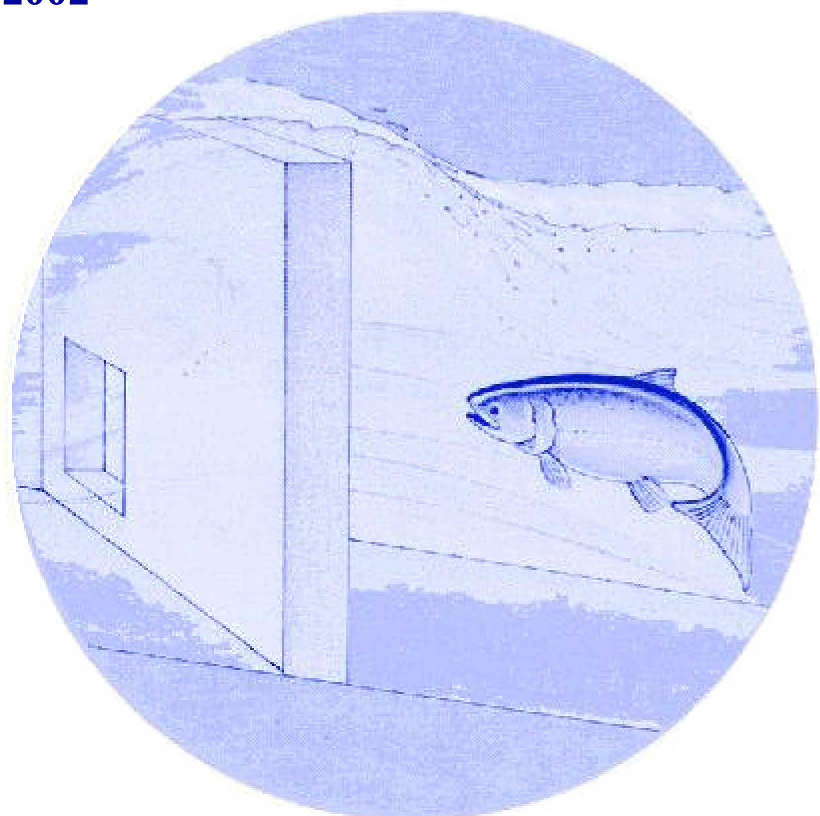
Abundance, Distribution and Estimated Consumption (kg fish) of Piscivorous Birds Along the Yakima River, Washington State

Implications for Fisheries Management

Annual Report
2002



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Abundance, Distribution and Estimated Consumption (kg fish) of Piscivorous Birds along the Yakima River, Washington State: Implications for Fisheries Management

Yakima/Klickitat Fisheries Project Monitoring and Evaluation

Annual Report 2002

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CHAPTER I

Distribution and Abundance of Piscivorous Birds along the Yakima River,

Washington State: Implications for Fisheries Management.

CHAPTER II

Piscivorous Bird Abundance, Fish Take and Flow Conditions at Artificial Structures within the Yakima River in Washington State

Chapter I: Distribution and Abundance of Piscivorous Birds along the Yakima River, Washington State: Implications for Fisheries Management.

Abstract - Understanding of the abundance and spatial and temporal distributions of piscivorous birds and their potential consumption of fish is an increasingly important aspect of fisheries management. During 1999-2002, we determined the abundance and distribution and estimated the maximum consumption (kg biomass) of fish-eating birds along the length of the Yakima River in Washington State. Sixteen different species were observed during the 4-yr study, but only half of those were observed during all years. Abundance and estimated consumption of fish within the upper and middle sections of the river were dominated by common mergansers (M*ergus merganser)* which are known to breed in those reaches. Common mergansers accounted for 78 to 94% of the estimated total fish take for the upper river or approximately 28,383 ±1,041 kg over the 4 yrs. A greater diversity of avian piscivores occurred in the lower river and potential impacts to fish populations was more evenly distributed among the species. In 1999-2000, great blue herons potentially accounted for 29 and 36% of the fish consumed, whereas in 2001-2002 American white pelicans accounted for 53 and 55%. We estimated that approximately 75,878 ±6,616 kg of fish were consumed by piscivorous birds in the lower sections of the river during the study. Bird assemblages differed spatially along the river with a greater abundance of colonial nesting species within the lower sections of the river, especially during spring and the nesting season. The

abundance of avian piscivores and consumption estimates are discussed within the context of salmonid supplementation efforts on the river and juvenile out-migration.

INTRODUCTION

The impacts of piscivorous birds at areas of high prey concentration such as aquaculture facilities, hatcheries and artificial obstacles to migration have been investigated within many regional waterways (Ruggerone 1986, Pitt et al. 1998, Glahn et al. 1999). Similar investigations within particular river sections and tributaries have also led to a better understanding of the consumption of migrating salmonids by individual bird species (Wood 1987 a,b, Derby and Lovvorn 1997, Feltham 1995, Suter 1995, Kelly 1998). However, far less is known about the temporal and spatial distribution of multiple piscivorous bird species within an entire river system during times of salmonid smolt out-migration and how these populations might collectively impact fisheries. With a better understanding of the distribution and abundance of these populations, and their food habits and energy requirements, natural resource managers would be better prepared to estimate their potential impacts to fisheries or integrate that impact into a system wide management plan.

