 1997-2004 on the Columbia River and 1993 (previously published) and 2001 on the Willamette River were evaluated and compared. Largescale suckers (*Catostomus macrocheilus*) were the predominate fish species identified in collections from the Columbia River (61.5% [84.3% biomass]) and Willamette River (76.0% [92.7% biomass]). Prey fish diversity, when based only on ground collections, was higher in the Columbia (2.45) than the Willamette river (1.92) (P = 0.038). Prey fish diversity in collections from the Willamette River did not differ between this study (2001) and previous study (1993) (P = 0.62). Fish bones recovered in wire baskets are likely more representative of osprey diet compared to bones recovered from the ground, because prey diversity was higher among basket samples compared to ground collections (wire basket diversity = 5.25 vs. ground collection diversity = 2.45, P = 0.011). Soft-boned salmonids (*Oncorhynchus spp.*), American shad (*Alosa sapidissima*), and mountain whitefish (*Prosopium williamsoni*) were probably underrepresented in collections obtained from the ground. Study results suggest that baskets provide a better method for assessing osprey diet than other indirect methods. These findings augment available osprey food-habits information and provide additional biological and ecological information to better assess potential impacts of various environmental contaminants on nesting ospreys.

Introduction

Studying diets of raptors provides valuable information regarding prey distribution and abundance, community structure, contaminant sources, and ecosystem function (Johnson 1981, Clark et al. 1983, Katzner et al. 2005). Identifying changes in raptor diet or food supply is important, especially in species with restricted diets like the osprey (*Pandion haliaetus*) which feed on >99% fish, because such alterations may have broader ecosystem implications (Frenzel and Anthony 1989, Johnson 2005). Ospreys have been used as a bioindicator of aquatic ecosystem health since Ames and Mersereau (1964) implicated pesticides in the precipitous decline of the Connecticut River colony in the Northeastern United States. The osprey has a cosmopolitan distribution and numerous life history traits (piscivorous feeding habits, capture prey near nest site, strong nest site fidelity, habituates to humans, tolerant of short-term nest disturbance, nests at regular intervals along rivers, sensitive to many bioaccumulative pollutants) that make them a useful species for contaminant monitoring and research (Elliott et al. 2000). Further, in a systematic evaluation of 25 terrestrial vertebrates commonly found in Atlantic Coast estuarine habitats the osprey ranked highly suitable for monitoring persistent organic pollutants and mercury based on exposure potential and sensitivity (Golden and Rattner 2003). To effectively use ospreys as a biomonitoring tool, assess contaminant pathways, and recognize ecosystem change, feeding behaviors must be well understood.

Numerous studies have documented dietary habits for osprey populations in various regions (Bent 1937, Prevost 1977, Hakkinen 1978, Swenson 1979, Van Daele and Van Daele 1982, Poole 1989, McClean and Byrd 1991, Henny et al. 2003), and others have examined the diet and prey selection of other fish-eating birds on the Columbia River (Watson et al. 1991: bald eagles [*Haliaeetus leucocephalus*], Thomas and Anthony 1999: great blue herons [*Ardea herodias*], Collis et al. 2002: Caspian terns [*Sterna caspia*] and double-crested cormorants [*Phalacrocorax auritus*]); however, this is the first study to examine the diet of ospreys nesting on the Columbia River. Assessment of raptor diets is often accomplished

[1]Author to whom correspondence should be addressed.
Email: branden_johnson@usgs.gov

by prey collections at nests, observations at nests (direct or remote [videography]), or analysis of pellets (Marti 1987, Redpath et al. 2001, Lewis et al. 2004), but each method has inherent biases and disadvantages. Our objectives were: (1) to determine diets of nesting ospreys from prey remains on the Columbia and Willamette rivers and compare diet diversity between these rivers, (2) to assess whether prey fish collected in wire baskets were more representative of osprey diet than ground collections, and (3) to determine whether prey diversity changed in the osprey population on the Willamette River between 1993 (Henny et al. 2003) and 2001.

