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Colony Size and Diet Composition of Piscivorous Waterbirds on the Lower Columbia River: Implications for Losses of Juvenile Salmonids to Avian Predation

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Abstract.—We investigated colony size and diet composition of piscivorous waterbirds (gulls, terns, and cormorants) nesting on the lower Columbia River from the mouth (river km 0) to the head of McNary Pool (river km 553) in 1997 and 1998. The study was prompted by concern that avian predation might constitute a significant source of mortality to juvenile salmonids *Oncorhynchus* spp. during out-migration. The diet of California gulls *Larus californicus* and ring-billed gulls *L. delawarensis* nesting in colonies above The Dalles Dam (river km 308) included few fish and very few juvenile salmonids. The sole exception was a small colony of California gulls in which salmonids accounted for 15% (by mass) of the diet.

Juvenile salmonids were, however, an important component of the diet of colonial waterbirds nesting in the Columbia River estuary. On Rice Island (river km 34), salmonids accounted for 74% (by mass) of the diet of Caspian terns *Sterna caspia*, 46% for double-crested cormorants *Phalacrocorax auritus*, and 11% for glaucous-winged−western gulls *L. glaucescens* × *L. occidentalis*. Juvenile salmonids were especially prevalent in the diets of colonial waterbirds on Rice Island during April and May. By comparison, juvenile salmonids were significantly less prevalent in the diet of cormorants and gulls nesting lower in the estuary on East Sand Island (river km 8), presumably due to the greater availability of marine forage fishes. Our results indicate that avian predation on juvenile salmonids in the lower Columbia River is more prevalent in the estuary than near the large upriver gull colonies. Furthermore, the high incidence of salmonids in the diets of Caspian terns, cormorants, and gulls nesting on Rice Island suggests that the impact of avian predation on survival of smolts may be reduced by discouraging piscivorous birds from nesting there, while encouraging nesting on East Sand Island and other sites nearer to marine foraging areas.

Most populations of piscivorous (fish-eating) colonial waterbirds on the lower Columbia River have been growing over the last few decades. For example, several mixed colonies of California gulls *Larus californicus* and ring-billed gulls *L. delawarensis* on islands in the river near the Tri-Cities (Richland, Pasco, and Kennewick) area in

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southeastern Washington have increased multifold in the last 40 years (Thompson and Tabor 1981). A colony of Caspian terns *Sterna caspia* that became established on Rice Island in the Columbia River estuary in 1986 increased dramatically in the subsequent decade (A. Clark, U.S. Fish and Wildlife Service, personal communication; G. Dorsey, U.S. Army Corps of Engineers, personal communication). Also, a colony of double-crested cormorants *Phalacrocorax auritus* on East Sand Island in the estuary increased from less than 100 pairs in 1989 (R. Lowe, U.S. Fish and Wildlife Service, personal communication) to thousands of pairs by the early 1990s (Carter et al. 1995). Given the numbers, population trajectories, and wide distribution of avian predators on the lower Columbia River, system-wide losses of juvenile salmonids *Oncorhynchus* spp. to avian predators have become a concern to some salmon managers.

Anadromous salmonids that spawn in the Columbia River basin have been classified into six species and 20 evolutionarily significant units (ESUs; NMFS 2001). Since 1990, 12 of these 20 ESUs have been listed as threatened or endangered under the U.S. Endangered Species Act (ESA; NMFS 2001), and half of the remaining eight unlisted ESUs are declining or proposed for listing (H. Pollard, National Marine Fisheries Service, personal communication). Despite major efforts to (1) reduce mortality caused by dams, (2) severely restrict harvest, (3) restore spawning and rearing habitats, and (4) mitigate for all these population constraints through extensive hatchery production, most ESUs continue to decline at alarming rates (ISG 1996). Although predation of juvenile salmonids by birds, marine mammals, and predatory fishes has not been implicated as a cause of declines in Columbia River basin salmonids, some managers have identified predation as a potentially significant factor limiting recovery of threatened and endangered salmonids in the Columbia River basin.

Published research suggests that, under certain circumstances, avian predation can be a substantial source of mortality for juvenile salmonids. Mace (1983) estimated that 10.4–31.7% of hatchery-released smolts of chinook salmon *O. tshawytscha* in the Big Qualicum River on Vancouver Island succumbed to avian predation within just 2 km of the hatchery. A subsequent study on the same river estimated that predation by broods of common mergansers *Mergus merganser* accounted for 24–65% loss of smolt production (Wood 1987). Feltham (1995) estimated that mergansers removed 3–16% of smolt production on two Scottish rivers. In a 3-year study on the Penobscot River in Maine, predation by double-crested cormorants on hatchery-reared Atlantic salmon *Salmo salar* accounted for 7.5–9.2% of the run (Blackwell 1995; Krohn and Blackwell 1996). Perhaps most extreme is the estimate by Kennedy and Greer (1988) that 51–66% of smolts from a wild run in an Irish river were lost to predation by great cormorants *P. carbo*.

Feeding aggregations of piscivorous waterbirds have been observed on the Columbia River near dams (Steuber et al. 1993; Jones et al. 1996), at hatchery (Schaeffer 1991, 1992) and barge release points (K. Collis, personal observation), and near the large waterbird breeding colonies at Rice and East Sand islands in the estuary (Bevan et al. 1994). Ruggerone (1986) estimated that 2% of the juvenile salmonids passing Wanapum Dam on the mid-Columbia River during the spring were eaten by gulls foraging in the tailrace below the powerhouse. Avian predation on radio-tagged chinook salmon smolts has been documented in the tailraces below The Dalles and John Day dams, with 11.3% and 5.7% of radio-tagged yearling and subyearling chinook salmon falling prey to gulls below The Dalles Dam respectively (J. Snelling and C. Schreck, Oregon State University, personal communication). Detections of radio tags from yearling spring chinook salmon on bird colonies in the Columbia River estuary suggest that a substantial number (5–29% of fish from different release groups) were falling prey to avian predators (Schreck and Stahl 1998). Data from these studies prompted the present, more thorough, investigation of the numbers and diets of piscivorous waterbirds and their potential impact on survival of juvenile salmonids in the lower Columbia River.