A number of studies investigating individual bird species, especially mergansers (*Mergus spp.)*, have been successful in understanding the species' relationships to fish community dynamics (Wood 1986, Marquiss and Duncan 1994, Feltham 1995, Derby and Lovvorn 1997, Gregory et al. 1997, Kelly 1998). Even if bird populations are at natural and/or 'acceptable levels', a large scale ecological picture of their use of the river system is valuable because different birds may have very different habitat and prey selection criteria (Sjoberg 1987, Whitfield and Blaber 1978, Wood and Hand 1985). As a result, various bird species can utilize different locations (pools, riffles, fast or slow moving sections) of the river, effectively segregating the fish food resource spatially. Even without impacts from direct consumption, there is evidence that the presence of predation from piscivorous birds can lead to less foraging and reduced growth rates in fish (Allouche and Gaudin 2001). A direct measurement of bird species abundance and relative distribution as it relates to hatchery management practices and run timing of wild and hatchery salmon stocks can increase our understanding of avian impacts to restoration efforts for fisheries.

The Yakima River in Washington State runs approximately 322 km from its source on the eastern slopes of the Cascade Mountains to its junction with the Columbia River at the town of Richland, WA. Historically, the river has had substantial runs of fall and spring chinook (*Oncorhynchus tshawytscha*), coho (*Oncorhynchus kisutch*) and summer steelhead (*Oncorhynchus mykiss*), although in recent years particular runs have dwindled in response to a host of factors including reduced water quality, loss of acceptable salmon habitat, and an increase in predation and/or competition for resources from non-native species. Avian predators have been recognized as another source of potential loss. Relatively little is known about historic piscivorous bird abundance on the Yakima River, but evidence suggests there have been breeding populations of piscivorous birds in the region for decades, including (but not limited to): common mergansers (*Mergus merganser)*, belted kingfishers *(Ceryle alcyon)* and great blueherons *(Ardea herodias)* (Jewett 1953, Smith et al. 1997, Sauer et al. 2001). Other piscivorous birds such as double-crested cormorants *(Phalacrocorax auritus)*, Forsters terns (*Sterna* *forsteri*) and gulls (*Larus californicus and L. delawerensis)* which breed nearby (Thompson and Tabor 1981, Collis et al. 2002) are also commonly seen foraging within the river.

In response to these threats to native salmon populations, the Yakima/Klickitat Fisheries Project (YKFP) was initiated to "test the hypothesis that new supplementation techniques can be used in the Yakima River Basin to increase natural production and to improve harvest opportunities, while maintaining the long-term genetic fitness of the wild and native salmonid populations and keep adverse ecological interactions within acceptable limits" (Sampson and Fast 2000). Understanding the natural distribution of avian piscivores on the Yakima River and estimating their potential to impact supplementation efforts was considered a priority by the YKFP.

The current study documents the distribution and abundance of piscivorous bird species along the length of the Yakima River. We also estimate the maximum potential fish biomass consumed by the birds on the river over a period of 4 yrs, 1999-2002. Results are discussed within the context of current fish management practices and supplementation efforts.

METHODS

Study site

The Yakima River flows approximately 322 km from the outlet of Keechelus Lake in the central Washington Cascades southeasterly to the Columbia River, draining an area of 15,941 km^2. The river is perennial, with peak runoff during peak snowmelt, usually in April and May. The river drops approximately 663 m from a starting elevation of 767 m. The upper reaches of the Yakima River (Cle Elum, WA [47,196N 120,938W] and above) are high elevation loss areas predominated by mixed hardwood/conifer forests in association with a high degree of river braiding, log jams and woody debris. Reaches downstream from Cle Elum to Selah, WA [46,654N 120,529W] are intermediate elevation loss areas with less braiding and more varied terrain, including mixed conifer and hardwoods proximate to the river channel, frequent canyon type geography, and increasingly frequent arid steppe, sagebrush and irrigated agricultural lands. Middle and lower reaches (Selah to Richland, WA [46,286N 119,283W]) exhibit low elevation loss, an infrequently braided river channel dominated principally by hardwoods proximate to the river channel with arid steppe and irrigated agricultural lands abutting the shoreline. Private residential development is common along most parts of the river, except where it is absent in the Yakima Canyon (middle reaches). Significant commercial development is non-existent. Mean annual precipitation in the basin ranges from 356 cm per year in the mountains to less than 26 cm per year in Richland, WA, near the mouth.

River flow on the Yakima varies widely across seasons and the length of the river. Spring snow melt and rain produce large flows early in the year which decline dramatically during the hot summers east of the Cascade Mountains. Lower sections of the river are also damned and heavily drawn upon for agricultural purposes, creating a more consistent daily flow profile throughout the summer. Flow conditions on the Yakima River during the 4-yrs of our study are given in Figures 1 and 2. Measurements presented are for the lower Yakima River. Upper river flows are greater in their magnitude of daily variability, but show the same general patterns as that seen in the lower river. We observed a wide variety of flow conditions within and among years.