Methods

Study Area

The Columbia is the largest river (measured by volume: 7,500 m^3/s mean annual discharge) flowing into the Pacific Ocean in the Western Hemisphere, is 2,010 km long, drains an area of 668,220 km^2, and supports 14 mainstem dams (11 in the US) (Kammerer 1990, Wydoski and Whitney 2003) (Figure 1). Columbia River fish community structure is diverse, varies from headwaters to the mouth, and has been altered by dam construction, dredging, and other anthropogenic actions (Beecher et al. 1988, Williams et al. 1999, Wydoski and Whitney 2003). Agriculture is extensive within the Columbia River drainage as well as hydroelectric power industries (aluminum smelters and others) and bleached-kraft paper mills. Historically, ospreys were common along the Columbia and Willamette rivers (Gabrielson and Jewett 1940). Nationwide the species declined in the era of DDT use (1947-1972) (Henny 1977, Wiemeyer et al. 1988) and increased during the 1980s and 1990s (Henny 1983, Houghton and Rymon 1997). The number of nesting osprey pairs on the lower portion of the Columbia River (river kilometer [rkm] 47-460) was 94 in 1997, increased to 225 pairs in 2004, and continues to proliferate (Henny et al. 2007). Each year numerous hatcheries release millions of salmonids into the Columbia, and to a lesser degree into the Willamette (Wydoski and Whitney 2003, Fish Passage Center 2007). The Willamette River, approximately 301 km long and draining 29,800 km^2, is the largest of the lower Columbia River tributaries; their confluence is at rkm 164 in Portland, Oregon (Figure 1). The upper mainstem Willamette River (Willamette Falls to the confluence of the Willamette and McKenzie rivers [rkm 43-282]) is primarily bordered by cropland on the valley floor with forested and urbanized areas (Bonn et al. 1995). The number of nesting osprey pairs on the Willamette was 13 in 1976 and increased to 234 pairs in 2001 (Henny at al. 2002).

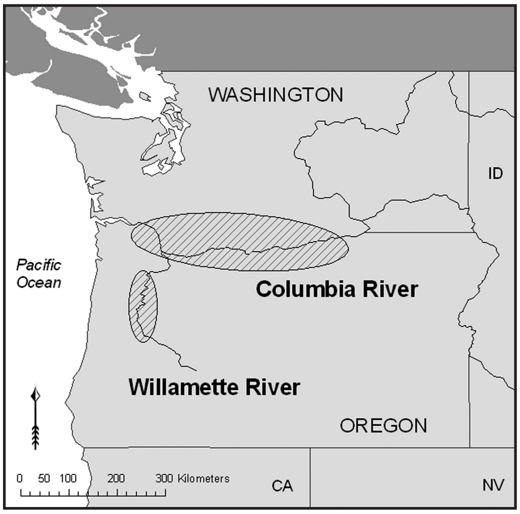

Figure 1. Columbia River and Willamette River study areas (circled portions) where assessment of osprey diet was conducted.

Study Design

We collected prey fish remains periodically from the ground beneath osprey nests and natural feeding perches or from constructed wire prey baskets at 44 osprey nests along the lower Columbia River between 1997 and 2004 (rkm 92-455), and from 14 osprey nests on the upper mainstem Willamette River (rkm 81-253) in 2001 (Figure 1). Four nests on the Columbia River utilized baskets for collection of prey remains; for all other nests (N = 40 Columbia River, N = 14 Willamette River), prey remains were collected from the ground. Rectangular wire baskets (71 x 107 cm) were constructed from 5 x 10 cm light gauge wire mesh (hardware cloth) supported on a wood lathe frame to which two nylon mesh bags were attached for collection of the fish remains (Figure 2). The wire and nylon mesh bags were essential in preventing loss of prey remains to avian scavengers or during high winds. A “T” style wooden perch was constructed using a cedar lumber (5 x 5-cm and 2.4 m in length) passing through the center of the basket frame and rising approximately 0.61 m above the top surface

Figure 2. An example of a wire basket used to collect prey fish remains from ospreys nesting on the Columbia River in 2004 (design and photo, Jim Kaiser).

of the basket. The perch/basket assembly was then attached to overwater pilings near Columbia River nest sites, often at previously observed feeding locations, using lag bolts. Prey remains collected at each site were identified via pharyngeal arches, dentaries, cleithra and opercules, as well as skin, caudal fins and whole body specimens (Swenson 1978, Frost 2000, Wydoski and Whitney 2003, and a USGS Willamette River reference collection, for details see Henny et al. 2003). When applicable, bones were paired by size and appearance (degree of bleaching/deterioration) and pairs were treated as one individual; each unpaired bone was treated as one individual. For each site and collection date, the different bones (paired and unpaired) of the same species were fitted together when appropriate so that individual fish were reconstructed unless bone sizes were notably different or bone age (appearance) was conspicuously dissimilar.