We present the results from our investigation of the colony size and diet composition of piscivorous waterbirds nesting at colonies on the lower Columbia River in 1997–1998. Our objectives were to:

(1) determine the location and size of major colonies (>100 nesting pairs) of piscivorous waterbirds (i.e., gulls, terns, cormorants) on the lower Columbia River;

(2) determine the taxonomic composition of the diets of piscivorous colonial waterbirds and compare the prevalence of juvenile salmonids in the diet among various bird species and colonies in the lower Columbia River;

(3) determine seasonal patterns in prevalence of juvenile salmonids in the diets of piscivorous co-

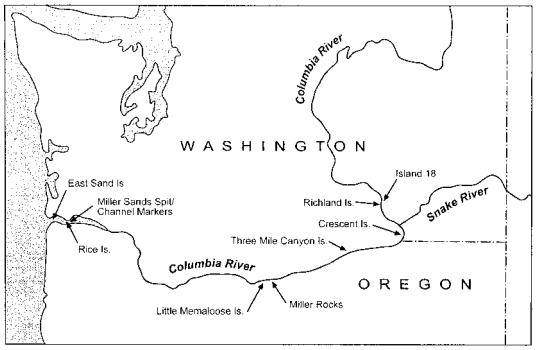

FIGURE 1.—Large colonies of breeding piscivorous waterbirds on the lower Columbia River in 1997 and 1998. All colonies located on the lower Columbia River above Miller Sands Spit/Channel Markers are referred to in the text as ''upriver'' colonies.

lonial waterbirds nesting on the lower Columbia River; and

(4) suggest potential methods for reducing the impact of avian predators on survival of juvenile salmonids in the Columbia River basin.

Study Area and Species

In 1997–1998, we investigated colony size and diet composition of piscivorous colonial waterbirds nesting on the lower Columbia River. Our study area included the Columbia River from the mouth (river km 0) to the head of the impoundment created by McNary Dam (river km 553; Figure 1). The species investigated were California gulls, ring-billed gulls, glaucous-winged–western gull hybrids *Larus glaucescens* × *L. occidentalis*, Caspian terns, and double-crested cormorants. Preliminary surveys indicated that sizable colonies (>100 breeding pairs) of these taxa occurred on nine islands in the lower Columbia River. Three of those islands are located in the Columbia River estuary: East Sand Island (river km 8), Rice Island (river km 34), and Miller Sands Spit (river km 38). The other six islands are located in impoundments above The Dalles Dam: Little Memaloose Island (river km 315), Miller Rocks (river km 333), Three Mile Canyon Island (river km 414), Crescent Island (river km 510), Richland Island (river km 547), and Island 18 (river km 553; Figure 1).

Methods

Population Estimates

The number of piscivorous waterbirds at each colony was estimated by direct counts from aerial photographs taken during late incubation, when maximum colony attendance of breeding birds was assumed (Bullock and Gomersal 1981; Gaston and Smith 1984). Aerial photographs of each bird colony were taken with a high resolution (1:1,200), large format camera (Zeiss RMK Top 30) from a fixed-wing aircraft flying at low altitude (approximately 350 m) and low air speed (approximately 125 km/h). Overlapping color diapositive emulsions of each colony were analyzed with a Zeiss P-1 Stereoplotter and Zeiss PHOCUS software. Because the aerial photos were taken in color and at a large scale, individual nests and birds of different species were readily identified, with the exception of several species of gulls that could not be distinguished on photos. Consequently, at colonies where two or more species of gulls nested, no effort was made to estimate breeding population size of each gull species separately. Direct counts of the number of adult birds on each colony were used as indices to the number of nesting pairs.

Diet Composition

We measured the diet composition of piscivorous waterbirds nesting at seven of the nine study islands: three islands (East Sand Island, Rice Island, and Miller Sands Spit) and nearby channel markers in the Columbia River estuary, and four upriver islands (Little Memaloose Island, Miller Rocks, Three Mile Canyon Island, and Island 18; Figure 1). The diet composition of gulls, terns, and cormorants was investigated during the period that the birds normally reside on breeding colonies, roughly from late April through early August. A variety of methods (see below) were used to assess diet composition.

Nondestructive diet sampling.—Because terns transport whole fish in their bills to their mates and young, the general taxonomic composition of the diet can be obtained by direct observation of adults as they return to the colony with fish (referred to hereafter as ''bill load observations''). Bill load observations were conducted throughout the breeding season at tern colonies on Rice and Three Mile Canyon islands in 1998. Observation blinds were set up at the periphery of the colony prior to egg laying so that prey items could be identified with binoculars or spotting scopes. The target sample size was 100 bill load observations per week at Rice Island and 20 bill load observations every 2 weeks at Three Mile Canyon Island. We were confident in our ability to distinguish salmonids from nonsalmonids and to identify most nonsalmonid taxa based on bill load observations from blinds. However, in most cases, we could not distinguish among the various sal-

monid species, necessitating the collection of adult foregut contents and bill loads from terns (see below).

In all three taxa of fish-eating birds, diet samples could also be collected nondestructively when chicks spontaneously regurgitated during handling (i.e., chick regurgitations). Chick regurgitations from gulls and cormorants were collected throughout the chick-rearing period in both 1997 and 1998. The target sample size for gull and cormorant colonies in the estuary was 6–10 chick regurgitations per week. At upriver gull colonies, 6–10 chick regurgitations were collected every 2 weeks. Chick regurgitations were also collected at the Rice Island tern colony, but on an irregular basis (i.e., when researchers were on the colony for other purposes, primarily during chick banding). Chick regurgitations were placed in labeled plastic bags (Whirl-paks), weighed on an Ohaus battery-powered, top-loading balance (nearest 0.1 g), and stored on ice until placed in a freezer at the end of the day. The samples were kept frozen at −20°C until laboratory analysis to determine taxonomic composition.