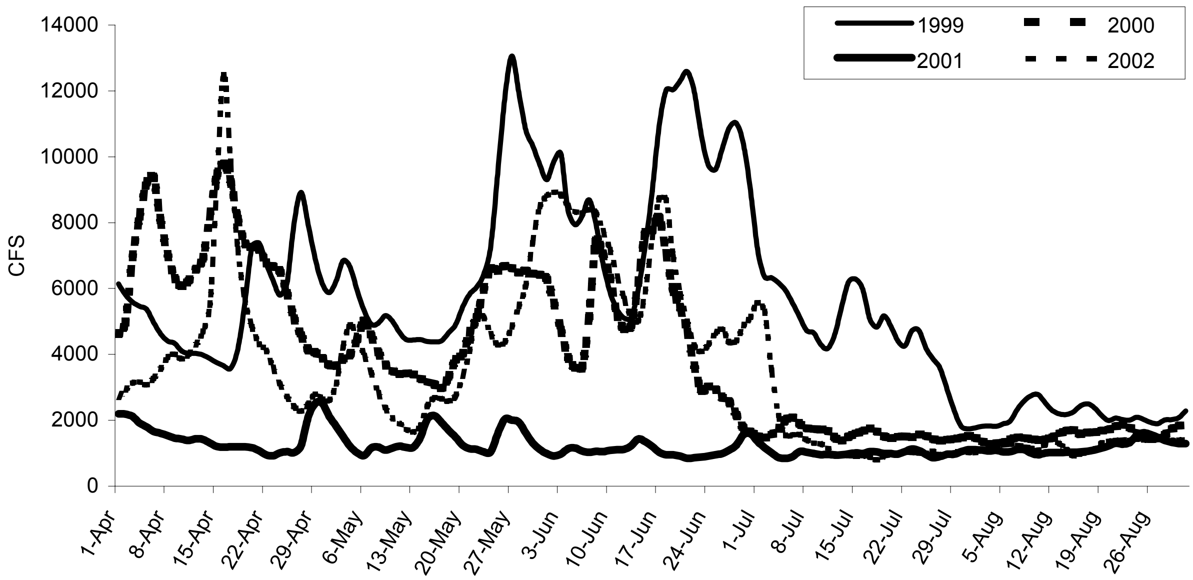

Figure 1. Daily flow (cfs) for the Yakima River during 1999-2002. Flow measured at Kiona gauging station (river km 30).

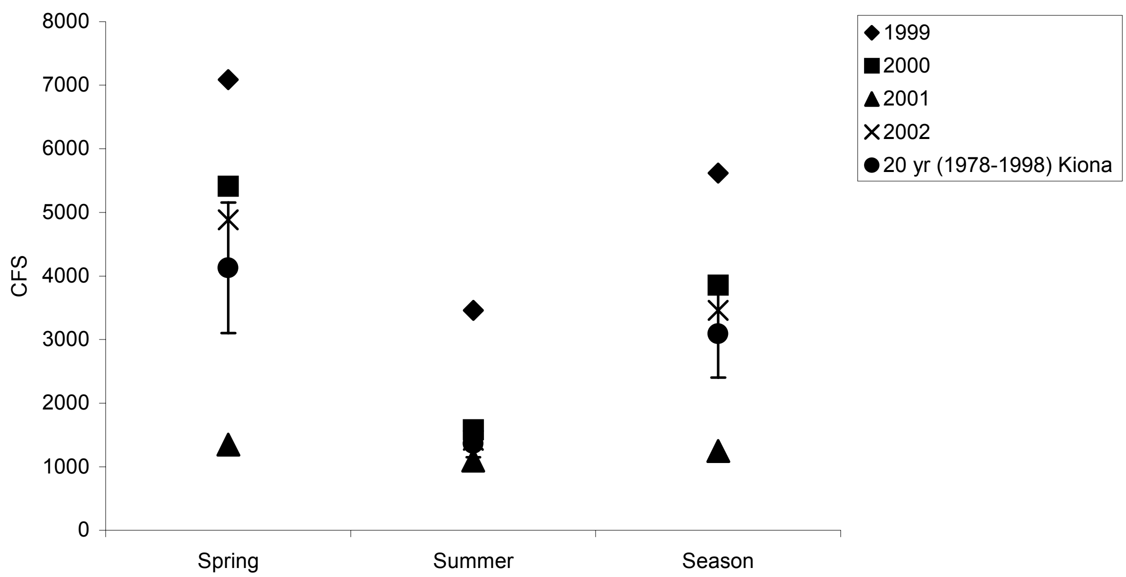

Figure 2. Average seasonal flows (cfs) for the Yakima River during 1999-2002 versus a 20-year average and standard deviation. Flow measured at Kiona gauging station (river km 30).

Bird abundance surveys

Our survey effort was distributed temporally and spatially in order to quantify bird distributions according to the specific out-migration periods of individual fish stocks and existing hatchery management practices on the river. The river was divided into three separate strata qualitatively based on shoreline habitat type, river flow and water quality characteristics, and logistical constraints such as boat access and avoidance of dams and other dangerous obstacles. Stratum 1 included the source to 84 km downstream. Stratum 2 consisted of the Yakima Canyon (40 km), and Stratum 3 included the river below the canyon to the mouth (198 km). Surveys were conducted on six reaches across the three strata, totaling 113.3 km or 35% of the entire river length. Surveys were targeted to time periods of out-migration of juvenile salmonids and/or residualized smolts or summer parr and were defined as spring (4/8 – 6/30) and summer (7/1 – 8/31) (Figure 3). Reaches within Stratum 1 were surveyed in spring and summer all 4-yrs. Stratum 2 was surveyed during spring 2001, and spring and summer in 2002. Reaches in Stratum 3 were surveyed in spring (April through June) before water temperatures reached lethal levels for salmonids and juvenile smolts had out-migrated. Seasonal start dates and frequency of individual surveys (once or twice every 2 weeks) differed only slightly between years.