Bones were identified to genus and species, when possible. For *Catostomus spp*. (suckers), bones were not diagnostic for species identification. However, 94% of sucker individuals in the mainstem Columbia River are *Catostomus macrocheilus* (largescale suckers) (Wydoski and Whitney 2003) and thus identified *Catostomus spp.* are assumed and hereafter referred to as largescale suckers. Likewise, large and smallmouth bass (*Micropterus spp*.) and salmonids (*Oncorhynchus spp*.) could not be differentiated and are referred to as bass and salmonids, respectively. Based on direct field observations of osprey with prey items, whole body specimens in our prey remain collections, and the fact that channel catfish are not readily found, if at all, in the Columbia mainstem, (Gary Galovich, Oregon Department of Fish and Wildlife [ODFW], personal communication), bones identified as *Ictalurus spp.* (Frost 2000) are most likely brown and yellow bullheads (*Ameiurus spp*.), more specifically *Ameiurus nebulosa* (brown bullhead) based on distributions and habits (Wydoski and Whitney 2003), and are hereafter referred to as bullheads.

Linear regression analysis was used to predict total fish mass from opercule length (Newsome 1977, Van Daele et al. 1982) using reference collections (Henny et al. 2003). Only intact opercules were measured in this analysis. For species with no reference samples for opercule-mass relationships (salmonids, American shad [*Alosa sapidissima*], peamouth [*Mylocheilus caurinus*], goldfish [*Carassius auratus*], bullheads, yellow perch [*Perca flavescens*] and walleye [*Sander vitreus*]), a mean mass was used for fish 203-305 mm in length based on Columbia River collections (2000-2003) from ODFW (Gary Galovich, ODFW, personal communication). No morphometric information for Tench (*Tinca tinca*) was available from ODFW, therefore, mean mass was estimated based on Wydoski and Whitney (2003).

The number of sampling events conducted varied among nest sites (range 1-10) and among years (range 1-3). To reduce potential biases associated with unequal sampling effort, sampling events at individual nests were combined by year, and only nest sites with ≥ five fish were used. For nest sites with multiple sampling years, we selected the year yielding the largest sample size to use in analysis. This produced 23 and 12 independent data points for the Columbia River (four nests had prey baskets) and Willamette River, respectively. Percent occurrence was determined for each fish species identified from prey remains on an equally weighted nest by nest basis and mean mass was used to convert frequencies in diet to percent biomass. Goldfish, walleye and perch were grouped together because individuals were identified from collections in low numbers (N = 1, 2, and 2, respectively). We calculated species diversity using Simpson's Reciprocal Index (1/D) based on Simpson's Index:

$D = [\sum (n_i (n_i - 1))] / [N (N - 1)]$ where D is the diversity index, N is the total number of individuals of all species, and n_i is the number of individuals of the ith species. Using the reciprocal of the Simpson's Index original formulation ensures that the increase in the reciprocal index reflects an increase in diversity (Magurran 1988). We used a two-tailed Wilcoxon Rank Sum test to compare prey diversity between Columbia River nest sites with and without wire baskets (Zar 1999). We also used a rank sum test to compare prey diversity of ground collections between the Willamette and Columbia rivers, and between years on the Willamette (1993 vs. 2001, SAS 1999).

Results

Columbia River

We identified 269 individual fish from ground collected prey remains along the Columbia River (Table 1). Largescale suckers dominated the collection (61.5%), common carp (*Cyprinus carpio*) (10.9%) and northern pikeminnow (*Ptychocheilus oregonensis*) (8.9%) were the second and third most abundant. Biomass calculations indicated that largescale suckers were the most abundant species in the osprey diet (84.3%), followed by carp (6.5%) and northern pikeminnow (2.8%).

Willamette River

We identified 197 individual fish from ground collected prey remains along the Willamette River (Table 1). Largescale suckers were the predominate species (76.0%) in collections, followed by northern pikeminnow (12.5%), bass (4.5%) and peamouth (2.7%). Biomass results followed the same general pattern, largescale suckers were the most important prey species (92.7%) followed by northern pikeminnow (3.5%).

Prey Fish Diversity Comparisons

We identified 239 individual fish from prey remains recovered from wire baskets along the Columbia River (Table 1). Largescale suckers represented 29.2% of collections, followed by American shad, bass and salmonids (16.9%, 15.0%, and 13.6%, respectively). Biomass calculations indicated that largescale suckers were the predominate species in osprey diet (57.5%) followed by American shad (17.7%), while salmonids, peamouth, bass, and northern pikeminnow occurrence were of similar proportions (6.5%, 5.2%, 4.8%, and 4.4%, respectively). Prey fish diversity was higher in collections from wire baskets (1/D = 5.25, N = 4) compared to collections from the ground under natural feeding perches and nests (1/D = 2.45, N = 19) (Z = 2.5563, $P = 0.011$). Further, prey fish numbers in wire basket collections (mean = 59.8, SD 53.3, N = 4) were higher than in collections at nest sites with no wire basket (mean = 14.2, SD 9.2, N = 19) (Z = 2.2801, $P = 0.023$) (Table 1). Most of the identified salmonids (87%, N = 31), American shad (88%, N = 42), and mountain whitefish (100%, N = 7) were collected from nest sites with wire baskets.