Lethal diet sampling.—Lethal sampling techniques were necessary to assess the diet composition of adult birds when nondestructive methods were inadequate (i.e., to sample diets of gulls and cormorants outside the chick rearing period or to assess relative proportions of various salmonid species in the diet of terns). The best method to obtain a random diet sample was to collect adult birds commuting toward the colony from foraging areas or adult birds on the colony. A shotgun was used to collect commuting adults, and an air rifle was used to collect adults on the colony when collecting birds in flight was not feasible.

Samples of adult foregut contents were collected primarily before the chick rearing period for gulls and cormorants and throughout the breeding season for Caspian terns nesting on Rice Island and Three Mile Canyon Island (1998 only). The target sample size for colonies in the estuary was 6–10 adult foregut samples per colony each week. Five to 10 samples were collected bimonthly from the upriver gull and tern colonies. Immediately after collection, the abdominal cavity was opened, the foregut removed, and the contents of the foregut emptied into a Whirl-pak. Each foregut sample was weighed, stored, and frozen as described for chick regurgitation samples.

Whenever possible, we collected terns returning to the colony with whole fish in their bills so that bill loads could be collected along with adult foregut samples. At Rice and Three Mile Canyon islands, terns were collected at a location over land (allowing easy retrieval of samples) and approximately 0.5 km east of each colony (to avoid disturbance to the colony). Each bill load was identified to species, measured (fork length, FL), weighed, and placed into frozen storage. All procedures involving the use of live birds were part of a protocol approved by the Institutional Animal Care and Use Committee at Oregon State University.

Laboratory and data analysis.—Laboratory analysis of semidigested diet samples (i.e., adult foregut and chick regurgitation samples) and bill load samples was conducted at the Oregon Department of Fish and Wildlife laboratory in Clackamas, Oregon. Samples were partially thawed, removed from Whirl-paks, reweighed, and separated into major food categories: crustaceans, mollusks, annelids, insects, nonfish vertebrates, anthropogenic (e.g., human refuse, agricultural products), fish eggs, and fish. Items from each food category were weighed and enumerated. Fish were further identified to genus and species whenever possible. Intact salmonids in foregut and bill load samples from terns were identified as chinook salmon, sockeye salmon *O. nerka*, coho salmon *O. kisutch*, steelhead *O. mykiss*, or unknown based on soft tissue or otolith analysis. Chinook salmon were further separated into fall (subyearlings) and spring–summer stocks (yearlings) based on fork length and migration timing criteria (E. M. Dawley, National Marine Fisheries Service, unpublished). Semidigested fish matter was not always identifiable. Unidentifiable fish samples were artificially digested according to the methods of J. H. Petersen (U.S. Geological Survey–Biological Resources Division, unpublished). Once digested, diagnostic bones (i.e., cleithra, dentaries, pharyngeal arches, and opercles) were removed from the sample and identified to species with a dissecting microscope (Hansel et al. 1988). Unidentified fish samples that did not contain diagnostic bones and samples comprising bones only (i.e., no soft tissue) were not included in diet composition analysis. The taxonomic composition of the unidentifiable portion of the diet was assumed to be the same as the identifiable portion; thus the taxonomic composition of waterbird diets was expressed as percentage of identifiable biomass and percentage of identifiable prey items.

For terns, percentages of identifiable prey items were based on identified bill loads observed from blinds and were calculated for 2-week periods throughout the nesting season. For each 2-week period, percentages of identifiable prey biomass

were calculated by multiplying the average mass of intact prey items in bill load and foregut samples by the total number of prey items identified in bill load observations and dividing by the total estimated mass for all prey items. The diet composition of terns over the entire breeding season was based on the average of these 2-week percentages.

Because adult gulls and cormorants feed their young by regurgitation, we assumed that the taxonomic composition of adult foregut and chick regurgitation samples were similar and, therefore, could be pooled to describe overall diet composition. To increase the sample size per time period, percentages of identifiable prey items and biomass were calculated for gulls and cormorants over 4-week periods (compared with 2-week periods for terns) encompassing the entire breeding season. The diet composition of gulls and cormorants over the breeding season was based on the average of the 4-week percentages.

In order to increase sample sizes for comparisons, we pooled (1) diet composition data from 1997 and 1998, (2) diet samples collected from cormorants nesting on Rice Island and the nearby channel markers (approximately 5 km apart), (3) diet samples collected from gulls nesting on Rice Island and nearby Miller Sands Spit (approximately 4 km apart), and (4) bill load observations and adult foregut samples from Caspian terns nesting on Three Mile Canyon Island. Chi-square tests for independence and paired *t*-tests were used for statistical comparisons. Means are expressed as $x \pm$ SE. Significance was determined at P values less than 0.05 for all tests.

TABLE 1.—Direct counts (from aerial photographs) of piscivorous waterbirds at large breeding colonies (>100 breeding pairs) on the lower Columbia River, 1997–1998.

Species and location	River km[a]	Number of birds 1997	1998
Caspian tern			
Rice Island	34	9,415	11,223
Three Mile Canyon Island	413	571	339
Crescent Island	510	990	575
California gull and ring-billed gull			
Little Memaloose Island[b]	315	939	357
Miller Rocks[c]	333	3,783	2,179
Three Mile Canyon Island[c]	413	13,305	11,102
Crescent Island[b]	510	5,769	4,597
Richland Island[c]	547	18,820	22,348
Island 18[c]	553	14,495	12,669
Glaucous-winged–western gull[d]			
East Sand Island	8	7,106	5,496
Rice Island	34	1,583	827
Miller Sands Spit	37	1,268	742
Double-crested cormorant			
East Sand Island	8	5,271	7,501
Rice Island	34	1,221	1,082
Channel markers near Rice Island	37	80	70

[a] Measured from the river's mouth.
[b] California gull colony.
[c] Mixed California and ring-billed gull colony.
[d] Hybrids.