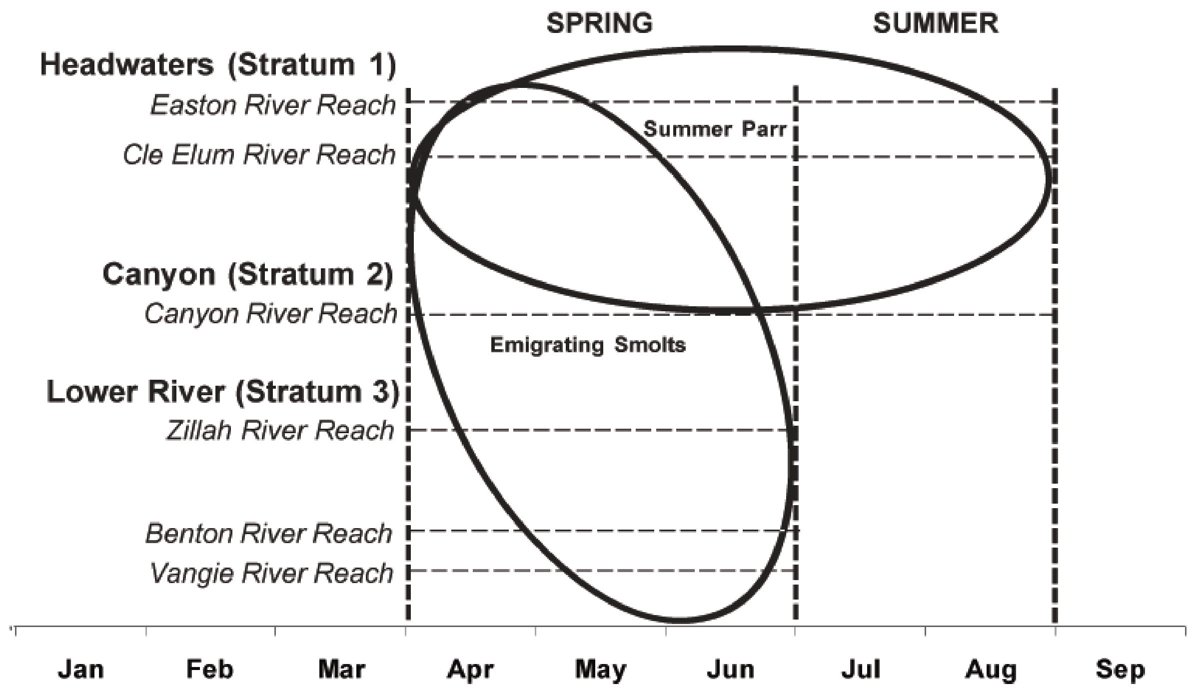

Figure 3. River reach survey sampling schedule. Survey effort was based upon timing of smolt out-migration and probable location of resident summer parr.

Individual river reaches were floated once or twice every 2 weeks in a 5.2 m aluminum drift boat or a two-person raft depending upon water conditions. All surveys began between 0800 and 0900 and lasted 2.5 to 5.5 h, depending upon length of reach, water flow and wind speed. Survey methods required actively rowing the drift boat/raft down stream to limit the interval of time required to complete the reach. A minimum of two people were on each survey for safety reasons and to assist in bird sightings. Piscivorous birds detected visually or aurally were recorded, including: time of observation, species, sex, and age if distinguishable. Binoculars (Leica, 10x42) were used to aid identification. All piscivorous birds encountered on the river by survey personnel were recorded at the point of initial observation. Most birds observed were only slightly disturbed by the presence of the survey boat and were quickly passed. Navigation of the survey boat to the opposite side of the river away from encountered birds minimized escape behaviors. If subsequent to the encounter, the bird attempted to escape from the survey boat by moving down river a note was made that the bird was being 'pushed'. If the bird being pushed down river moved out of sight of the survey personnel, a note was made, and the next bird of the same species/age/sex to be encountered within the next 1,000 m of river was assumed to be the pushed bird. If a bird of the same species/age/sex was not encountered in the subsequent 1,000 meters, the bird was assumed to have departed the river or passed the survey boat without detection, and the next identification of a bird of the same species/age/sex was recorded as a new observation.

One walking survey of the North Fork Teanaway, a tributary of the Yakima River, was included in the survey schedule. This stream was included because of its proximity to a newly established rearing and release facility for juvenile coho and chinook. Approximately 5.5 km of shoreline was surveyed by foot allowing the observer to view the entire stream. Data collected on piscivorous birds was the same as that for river drifts.

Estimates of bird abundance and consumption

Estimates of biomass consumed by piscivorous birds were calculated for the three strata. The equations used to estimate bird abundance, biomass consumed and eventually calculate the number of smolts taken (when more precise fish population data become available), use a stratified approach which allows data taken with varying degrees of effort to be combined.

The primary data used to calculate smolt predation were abundance estimates of piscivorous bird species on the river as described above and daily dietary requirements (g/day) for individual bird species from the published literature. Values taken from the literature vary in their estimates for different species and include: bio-energetic models, stomach content analyses, laboratory-based nutritional studies and calculations of field metabolic rates based on direct foraging observations. Where data were lacking for an individual species, a surrogate was used of similar genus, size and life history, and the daily energy requirements expanded as percent of body mass consumed for the surrogate was applied to our species of interest. Values for daily consumption are given in Table 1.

Table 1. Daily consumption values derived from sources within the literature and interpreted to appropriately account for regional life history, breeding phenology and foraging patterns of piscivorous bird species on the Yakima River.

Species	**Consumption (g/day)**
American Bittern	87
American White Pelican	1339
Black-crowned Night Heron	138
Belted Kingfisher	59
Caspian Tern	231
Common Merganser	455
Double-crested Cormorant	499
Forster's Tern	57
Great blueHeron	415
Green-back Heron	34
Great Egret	145

Gull spp.	94
Hooded Merganser	240
Osprey	350
Red-breasted Merganser	455

Assumptions concerning river strata were 1) birds are detected with probability of 1.0, 2) birds are not counted more than once, 3) birds predating on fish in the river were observable from the river, 4) consumption rates were the same across days, and 5) out-migrating fish released from hatcheries exit the survey reach before the start of the next survey. Assumption 5 is only pertinent to the calculation of consumption when attempting to partition consumption among various fish stocks.