Prey fish diversity (based on ground collections only) along the Columbia River (1/D = 2.45, range 1.00 - 4.71, N = 19) was significantly higher than along the Willamette River (1/D = 1.92, range 1.00 - 2.75, N = 12) (Z = -2.0712, $P = 0.038$). Diet diversity of ospreys nesting along the Willamette River was not different between this and the previous study (1/D = 2.22, N = 21) (Henny et al. 2003, Z = -0.4965, $P = 0.62$).

Discussion

Study results indicate largescale suckers are the major component of diet in ospreys nesting along the Columbia and Willamette rivers. Northern pikeminnow, bass, carp, peamouth and bullheads also were represented in the osprey diet from both systems in varying frequencies. These results provide the best available estimate of proportions of fish species found in the osprey diet for the two populations although salmonids, American shad and mountain whitefish were probably underrepresented in ground collections. Although we found that using wire baskets to assess osprey diet provides a more representative sample compared to ground collection methods, further experimental study is needed (see later discussion).

Studies conducted on the Columbia River have found a variety of chemicals in the food web (Anthony et al. 1993, Foster et al. 1999, Foster et al. 2001, U.S. EPA 2002, Henny et al. 2004). These studies and others (Mecozzi 1988, Cizdziel et al. 2003) have shown that certain fish species have higher residue concentrations than others. For example, Northern pikeminnow and peamouth had higher concentrations of organochlorine pesticides (OCs), polychlorinated biphenyls (PCBs), and mercury compared to largescale suckers and American shad (Anthony et al. 1993). In the Willamette River, Henny et al. (2003) found that

TABLE 1. Prey remains collected from osprey nests along Columbia River, Oregon and Washington, and Willamette River, Oregon, 1997-2004.

Nest Site[a]	RKM	Fish Species (% Incidence)[b] LSS	CAR	SHA	NPM	BAS	PEA	SAL	BUL	TEN	MWF	OTH	N	Div[c]	Year[d]
C 57	92	76.9	7.7		15.4								13	1.70	2000
C 57S	92	72.7			18.2		9.1						22	1.82	2000
C 62	100	66.7			16.7							16.7	6	2.50	2000
C 69	111	82.9	2.9		5.7	5.7		2.9					35	1.46	2000
C 72	116	40.7			7.4	22.2	11.1	3.7	7.4	3.7		3.7	27	4.68	2000
C 81	130	71.4	14.3							14.3			7	2.10	1197-98
C 84	135	100											12	1.00	2000
C 89	143		60.0			20.0			20.0				5	3.33	1997-98
C 91	146	33.3	50.0	5.6					11.1				18	2.94	1997-98
C 91A	146	83.3			16.7								6	1.50	2000
C 101A	163	35.7	50.0		7.1					7.1			14	2.94	1997-98
C 109	175	66.7							16.7			16.7	6	2.50	2000
C 111A	179	41.7		16.7	25.0		8.3		8.3				12	4.71	2000
C118	190	87.5			12.5								8	1.33	2000
C 118A	190	58.8	5.9	2.9	14.7	5.9			5.9	5.9			34	4.05	2000
C 142	229	58.3			16.7		8.3		8.3			8.3	12	3.00	2000
C 173A	278	50.0			12.5	12.5			25.0				8	4.00	2000
C 258	415	70.0	10.0			20.0							10	2.05	1997-98
C 283	455	71.4	7.1	7.1				14.3					14	1.98	1997-98
C 111[e]	179	49.6	1.5	5.2	19.3	3.0	11.1	5.2	1.5	3.0	0.7		135	3.35	2004
C 117C[e]	188	41.7			8.3	33.3	8.3	8.3					12	4.13	2004
C 134B[e]	216	16.7		25.0	5.6	11.1	13.9	19.4			5.6	2.8	36	7.00	2004
C 134C[e]	216	8.9		37.5	5.4	12.5	7.1	21.4			7.1		56	4.78	2004
W 11	81	70.0		5.0	10.0	10.0		5.0					20	2.04	2001
W 11A	81	63.6		4.5	13.6	4.5	13.6						22	2.38	2001
W 12	83	74.2	3.2	3.2	3.2	3.2	3.2		9.7				31	1.82	2001
W 13	87	56.6			13.0	21.7	8.7						23	2.75	2001
W 21	108	77.8			5.6	11.1			5.6				18	1.66	2001
W 30B	120	75.0			25.0								8	1.75	2001
W 38B	137	50.0			40.6	3.1	6.3						32	2.49	2001
W 52	155	100											7	1.00	2001
W 98A	219	94.4			5.6								18	1.13	2001
W 110	232	83.3	16.7										6	1.50	2001
W 121A	242	83.3			16.7								6	1.50	2001
W 132	253	83.3			16.7								6	1.50	2001
Mean Weight(g)[f]		787	341	419	181	127	206	190	146	300	290	231			
C % Incidence (% Biomass)		61.5 (84.3)	10.9 (6.5)	1.7 (1.2)	8.9 (2.8)	4.5 (1.0)	1.9 (0.7)	1.1 (0.4)	5.4 (1.4)	1.6 (0.8)	0.0 (0.0)	2.4 (1.0)	269	2.45	N nests = 19
C[e] % Incidence (% Biomass)		29.2 (57.5)	0.4 (0.3)	16.9 (17.7)	9.7 (4.4)	15.0 (4.8)	10.1 (5.2)	13.6 (6.5)	0.4 (0.1)	0.8 (0.6)	3.4 (2.5)	0.7 (0.4)	239	5.25	N nests = 4
W % Incidence (% Biomass)		76.0 (92.7)	1.7 (0.9)	1.1 (0.7)	12.5 (3.5)	4.5 (0.9)	2.7 (0.9)	0.4 (0.1)	1.3 (0.3)				197	1.92	N nests = 12