Results

Over 80,000 piscivorous waterbirds nested in the study area in 1997 and 1998 (Table 1). Ring-billed and California gulls nesting on islands in The Dalles, John Day, and McNary dam impoundments made up the majority of piscivorous waterbirds nesting in the study area (67% in 1997 and 66% in 1998). These two species of gulls were followed in numerical abundance by Caspian terns (13% in 1997 and 15% in 1998), most of which were nesting on Rice Island in the Columbia River estuary (86% and 92% of the total count of Caspian terns in 1997 and 1998, respectively; Table 1). Large colonies of double-crested cormorants and glaucous-winged–western gulls were found only in the Columbia River estuary (river km 0–75; Table 1). Fewer than 100 pairs of double-crested cormorants were also found nesting on Foundation Island (river km 518) near the mouth of the Snake River, and fewer than 50 pairs of glaucous-winged–western gulls were found nesting among California and ring-billed gulls on Miller Rocks. Also, a small colony of ring-billed gulls (<100 pairs) was found on Miller Sands Spit in the estuary.

Diet composition varied by bird species and colony location (Tables 2–4). Caspian terns and double-crested cormorants were strictly piscivorous (Tables 2–3), whereas the three gull species consumed a diverse array of food types (Table 4). Gulls nesting at upriver colonies consumed primarily anthropogenic food items (Table 4). Cherries (Little Memaloose Island and Island 18 colonies), potatoes (Three Mile Canyon Island colony), and human refuse (all upriver gull colonies) were the principal items by mass in the anthropogenic portion of the diet of upriver gulls. In contrast, glaucous-winged–western gulls nesting in the Columbia River estuary consumed primarily fish (Table 4). In general, gulls nesting on Rice Island (river km 34) ate primarily riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes (Tables 5). The contrast between riverine and estuarine diets was

TABLE 2.—Diet composition of Caspian terns nesting on Rice Island (Columbia River, km 34) and Three Mile Canyon Island (Columbia River, km 414) in 1997–1998 based on identifiable fish in diet samples (adult foreguts, bill load collections, and chick regurgitations) and bill load observations.

	Rice Island				Three Mile Canyon Island
	Diet samples (N = 448)		Bill load observations (N = 1,448)		Diet samples/bill load observations (N = 26/60)
Prey type	% mass	% number	% mass	% number	% number
Herring, shad					
Clupeidae	7.4	7.2	12.3	10.7	0.0
Peamouth, pikeminnow					
Cyprinidae	9.2	8.9	2.6	2.0	0.0
Sucker					
Catostomus spp.	0.4	0.4	0.0	0.0	1.9
Smelt					
Osmeridae	1.7	1.7	4.6	6.2	0.0
Salmonid					
Oncorhynchus spp.	76.7	77.1	73.5	72.7	80.6
Stickleback					
Gasterosteidae	0.0	0.1	0.0	0.3	0.0
Sculpin					
Cottidae	1.1	1.3	0.7	1.2	0.0
Bass					
Micropterus spp.	0.0	0.0	0.0	0.0	12.5
Yellow perch					
Perca flavescens	0.0	0.0	0.0	0.0	1.2
Surfperch					
Embiotocidae	1.1	1.0	5.6	5.5	0.0
Pacific sand lance					
Ammodytes hexapterus	0.4	0.4	0.0	0.1	0.0
Flounder					
Pleuronectidae	0.0	0.0	0.4	0.2	0.0
Other[a]	2.0	1.9	0.3	1.1	3.8
Total mass (g) and number of prey	13,835	626	40,357	1,448	86

[a] Lamprey (*Lampetra* spp.) or unidentified nonsalmonids.

also evident for double-crested cormorants nesting on Rice and East Sand islands (Table 3).

In general, piscivorous waterbirds nesting in the Columbia River estuary ate more juvenile salmonids than those nesting upriver. For Caspian terns, however, those nesting at the colony on Three Mile Canyon Island consumed a similar proportion of juvenile salmonids (80.6% of identified

TABLE 3.—Diet composition of double-crested cormorants nesting on Rice Island and nearby channel markers (Columbia River, km 34/39) and East Sand Island (Columbia River, km 8) in 1997–1998 from identifiable fish in adult foregut and chick regurgitation samples.

	Rice Island/Channel Markers (N = 206)		East Sand Island (N = 128)	
Prey type	% mass	% number	% mass	% number
Herring, shad	0.6	0.6	27.8	26.3
Peamouth, pikeminnow	24.0	23.1	10.7	8.3
Sucker	5.8	5.0	4.7	4.5
Smelt	0.3	0.3	7.6	6.9
Salmonid	45.7	45.5	15.9	14.5
Stickleback	5.0	6.7	2.1	4.7
Sculpin	8.0	8.3	9.2	10.3
Bass	0.0	0.0	0.0	0.0
Yellow perch	0.0	0.0	0.0	0.0
Surfperch	0.3	0.2	7.3	6.9
Pacific sand lance	0.0	0.0	1.8	4.1
Flounder	8.5	8.5	9.8	10.3
Other	1.8	1.8	3.1	3.2
Total mass (g) and number of prey	20,370	856	13,016	750

TABLE 4.—Diet composition (% mass) of gulls nesting on islands in the lower Columbia River in 1997–1998 from the analysis of adult foregut and chick regurgitation samples.

	Glaucous-winged–western gull		California gull				Ring-billed gull
Diet category	East Sand Island (N = 149)	Rice Island[a] (N = 181)	Little Memaloose Island (N = 97)	Miller Rocks (N = 31)	Three Mile Canyon Island (N = 74)	Island 18 (N = 33)	Island 18 (N = 38)
Crustacean	0.0	0.0	0.8	0.0	0.0	0.0	0.0
Mollusk	8.2	7.6	3.7	23.3	1.2	0.0	0.0
Annelid	0.0	0.6	12.3	0.0	0.3	20.5	11.4
Insect	0.5	1.2	2.8	8.7	8.0	16.4	25.0
Vertebrate (non-fish)	0.0	0.7	0.0	6.2	4.6	0.0	0.0
Anthropogenic	32.4	43.9	56.1	51.6	83.5	60.4	63.6
Fish eggs	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Fish							
Salmonids	4.2	10.9	14.9	3.3	0.0	0.0	0.0
Nonsalmonids	23.0	10.6	5.4	0.4	1.2	0.3	0.0
Unidentified fish	29.5	24.5	4.0	6.5	1.2	2.4	0.0
Total fish	56.7	46.0	24.3	10.2	2.4	2.7	0.0
Total mass (g)	4,374	5,136	1,754	373	1,716	338	435

[a] Includes glaucous-winged–western gulls nesting on Miller Sands Spit.

diet samples and bill load observations) as those nesting on Rice Island (72.7% of identified bill load observations; $\chi^2 = 2.33$, $P = 0.13$; Table 2). Gulls that nested upriver were less dependent on salmonids as a food source, with salmonids present in the diet samples of gulls nesting at only two of the five upriver colonies where diet composition data were collected (Little Memaloose Island and Miller Rocks; Table 4).