The survey season was divided into blocks of approximately 2 wks, centered on a river reach drift. Blocks were constructed to account for changes in species composition of juvenile salmonids during out-migration. Bird abundance during the river drift survey was considered representative of the entire block. Either one or two river reaches were surveyed in each block, and bird abundance was expanded by the appropriate temporal and spatial sampling fraction.

Bird abundance for each block was estimated by:

$$\frac{T_{1k}}{\sum_{s=1}^{n} t_{1ks}} \cdot \frac{Km_{1}}{\sum_{s=1}^{n} km_{1ks}} \cdot \sum_{s=1}^{n} b_{1jks}$$

where:

$$\sum_{s=1}^{n} b_{1jks}$$

is the sum of the number of birds of each species counted in the river drifts, *s*, expanded by the sampling fractions for the k^{th} survey block.

Estimates of consumption (grams per day or number of fish) were calculated using the dietary values taken from the literature and information on the average size of different fish species, and their occurrence in the river over the survey season. The proportion of each species available for consumption (species composition) can be calculated from the number of smolts released from hatcheries in the appropriate Stratum, and from the abundance of resident fish species estimated by river surveys. The composition of salmonid species can be calculated by the following:

$$p_{1hk} = \frac{n_{hk}}{\sum_{h=1}^{H} n_{hk}}$$

where n_{hk} = the abundance of the h^{th} salmonid species in the k^{th} block.

The abundance of hatchery juvenile salmonids can be calculated using the number of each species released from the hatcheries and rearing ponds during the survey block. It is assumed that all migrating juvenile fish exit the Stratum in each block, so that the species composition estimated from the release data is representative of the species composition in the survey block. Further, not all fish size preferences are available for all bird species. Therefore, different size classes of the resident fish were taken into account.

Finally,

$$\sum_{k=1}^{t_1} \frac{W_j P_j}{\left(\sum_{h=1}^{H} s_{1kh} p_{1kh}\right)^I} \left[\frac{T_1}{\sum_{s=1}^{n} t_{1ks}} \cdot \frac{Km_1}{\sum_{s=1}^{n} km_{1ks}} \cdot \sum_{s=1}^{n} b_{1jks} \right]$$

is an estimate of the total number of fish consumed by the j^{th} bird species based on the consumption estimate W_j. Both estimates of biomass and numbers of fish consumed were calculated for each species in each survey block. Then, summing over all bird species to obtain an estimate of total fish consumption in a given Stratum gives,

$$\hat{M}_1 = \sum_{j=1}^{B_i} \sum_{k=1}^{t_1} \frac{W_j P_j}{\left(\sum_{h=1}^{H} s_{1kh} p_{1kh} \right)^I} \left[\frac{T_1}{\sum_{s=1}^{n} t_{1ks}} \cdot \frac{Km_1}{\sum_{s=1}^{n} km_{1ks}} \cdot \sum_{s=1}^{n} b_{1jks} \right]$$

where:

T_1= number of possible days in the survey.

t_{1ks} = number of float trips during of s^{th} river section (s = 1,2) in the kth block.

Km_1 = the total length of river in the Stratum.

km_{1ks} = the number of river miles drifted on the s^{th} river section, in the k^{th} block, in the Stratum.

b_{1jks} = the number of birds observed on the s^{th} river section of the k^{th} trip, of the j^{th} species in the Stratum.

B_1 = the number of bird species in the Stratum.

W_j = daily dietary food consumption rate (g/day) for the j^{th} (j = 1,2,…,B) bird species.

P_j = the proportion of the j^{th} (j = 1,2,…,B) bird species diet comprised of the h^{th} salmonid species (h = 1,2,…,H),

s_h = the size of the h^{th} salmonid species in grams,

p_h = the proportion of the h^{th} salmonid species available for feeding.

When the last three calculations (P_j, s_h and p_h) are removed from the final equation, there is no longer a conversion of grams per day to numbers of fish. The remaining estimate is equivalent to a total biomass consumed across the species and time period of interest.

Calculations for estimating abundance and consumption from the North Fork Teanaway foot survey were similar to those for river strata. However, because the entire Stratum was surveyed, the length fraction, $\frac{Km_5}{\sum_{s=1}^{n} km_{5ks}}$ is equal to 1, and thus not explicitly in the equation.

RESULTS

Results are separated by individual Stratum and the North Fork Teanaway foot survey. River-wide bird abundance and fish consumption estimates are presented separately. Potential impacts to migrating salmonids and resident fish stocks are addressed in the discussion.

Stratum 1

Eleven species of avian piscivores were encountered in Stratum 1 across the 4 yrs and 2 survey seasons (Figures 4 and 5). These included: black-crowned night heron (*Nicticorax nictocorax*), belted kingfisher (*Ceryle alcyon*), Caspian tern (*Sterna caspia)*, common merganser (*Mergus merganser*), double-crested cormorant (*Phalacrocorax auritus*), great blue heron (*Ardea herodias*), green-backed heron (*Butorides virescens*), california gull (*Larus californicus*), ring-billed gull (*Larus delawarensis*), hooded merganser (*Lophodytes cucullatus*), and osprey (*Pandion haliaetus*) Of these eleven, seven were observed in 1999, 2001-2002 and eight in 2000. Common mergansers, belted kingfishers, osprey, and great blue herons were the only species observed in all 4 yrs and during both spring and summer.