RKM = river kilometer.

[a] C—Columbia River, W—Willamette River.

[b] LSS—largescale suckers (*Catostomus macrocheilus*), CAR—common carp (*Cyprinus carpio*), SHA—American shad (*Alosa sapidissima*), NPM—northern pikeminnow (*Ptychocheilus oregonensis*), BAS - bass (*Micropterus spp.*), PEA—peamouth (*Mylocheilus caurinus*), SAL—salmonid (*Oncorhynchus spp.)*, BUL—bullheads (*Ameiurus spp.*), TEN—tench (*Tinca tinca*), MWF - mountain whitefish (*Prosopium williamsoni*), OTH—other: goldfish (*Carassius auratus*), yellow perch (*Perca flavescens*), walleye (*Sander vitreus*); blank cells denote zero values.

[c] Simpson's Reciprocal Diversity Index (1/D).

[d] Sampling year.

[e] Nests with deployed wire prey baskets.

[f] Weights determined using opercula lengths (LSS, CAR, NPM, BAS, MWF), weights for fish 8-12 inches (203-305 mm) determined by Oregon Department of Fish and Wildlife (SHA, PEA, SAL, BUL, OTH), TEN estimated according to Wydoski and Whitney (2003).

northern pikeminnows generally had OC and PCB concentrations higher than largescale suckers, and mercury concentrations higher than largescale suckers and mountain whitefish. If Ospreys primarily captured the higher food chain northern pikeminnows instead of the less contaminated suckers, perhaps contaminants would have extirpated the species from these rivers during the 1950s and 1960s (e.g., only 13 pairs on the Willamette River in 1976, Henny et al. 1978). Our prey species study provides a better understanding of contaminant food-web dynamics that result in the observed concentrations reported in osprey eggs collected on these rivers and provides additional biological and ecological information that will benefit future efforts to assess the impacts of environmental contaminants that biomagnify through the aquatic food chain and effect ospreys.

The use of prey remains to assess raptor diets is generally thought to over-represent large and bony prey (Marti 1987, Redpath et al. 2001, Lewis et al. 2004). Despite these assumed biases, examining uneaten food remains, pellets and/or bones is the most common method to study diets of birds of prey, and recently this method has been shown to give fairly reliable results of the true diet if no one prey species occurs in high proportion (Tornberg and Reif 2007). Although largescale suckers were found in high numbers, and salmonids, American shad and mountain whitefish were probably underrepresented, results do provide general estimates of the proportions of prey species in osprey diet in these systems. Prey remains collected in the wire baskets were probably more representative of true osprey diet, because of the greater fish diversity reported using this collection method. Most salmonids (87%), American shad (88%), and mountain whitefish (100%) were recovered from the wire basket collections. These soft-boned fish species are more widely dispersed by weather conditions (e.g., wind and rain) and often consumed by scavengers. Our results support the assumed limitations of ground collected prey remains to assess raptor diets, and we agree with Prevost's (1982) suggestion that wire basket collection devices reduce such biases. We recommend using wire baskets in future osprey dietary studies, but suggest incorporating simultaneous direct (video or photo imagery) and indirect (wire basket) methods to quantify sampling biases. Other studies that compared methods for assessing raptor diet have concluded that biases are greater in pellet and prey-remain evaluations compared to those based on direct observations, and that no one technique provides a thorough dietary account (Collopy 1983, Mersmann et al. 1992, Lewis et al. 2004).