Of the species of piscivorous waterbirds nesting in the estuary, Caspian terns consumed the highest percentage of juvenile salmonids. Based on bill load observations, 73.5% of diet mass of terns consisted of juvenile salmonids. Based on prey identified in tern diet samples (including adult foregut samples, collected bill loads, and chick regurgitations), 77.1% of prey items and 76.7% of diet mass consisted of juvenile salmonids (Table 2). Comparisons of Caspian tern diet composition on Rice Island based on bill load observations versus diet samples confirmed our suspicion that diet samples from lethally sampled birds were not representative of the colony as a whole. The proportions of juvenile salmonids and other riverine fishes in the diet samples were greater than in the bill load observations ($\chi^2 = 33.72$, $P < 0.0001$; Table 2). The discrepancy was likely due to the disproportionate number of diet samples collected from terns returning to the colony from upriver foraging sites. This interpretation was supported by the

TABLE 5.—Composition of the fish portion of the diet of glaucous-winged–western gulls nesting on Rice Island/Miller Sands Spit (Columbia River, km 34/38) and East Sand Island (Columbia River, km 8) in 1997–1998 from identifiable fish in adult foregut and chick regurgitation samples.

	Rice Island/Miller Sands Spit (N = 38)		East Sand Island (N = 43)	
Prey type	% mass	% number	% mass	% number
Herring, shad	4.6	4.6	40.1	39.2
Peamouth, pikeminnow	15.9	15.9	6.0	6.0
Sucker	2.8	2.8	1.8	1.8
Smelt	0.0	0.0	0.4	1.1
Salmonid	52.1	51.0	15.5	15.4
Stickleback	2.3	3.4	2.1	2.1
Sculpin	2.3	2.3	8.7	8.7
Pacific sand lance	0.0	0.0	0.4	1.4
Flounder	7.8	7.8	0.8	0.9
Other[a]	12.2	12.2	24.2	23.4
Total fish mass (g) and no. of prey	1,286	89	1,654	78

[a] Unidentified non-salmonids.

composition of adult foregut samples from terns commuting back to the Rice Island colony from downriver foraging sites, which contained significantly smaller proportions of juvenile salmonids and other riverine fishes ($\chi^2 = 17.11$, $P < 0.0001$).

Double-crested cormorants nesting on or near Rice Island consumed the next highest percentage of salmonids (45.5% of identified prey items, 45.7% of identified diet mass; Table 3), followed by double-crested cormorants nesting on East Sand Island (14.5% of identified prey items, 15.9% of identified diet mass; Table 3), glaucous-winged–western gulls nesting on or near Rice Island (10.9% of identified diet mass; Table 4), and glaucous-winged–western gulls nesting on East Sand Island (4.2% of identified diet mass; Table 4).

There were significant differences ($P < 0.05$) in the diets of piscivorous waterbirds nesting at different locations within the Columbia River estuary (Tables 2–5). Cormorants nesting on Rice Island and nearby channel markers, located in the upper part of the estuary, consumed significantly more salmonids compared with cormorants nesting at East Sand Island, near the mouth of the Columbia River ($\chi^2 = 178.23$, $P < 0.0001$). Juvenile salmonids were also more prevalent in the diet of glaucous-winged–western gulls nesting on Rice Island and nearby Miller Sands Spit (51.0% of identified fish prey items in combined samples) compared with those nesting on East Sand Island (15.4% of identified fish prey items; $\chi^2 = 21.34$, $P < 0.0001$). Similarly, terns returning to the Rice Island colony from downriver foraging locations had significantly fewer juvenile salmonids in the diet, as compared with terns returning to the colony from upriver areas (42% and 70% of identified prey items, respectively; $\chi^2 = 4.44$, $P = 0.04$). In each case, clupeids (i.e., primarily juvenile Pacific herring *Clupea pallasi*) replaced juvenile salmonids in the diets of cormorants and gulls nesting on East Sand Island (Tables 3 and 4) and terns foraging at downriver locations.

Our estimate of the relative proportions of different salmonid species in the diet of Caspian terns nesting on Rice Island was based on the sample of collected bill loads (Table 6). By mass, coho salmon (38.4%), steelhead (28.5%), and fall chinook salmon (24.9%) were the most prevalent species in the salmonid portion of the diet of Caspian terns nesting on Rice Island. Numerically, coho salmon (38.2%), fall chinook salmon (37.7%), and steelhead (16.3%) were the most prevalent species in the salmonid portion of the diet of Rice Island terns. Spring–summer chinook salmon were a comparatively minor part of the salmonid portion of the diet of Caspian terns nesting on Rice Island (7.8% by mass, 8.2% numerically; Table 6; Figure 2), while sockeye salmon and chum salmon were negligible components of tern diets. Juvenile salmonids were especially prevalent in the diets of fish-eating waterbirds on or near Rice Island during late April and May (Figures 2–4). Caspian terns fed primarily on steelhead during late April to early May, coho salmon during late May to early June, and fall chinook salmon during late June to late July (Figure 2).

TABLE 6.—Composition of the salmonid portion of the diet of Caspian terns nesting on Rice Island in 1997–1998, based on the analysis of bill load fish collected from breeding adults.