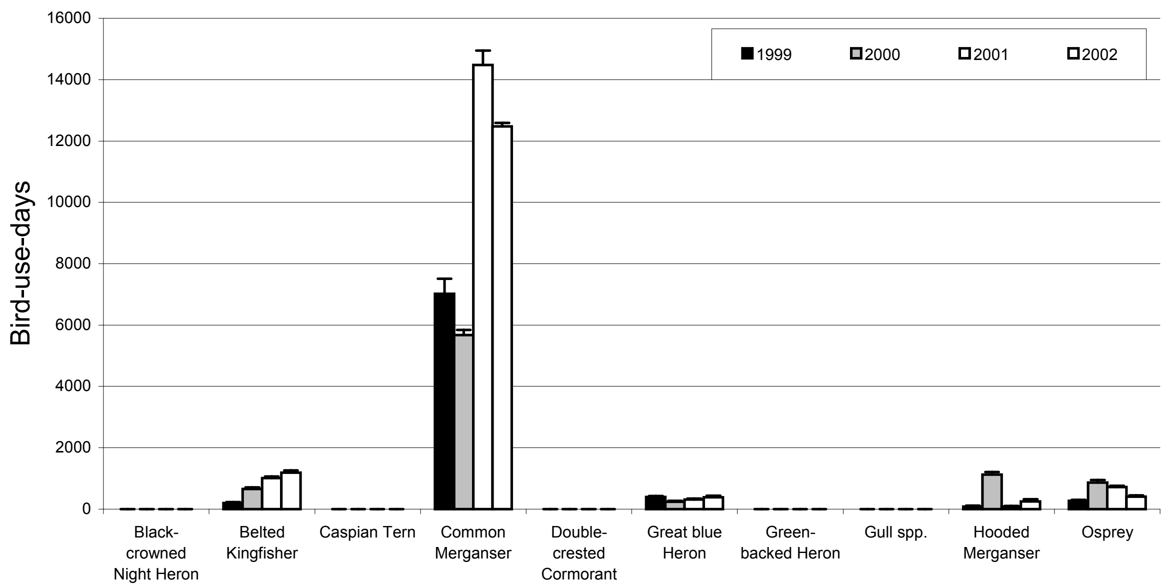

Figure 4. Abundance (bird-use- days ± SE) of all piscivorous birds in Stratum 1 during the spring survey season, 1999-2002

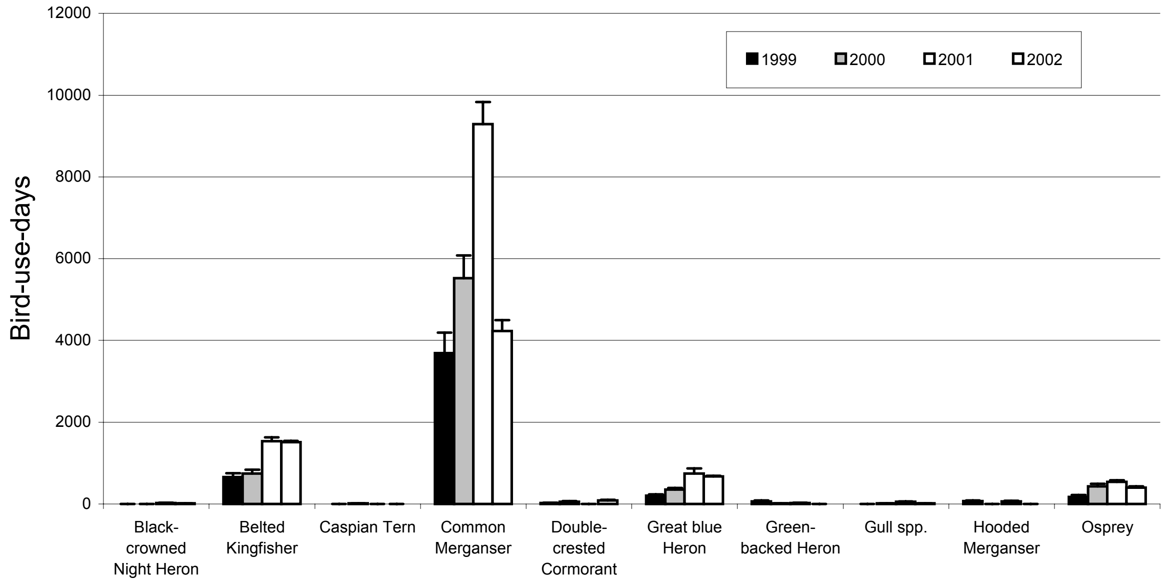

Figure 5. Bird abundance (bird-use-days ± SE) of all piscivorous birds in Stratum 1 during the summer survey season, 1999-2002

The estimated maximum consumption of fish by all birds during the spring survey season was between 3,292.9 kg (±61.2) in 2000 and 7,048.5 kg (±210.8) in 2001. Results for the summer season ranged from 1,890.2 (±228.8) in 1999 to 4,838.7 (±251.5) in 2001. Total consumption as a function of river kilometers is presented in Figure 6. Consumption by avian piscivores in Stratum 1 was dominated by common mergansers during all 4 yrs and both survey seasons (spring and summer). The percentage of fish consumed by common mergansers ranged between 78% in 2000 and 94% in 2001. Comparable figures for the summer were 78% in 2002 to 89% in 1999. After accounting for merganser consumption, only great blue herons and osprey consumed significant amounts of fish. These two birds combined consumed an average of 8 and 12% of the total estimated take in spring and summer, respectively across the 4 yrs.