We expected fish diversity to vary between the two river systems because structure and function change as stream size increases (Vannnote et al. 1980), and four fish species (tench, walleye, goldfish, and yellow perch) identified from Columbia River ground collections were not found in Willamette River collections. Two of the four species (tench and walleye) not found in Willamette River osprey prey remains were also not found during fish surveys conducted between 1944 and 2006 on the Willamette River (LaVigne et al. 2008). It is not surprising that goldfish were not found in Willamette River osprey prey remains as summer fish surveys found the species in low numbers at only a few sites (rkm 5-58) outside of our study area (rkm 81-253) (LaVigne et al. 2008). Yellow perch were reported in low numbers during summer Willamette River fish surveys (LaVigne et al. 2008) and the lack of yellow perch remains in Willamette River collections is best explained by the unavailability of the species. It also is not surprising that the osprey diet was largely represented by largescale suckers in both of the river systems studied. Largescale suckers are slow moving fish that swim near the surface, feed on benthic macroinvertebrates, and are found in large numbers throughout the Columbia and Willamette rivers (Wydoski and Whitney 2003). Benthic feeding fish direct their sight downward and are slow swimmers making them especially vulnerable to osprey (Swenson 1979). Largescale suckers were the predominate species in nesting osprey diet at Flathead Lake, Montana and in previous study along the Willamette River (MacCarter 1972, Henny et al. 2003); however, various species have been reported as the major prey item in other systems and is largely dependant on fish availability and vulnerability (Poole 1989). Ospreys are opportunistic foragers and their diet is often composed of only two or three vulnerable fish species regardless of fish community composition (Poole et al. 2002). Despite the possible limitations of not utilizing the whole food web, ospreys are well suited for biomonitoring, as long as feeding specifics are well understood. Although the optimal model for biomonitoring encompasses multiple species, this is not always possible due to funding, time and other logistical constraints. Ospreys are sensitive to bioaccumulative pollutants and are top predators in many aquatic systems they inhabit. Aquatic systems are dynamic and interval studies of osprey diet will provide information on contaminant pathways as well as changes in diet, which may have broader ecosystem implications.

Acknowledgements

Authors thank V. R. Bentley for assisting with prey remains and reference fish collections, G. Galovich, ODFW, for providing morphometric information for several fish species, and D. Anderson, M. Johnson, and J. Watson for comments and suggestions on earlier manuscript drafts.

Literature Cited

Ames, P. L. and G. S. Mersereau. 1964. Some factors in the decline of the osprey in Connecticut. Auk 81:173-185.

Anthony, R. G., M. G. Garrett, and C. A. Schuler. 1993. Environmental contaminants in bald eagles in the Columbia River Estuary. The Journal of Wildlife Management 57:10-19.

Beecher, H. A., E. R. Dott, and R. F. Fernau. 1988. Fish species richness and stream order in Washington State. Environmental Biology of Fishes 22:193-209.

Bent, A. C. 1937. Life histories of North American birds of prey. Pt. 1. U.S. National Museum Bulletin 167, Washington, D.C.

Bonn, B. A., S. R. Hinkle, D. A. Wentz, and M. A. Uhrich. 1995. Analysis of nutrient and ancillary water-quality data for surface and ground water of the Willamette Basin, Oregon 1980-1990, U.S. Geological Survey Water-Resources Investigation Report 95-4036.

Cizdziel, J., T. Hinners, C. Cross, and J. Pollard. 2003. Distribution of mercury in the tissues of five species of freshwater fish from Lake Mead, USA. Journal of Environmental Monitoring 5:802-807.

Clark, D. R., R. L. Clawson, and C. J. Stafford. 1983. Gray bats killed by dieldrin at two additional Missouri caves: aquatic macroinvertebrates found dead. Bulletin of Environmental Contamination and Toxicology 30:214-218.

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D. E. Lyons. 2002. Population size and diet composition of fish-eating colonial waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537-550.

Collopy, M. W. 1983. A comparison of direct observations and collected prey remains in determining the diet of golden eagles. Journal of Wildlife Management 47:360-368.

Elliott, J. E., M. M. Machmer, L. K. Wilson, and C. J. Henny. 2000. Contaminants in ospreys from the Pacific Northwest: II. Organochlorine pesticides, polychlorinated biphenyls and mercury, 1991-1997. Archives of Environmental Contamination and Toxicology 38:93-106.

Fish Passage Center. 2007. Hatchery release data. Available on the web at www.fpc.org (accessed 7 September 2007).