Coho salmon	38.4	38.2
Steelhead	28.5	16.3
Fall chinook salmon	24.9	37.7
Spring–summer chinook salmon	8.2	7.8
Total mass (g) and number of salmonids	5,908	210

To test the hypothesis that bill loads are representative of the prey consumed by adult Caspian terns, samples of foregut contents from individual terns were compared with the fish transported in their bills (bill load collections). Of the 48 paired adult foregut and bill load samples, 38 (79.2%) were similar in size and taxonomic composition of prey. Statistical comparisons revealed no significant differences in either the proportion of salmonids versus nonsalmonid in the two samples ($\chi^2 = 0.05$, $P = 0.82$) or prey size (intact fish in foregut samples: $x = 113.9 \pm 6.0$ mm FL; bill load collections: $x = 117.8 \pm 5.8$ mm FL; $N = 37$, paired $t = 0.51$, $P = 0.61$). These results suggest that adult terns generally consume the same prey types and sizes as those transported as bill loads to the colony, except perhaps when adults are feeding very young chicks.

Discussion

The number and size of piscivorous waterbird colonies in the lower Columbia River clearly indicate that breeding populations of Caspian terns, double-crested cormorants, and several gull species have increased dramatically in the last 20 years. Numbers of breeding pairs of gulls at colonies between The Dalles Dam and the head of McNary Pool were estimated at a little over 16,000 pairs in 1978 (Thompson and Tabor 1981); population estimates from the present study are at least twice as high. In 1991, a total of approximately

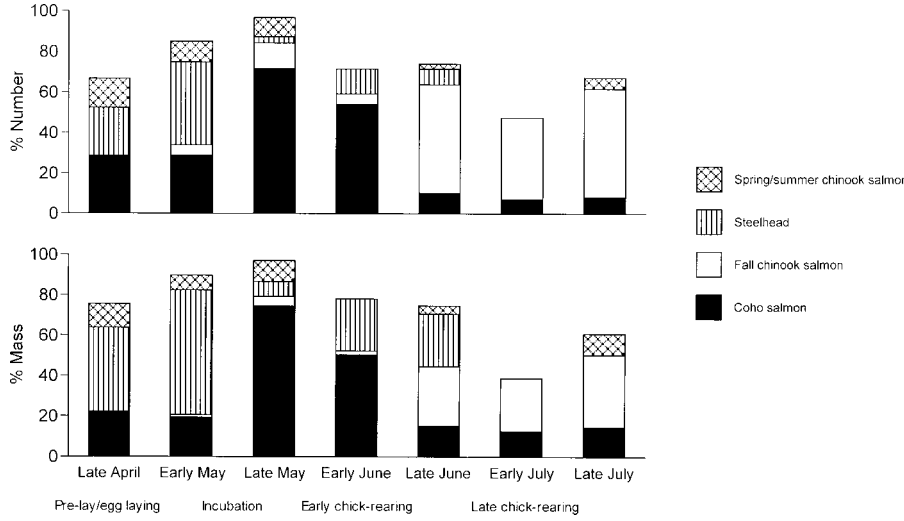

FIGURE 2.—Seasonal contributions (by number and mass) of salmonids to the diet of Caspian terns nesting on Rice Island (Columbia River km 34) from analysis of bill load samples (N = 201) and bill load observations (N = 1,448) in 1997 and 1998.

4,000 double-crested cormorant nests were counted on East Sand Island, whereas in 1998, over 7,500 cormorants were counted there, making it the largest colony of its kind on the Pacific coast of North America (Carter et al. 1995). As recently as 1985, no breeding colonies of piscivorous waterbirds existed on Rice Island in the Columbia River estuary, whereas by 1998, large colonies of Caspian terns, double-crested cormorants, and glaucous-winged–western gulls had become established on this artificial dredge spoil island. The Rice Island colonies are suspected of causing unexpectedly high predation pressure on outmigrating juvenile salmonids. In 1998, at least 16% of the steelhead smolts tagged with passive integrated transponders (PITs), 5% of PIT-tagged coho salmon smolts, and 2% of PIT-tagged yearling chinook salmon smolts that reached the estuary were consumed by Caspian terns and double-crested cormorants nesting on Rice Island (Collis et al. 2001). Actual predation rates may be considerably higher than suggested by PIT tag recoveries on bird colonies because many PIT tags ingested by birds are excreted off-colony.

Anthropogenic perturbations to the Columbia River system have probably exacerbated the impacts of some predators on juvenile salmonids (Li et al. 1987; Rieman et al. 1991) and may have contributed to increases in some predator populations (Conover et al. 1979; Gill and Mewaldt 1983; Speich and Wahl 1989; Beamesderfer and Rieman 1991). Hydroelectric dams create ''bottlenecks'' to salmon migration and often injure or disorient out-migrating juvenile salmonids, increasing their vulnerability to predators (Raymond 1979, 1988). Hatchery and juvenile transportation practices that release salmonids en masse offer predators additional opportunities to exploit concentrated prey (Collis et al. 1995) that are often stressed (Barton et al. 1986; Schreck et al. 1989; Congleton et al. 2000), diseased (VanderKooi and Maule 1999), or in the case of many hatchery fish, have poorly developed predator avoidance behavior (Reisenbichler and McIntyre 1977; Berejikian 1995). Multiple stressors associated with dam passage may result in greater losses of some smolts to avian, mammalian, and piscine predators in the lower Columbia River and estuary (Mesa 1994).

The dramatic increases in numbers of California and ring-billed gulls nesting along the lower Columbia River are probably associated with expanding irrigation-based agricultural development in the Columbia River basin (Conover et al. 1979). Also, new islands created by deposition of dredge spoils and impoundment of the Columbia River have provided safe nest sites, which have attracted gulls, terns, and cormorants to breed (Peters et al. 1978). Furthermore, the breeding season of these piscivorous birds generally coincides with the downriver migration period of juvenile salmonids, potentially resulting in heavy predation pressure in the vicinity of larger colonies.