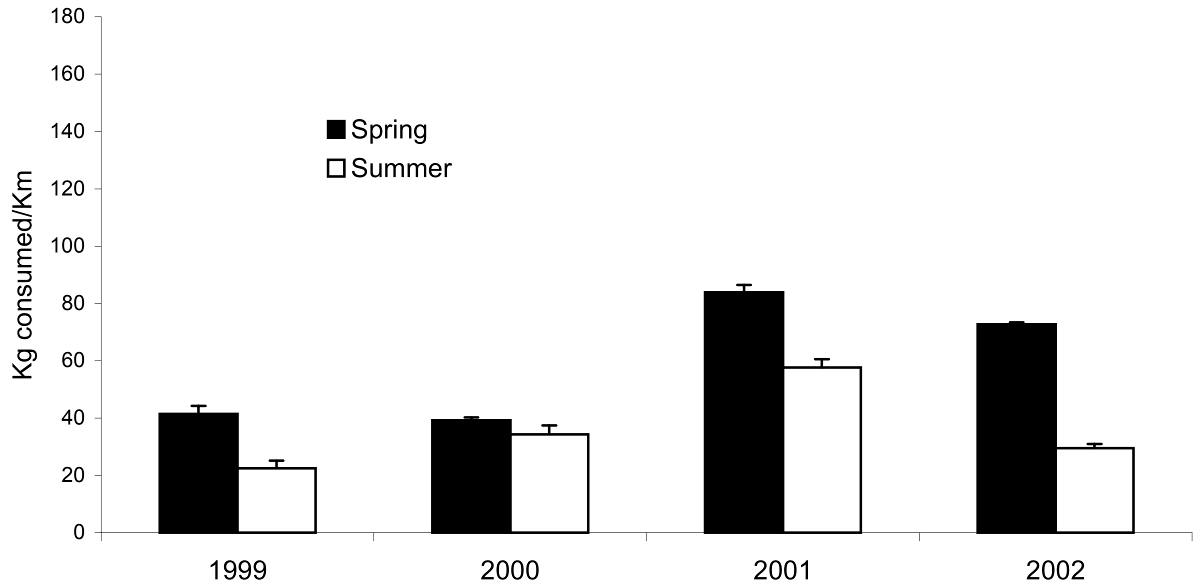

Figure 6. Estimated maximum total take (Kg consumed/Km ± SE) by piscivorous birds in Stratum 1, 1999-2002

Because mergansers were the primary potential threat to salmon supplementation efforts in Stratum 1, we investigated trends in numbers within and among years. Figure 7 details the variation in merganser abundance between survey dates during the 4 yrs. Adult male and female mergansers were already on site in small numbers when surveys began in early April. These numbers remained steady until broods began to emerge onto the river in late May and early June and adult males began to depart the area. The departure of adult males was compensated numerically by the presence of fledglings until the second or third week of July when all birds began to emigrate from the area.

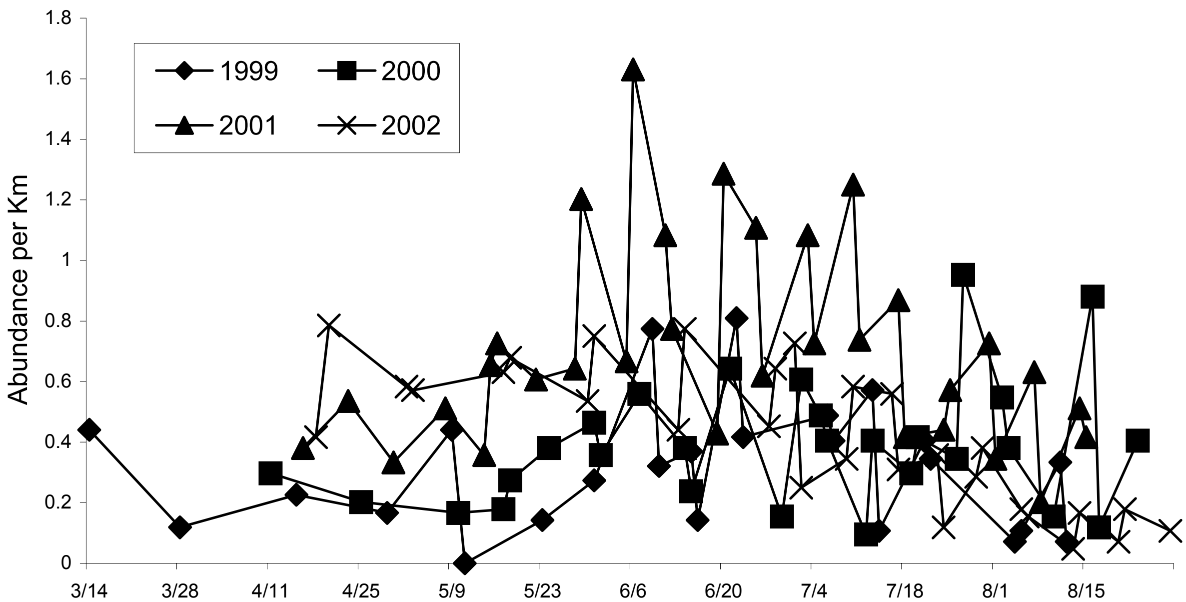

Figure 7. Seasonal abundance patterns for common mergansers in Stratum 1, 199-2002.

Trends in the abundance of mergansers during the spring and summer survey periods in 1999-2002 were assessed both graphically and using a weighted regression of years versus abundance. A plot of the abundance data and associated 95% upper and lower confidence limits for each season is shown in Figures 8 and 9. There is an increasing trend in merganser abundance during the spring across the 4-yrs, particularly between 2000 and 2001. No trend in the summer abundance indices is apparent, as the confidence intervals of the four estimates overlap significantly. A weighted least squares regression supports this interpretation of the graphical data. There was a significant increase in spring merganser abundance between 1999 and 2002 ($P = 0.083$), but no detectable upward or downward trend in summer merganser abundance.