Foster, E. P., D. Drake, and R. Farlow. 1999. Polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran congener profiles in fish, crayfish, and sediment collected near a wood treating facility and a bleached kraft pulp mill. Bulletin of Environmental Contamination and Toxicology 62:239-246.

Foster, E. P., M. S. Fitzpatrick, G. W. Feist, C. B. Schreck, and J. Yates. 2001. Gonad organochlorine concentrations and plasma steroid levels in white sturgeon (*Acipenser transmontanus*) from the Columbia River, USA. Bulletin of Environmental Contamination and Toxicology 67:239-245.

Frenzel, R. W. and R. G. Anthony. 1989. Relationship of diets and environmental contaminants in wintering bald eagles. Journal of Wildlife Management 53:792–802.

Frost, C. N. 2000. A key for identifying preyfish in the Columbia River based on diagnostic bones. U.S. Geological Survey, Western Fisheries Research Center, Columbia River Research Laboratory, Cook, Washington.

Gabrielson, I. N. and S. G. Jewett. 1940. *The Birds of Oregon.* Oregon College Press, Corvallis, OR.

Golden, N. H. and B. A. Rattner. 2003. Ranking terrestrial vertebrate species for utility in biomonitoring and vulnerability to environmental contaminants. Reviews of Environmental Contamination and Toxicology 176:67-136.

Hakkinen, I. 1978. Diet of the osprey *Pandion haliaetus* in Finland. Ornis Scandinavica 9:111-116.

Henny, C. J. 1977. Research, management, and status of the osprey in North America. *In* R. D. Chancellor (editor), World Conference on Birds of Prey Report of Proceedings Vienna 1975, The International Council for Bird Preservation, London. Pp. 199-222.

Henny, C. J., J. A. Collins, and W. J. Deibert. 1978. Osprey distribution, abundance, and status in Western North America: II. The Oregon population. Murrelet 59:14-25.

Henny, C. J. 1983. Distribution and abundance of nesting ospreys in the United States. *In* D. M. Bird (chief editor), Biology and Management of Bald Eagles and Ospreys. Harpell Press, Ste. Anne de Bellevue, Quebec. Pp. 175-186.

Henny, C. J., J. L. Kaiser, and R. A. Grove. 2002. Ospreys in Oregon and the Pacific Northwest. U.S. Geological Survey Fact Sheet 153-02, revised September 2005. Corvallis, Oregon.

Henny, C. J., J. L. Kaiser, R. A. Grove, V. R. Bentley, and J. E. Elliott. 2003. Biomagnification factors (fish to osprey eggs from the Willamette River, Oregon, USA) for PCDDs, PCDFs, PCBs and OC pesticides. Environmental Monitoring and Assessment 84:275-315.

Henny, C. J., R. A. Grove, J. L. Kaiser, and V. R. Bentley. 2004. An evaluation of osprey eggs to determine spatial residue patterns and effects of contaminants along the Lower Columbia River, U.S.A. *In* R. D. Chancellor and B. U. Meyburg (editors), Raptors Worldwide. World Working Group on Birds of Prey and Owls and MME/Bird Life Hungary, Budapest, Hungary. Pp. 369-388.

Henny, C. J., R. A. Grove, and J. L. Kaiser. 2008. Osprey distribution, abundance, reproductive success and contaminant burdens along lower Columbia River, 1997/1998 vs. 2004. Archives of Environmental Contamination and Toxicology 54:525-534.

Houghton, L. M. and L. M. Rymon. 1997. Nesting distribution and population status of United States ospreys. Journal of Raptor Research 31:44-53.

Johnson, C. N. 2005. Anthropology: The remaking of Australia's Ecology. Science 309:255-256.

Johnson, D. R. 1981. The study of raptor populations. University Idaho Press, Moscow.

Kammerer, J. C. 1990. Largest rivers in the United States. U.S. Geological Survey, Water Fact Sheet Open-File Report 87-242 (Revised), Reston, VA.

Katzner, T. E, E. A. Bragin, S. T. Knick, and A. T. Smith. 2005. Relationship between demographics and diet specificity of imperial eagles *Aquila heliaca* in Kazakhstan. Ibis 147:576–586.

LaVigne, H. R., R. M. Hughes, R. C. Wildman, S. V. Gregory, and A. T. Herlihy. 2008. Summer distribution and species richness of non-native fishes in the mainstem Willamette River, Oregon, 1944-2006. Northwest Science 82:83-93.

Lewis, S. B., M. R. Fuller, and K. Titus. 2004. A Comparison of 3 methods for assessing raptor diet during the breeding season. Wildlife Society Bulletin 32:373-385.