Caspian terns nesting at Rice Island in the Columbia River estuary and further upriver at Three

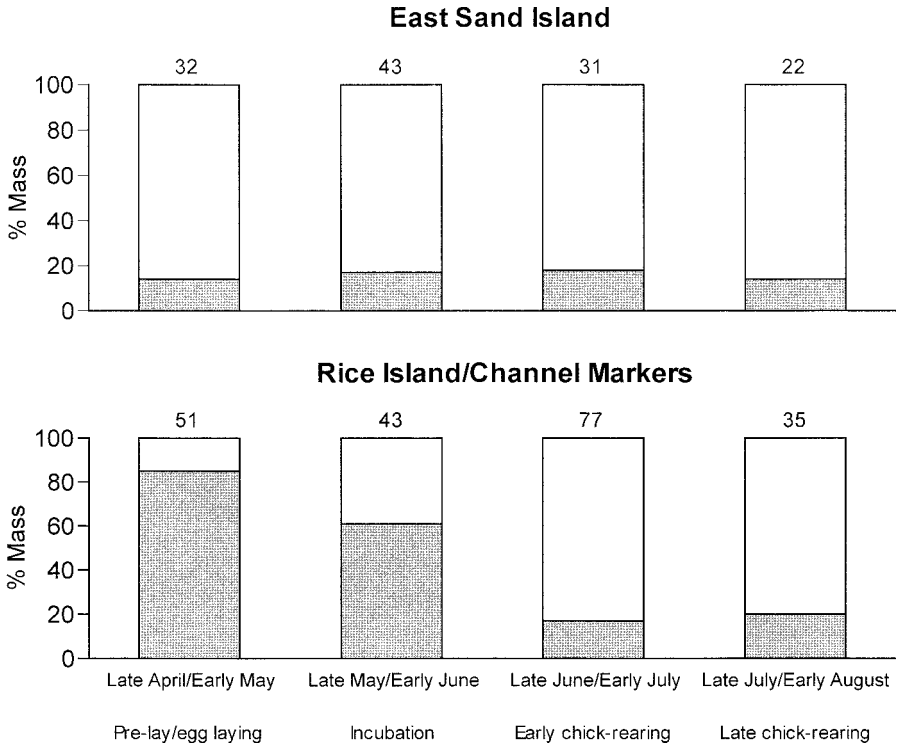

FIGURE 3.—Seasonal contributions (by mass) of salmonids to the diet of double-crested cormorants nesting on East Sand Island (Columbia River km 8) and Rice Island/channel markers (river km 34 and 39) from analysis of adult foregut and chick regurgitation samples in 1997 and 1998. Number of adult foregut and chick regurgitation samples with identifiable fish are presented over the bars for each sample period. White bars = non-salmonids, and gray bars = salmonids.

Mile Canyon Island had a higher percentage of juvenile salmonids in their diets (73% and 81% of identifiable prey items, respectively) than any other bird colonies investigated in this study. Although other studies have documented that Caspian terns prey on juvenile salmonids (Soikkeli 1973; Smith and Mudd 1978), this is the first study of Caspian tern diets to demonstrate that juvenile salmonids can be a primary food source for entire colonies (see Cuthbert and Wires 1999 for a review).

Several factors may explain the preponderance of juvenile salmonids in the diet of terns nesting on Rice Island. There is evidence that in the upper part of the Columbia River estuary (i.e., near Rice Island), juvenile salmonids are more available to terns than alternative forage fishes. Hinton et al. (1995) reported that spring purse seine catches near Rice Island were predominately juvenile salmonids, with peamouth *Mylocheilus caurinus* and other forage fishes becoming more prevalent in mid- to late-summer catches. This finding corresponds well with the run timing of out-migrating juvenile salmonids (FPC 2001) and the seasonal diet composition of terns nesting on Rice Island in 1997 and 1998. Salmonids constituted over 90% of identifiable prey items in May but declined to 57% of identifiable prey items in July. Furthermore, about 80% of juvenile salmonids from the Columbia River basin are raised in hatcheries, and some hatchery-reared stocks are more vulnerable to tern predation than their wild counterparts, presumably due to their greater tendency to reside near the water surface where terns forage (Collis et al. 2001). These data support the hypothesis that Caspian terns are generalist foragers (Koli and Soikkeli 1974; Horn et al. 1996), feeding opportunistically on forage fishes that are most available rather than specializing on juvenile salmonids.

We found unexpected differences in the diets of birds nesting on Rice Island compared with those nesting on East Sand Island, and the differences were apparent for both double-crested cormorants and glaucous-winged–western gulls. Although the

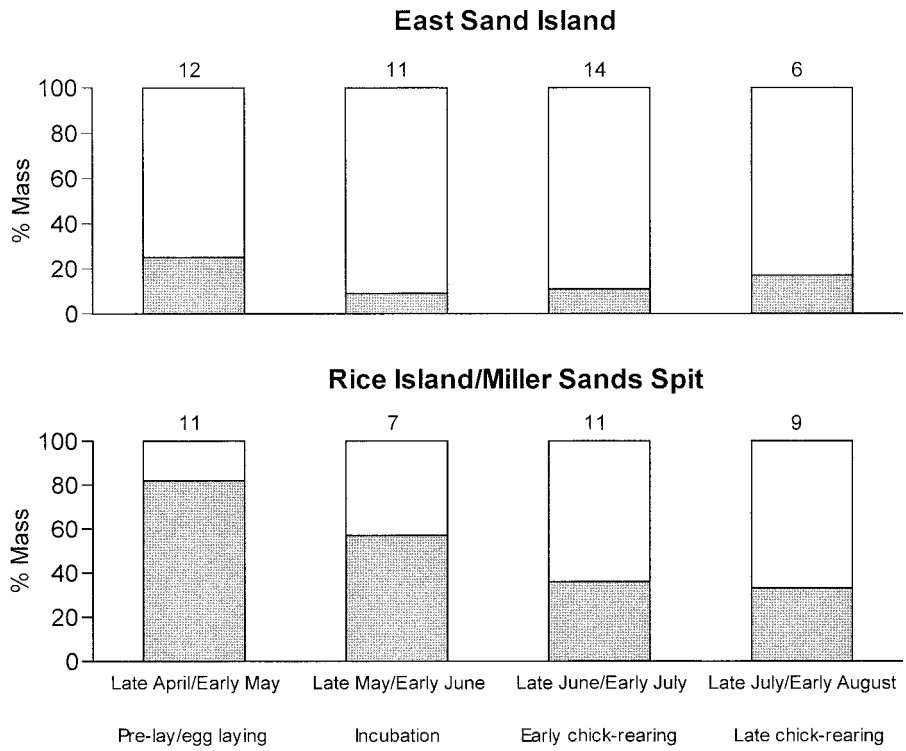

FIGURE 4.—Seasonal contribution of salmonids to the fish portion of the diet of glaucous-winged–western gulls on East Sand Island (Columbia River km 8) and Rice Island/Miller Sands Spit (river km 34 and 38) from analysis of adult foregut and chick regurgitation samples in 1997 and 1998. Number of adult foregut and chick regurgitation samples with identifiable fish are presented over the bars for each sample period. White bars = non-salmonids, and gray bars = salmonids.