MacCarter, D. L. 1972. Food habits of Ospreys at Flathead Lake, Montana. M.S. Thesis, Humboldt State University, Arcata, California.

Magurran, A. E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, N.J.

Marti, C. D. 1987. Raptor Food Habits Studies. *In* B. A. Giron Pendleton, B. A. Millsap, K. W. Cline, and D. M. Bird (editors), Raptor management techniques manual. National Wildlife Federation, Washington, D.C. Pp 67-80.

McClean, P. K. and M. A. Byrd. 1991. The diet of Chesapeake Bay ospreys and their impact on the local fishery. Journal of Raptor Research 25:109-112.

Mecozzi, M. 1988. Lake sturgeon (*Acipenser fulvescens*). Wisconsin Department of Natural Resources Bureau of Fisheries Management, PUBL-FM-704 88, Madison, Wisconsin.

Mersmann, T. J., D. A. Buehler, J. D. Fraser, and J. K. D. Seegar. 1992. Assessing bias in studies of bald eagle food habits. Journal of Wildlife Management 56:73-78.

Newsome, G. E. 1977. Use of opercular bones to identify and estimate lengths of prey consumed by piscivores. Canadian Journal of Zoology 55:733-736.

Poole, A. F. 1989. Ospreys—A Natural and Unnatural History. Cambridge University Press, Cambridge, United Kingdom.

Received 11 December 2007
Accepted for publication 8 May 2008

Poole, A. F, R. O. Bierregarrd, and M. S. Martell. 2002. Osprey (*Pandion haliaetus*). *In* A. Poole and F. Gill (editors), The Birds of North America, No. 683. The Birds of North American, Inc., Philadelphia, PA. Pp 1-44.

Prevost, Y. A. 1977. Feeding ecology of ospreys in Antigonish County, Nova Scotia. M.S. Thesis, Macdonald College of McGill University, Montreal, Quebec.

Prevost, Y. A. 1982. The wintering ecology of ospreys in Senegambia. Ph.D. Dissertation, University of Edinburgh, U.K.

Redpath, S. M, R. Clarke, M. Madders, and S. J. Thirgood. 2001. Assessing raptor diet: comparing pellets, prey remains, and observational data at hen harrier nests. Condor 103:184-188.

SAS Institute 1999. SAS User's Guide: Statistics, Version 9.1 Edition, SAS Inst., Inc., Cary, NC.

Swenson, J. E. 1978. Prey and foraging behavior of ospreys on Yellowstone Lake, Wyoming. Journal of Wildlife Management 42:87-90.

Swenson, J. E. 1979. The relationship between prey species ecology and dive success in ospreys. Auk 96:408-412.

Thomas, C. M. and R. G. Anthony. 1999. Environmental contaminants in great blue herons (*Ardea herodias*) from the lower Columbia and Willamette rivers, Oregon and Washington, USA. Environmental Toxicology and Chemistry 18:2804-2816.

Tornberg, R. and V. Reif. 2007. Assessing the diet of birds of prey: a comparison of prey items found in nests and images. Ornis Fennica 84:21-31.

U.S. EPA. Columbia River Basin Fish Contaminant Survey:1996-1998. EPA 910/R-02-006, Office of Environmental Assessment, Region 10, Seattle, WA.

Van Daele, L. J. and H. A. Van Daele. 1982. Factors affecting the productivity of ospreys nesting in West-Central Idaho. Condor 84:292-299.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Watson, J. W., M. G. Garrett, and R. G. Anthony. 1991. Foraging ecology of bald eagles in the Columbia River Estuary. Journal of Wildlife Management 55:492-499.

Wiemeyer, S. N., C. M. Bunck, and A. J. Krynitsky.1988. Organochlorine pesticides, polychlorinated biphenyls, and mercury in osprey eggs—1970-79—and their relationships to shell thinning and productivity. Archives of Environmental Contamination and Toxicology 17:767-787.

Williams, R. N., P. A. Bisson, D. L. Bottom, L. D. Calvin, C. C. Coutant, M. W. Erho, Jr., C. A. Frissell, J. A. Lichatowich, W. J. Liss, W. E. McConnaha, P. R. Mundy, J. A. Stanford, and R. R. Whitney. 1999. Return to the river: Scientific issues in the restoration of salmonid fishes in the Columbia River. Fisheries 24:10-19.

Wydoski, R. S. and R. R. Whitney. 2003. Inland Fishes of Washington. Second Edition. University Washington Press, Seattle.

Zar, J. H. 1999. Biostatistical Analysis. Prentice Hall, Upper Saddle River, New Jersey.