two islands are only 26 km apart, the proportion of juvenile salmonids in the diet of cormorants nesting on or near Rice Island was more than three times that of cormorants nesting on East Sand Island (Table 3). Hundreds of cormorants were regularly observed foraging on salmonids adjacent to the extensive system of pile dikes above Rice Island and roosting on the pile dikes between foraging bouts (D. E. Lyons, personal observation). In general, marine forage fishes (i.e., herring *Clupea* spp., smelt [Osmeridae], shiner perch *Cymatogaster aggregata*, and Pacific sand lance *Ammodytes hexapterus*) were more prevalent in the diet of cormorants nesting on East Sand Island than those nesting on Rice Island. The same trends were also apparent in the diets of glaucous-winged–western gulls nesting on Rice Island compared with gulls nesting on East Sand Island (Table 5). Similarly, the diets of terns returning to the Rice Island colony from downriver foraging locations had a higher percentage of marine forage fishes (52% of identifiable prey items) than diets of terns returning to the colony from upriver areas (8% of identifiable prey items). The magnitude of these local, intercolony differences in diets was surprising, but similar differences have been previously reported for cormorants (Neuman et al. 1997).

There were small amounts of fish in general, and salmonids in particular, in the diets of California and ring-billed gulls nesting at upriver colonies in 1997 and 1998. These colonies had the most diverse diets of all the waterbird colonies studied. The only upriver gull colonies where juvenile salmonids were found in diet samples were the California gull colonies on Little Memaloose Island (15% of the total diet mass) and Miller Rocks (3% of the total diet mass). Little Memaloose Island is situated closer to a main-stem dam than any other bird colony in this study (approximately 7 river km), and gulls from this colony are known to prey on juvenile salmonids in the tailrace of The Dalles Dam (J. Snelling, Oregon State University, personal communication). Gulls from other upriver colonies may occasionally prey on ju-

venile salmonids when available in shallow pools or near dams, but our data suggest that at the level of the colony, juvenile salmonids were a minor component of the diet. Current efforts to control avian predation on smolts at the lower Columbia River dams (Jones et al. 1996) and salmon hatcheries (Schaeffer 1991, 1992) have apparently been effective in reducing gull predation as a source of mortality to juvenile salmonids from previously reported levels (Ruggerone 1986).

Management Implications

Our results suggest that gulls nesting at upriver sites are not dependent on fish in general, or juvenile salmonids in particular, as a primary food source, at least at the level of the breeding population. A possible exception is a small California gull colony on Little Memaloose Island. Consequently, efforts to further increase survival of juvenile salmonids by controlling the size or productivity of California or ring-billed gull colonies in the lower Columbia River are not likely to be effective. Instead, the current practice of protecting smolts from gull predation in areas where they are vulnerable (i.e., at dams and hatcheries) is probably the most effective method for minimizing the impacts of gull predation on survival of juvenile salmonids at upriver sites.

Diets of double-crested cormorants in the Columbia River estuary, especially those nesting on Rice Island or nearby channel markers, include a substantial proportion of juvenile salmonids. The cormorant colonies in the estuary are also large and have been growing rapidly. Finally, cormorants are large birds with concomitant high food requirements. These factors, taken together, suggest that the magnitude of predation by double-crested cormorants on juvenile salmonids in the Columbia River estuary may be sufficient to warrant attention from salmon managers.

Caspian terns nesting on the lower Columbia River relied the most on juvenile salmonids as a food source, many of which represent stocks listed as threatened or endangered under the U.S. Endangered Species Act. Of particular concern is the impact of Rice Island's large Caspian tern colony on the survival of juvenile salmonids in the Columbia River estuary. Most juvenile salmonids produced in the Columbia River basin must pass close by Rice Island during out-migration, at a time when terns are in the estuary to breed. About 90% of all the Caspian terns nesting on the lower Columbia River nested on Rice Island, a growing colony that was the largest of its kind in North America (Cuthbert and Wires 1999).

In both 1997 and 1998, minimum estimates of the number of juvenile salmonids consumed by piscivorous waterbirds nesting on Rice Island were in the millions, based on smolt PIT tags recovered on the island (Collis et al. 2001). The high incidence of salmonids in the diets of piscivorous waterbirds nesting on Rice Island suggests that the impact of avian predation on smolt survival may be reduced by discouraging piscivorous birds from nesting there, while encouraging nesting on East Sand Island and other sites nearer to marine foraging areas. Regional resource managers are currently attempting to reduce predation rates on juvenile salmonids in the Columbia River estuary by relocating the Rice Island Caspian tern colony to East Sand Island (Roby et al. in press). Efforts to relocate cormorants and gulls that also nest on Rice Island may potentially alleviate avian predation rates on smolts as well. Cormorants widely use pile dikes throughout the estuary as perching and roosting sites while foraging on juvenile salmonids, especially near Rice Island. Smolt losses to cormorant predation may potentially be reduced by deploying bird excluders on pile dikes to prevent use by cormorants. Finally, the modification of hatchery practices to produce juvenile salmonids that are more ''predator wary'' and less surface oriented will probably reduce the vulnerability of hatchery stocks to some predators, particularly Caspian terns, which feed exclusively on the surface of the water. These management alternatives could reduce avian predation on juvenile salmonids in the lower Columbia River and may be considered an important part of a comprehensive plan to restore salmonids throughout the Columbia River basin.

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