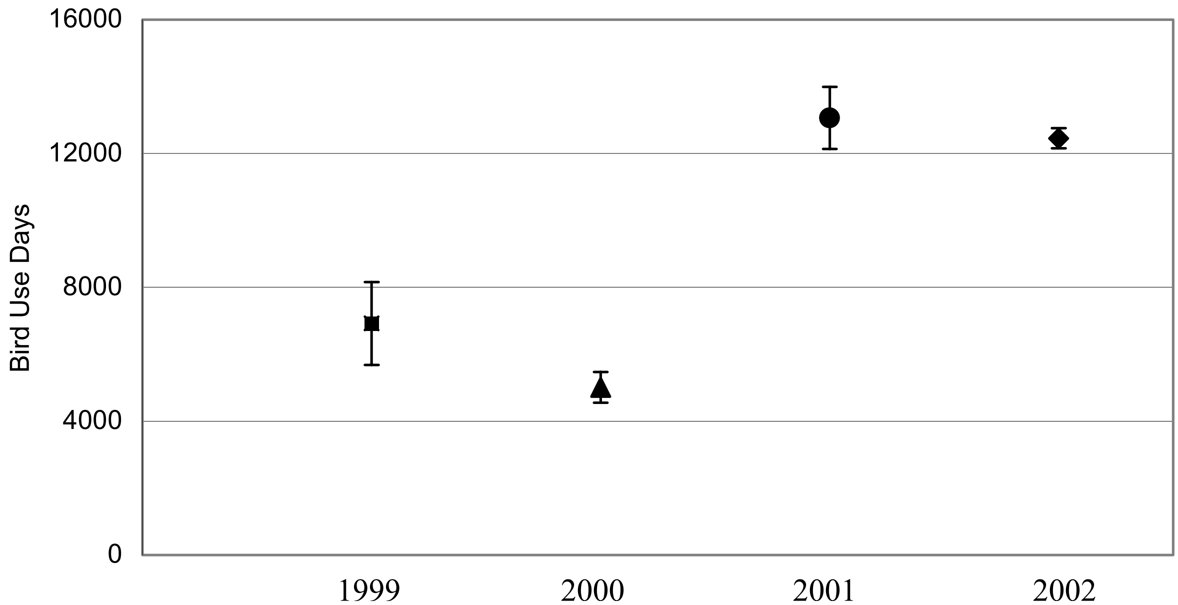

Figure 8. Mean abundance and 95% CI's for common merganser during the spring, 1999-2002.

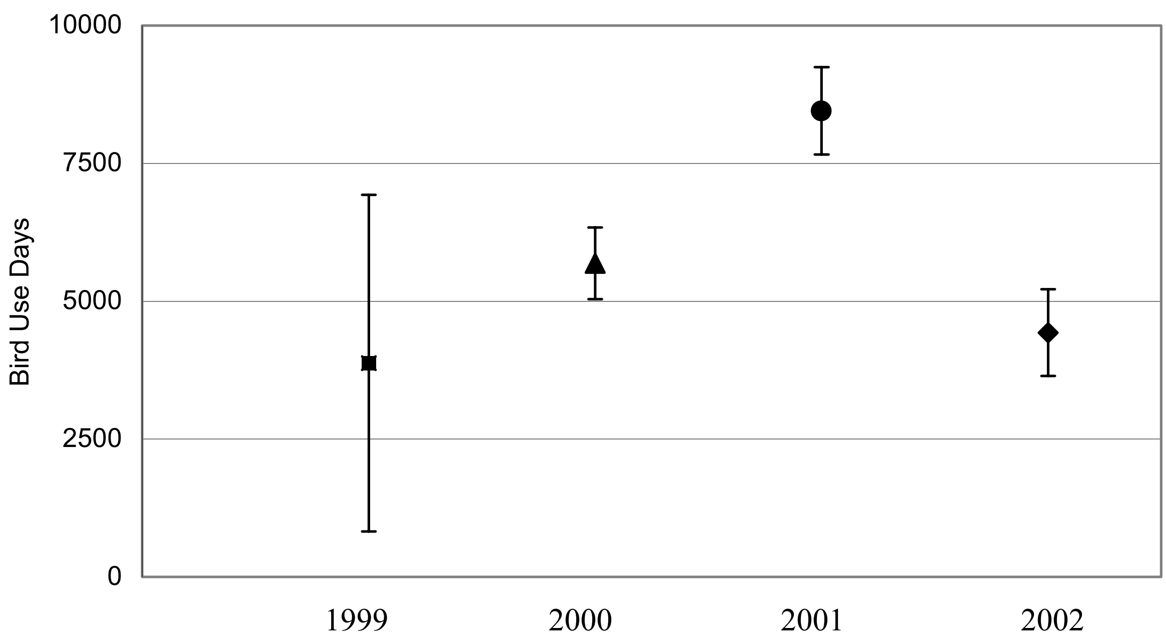

Figure 9. Mean abundance and 95% CI's for common merganser during the summer survey season, 1999-2002.

Stratum 2

Stratum 2 was only surveyed during spring 2001, and spring and summer 2002**.** Seven piscivorous bird species were observed across these three time, periods (Figure 10). These included: belted kingfisher, common merganser, double-crested cormorant, great blue heron, green-backed heron, hooded merganser, and osprey. All were seen during the spring survey period. During the summer period in 2002, hooded mergansers and green backed herons were not observed. Common mergansers, belted kingfishers, osprey, and great blue herons were the only species observed in both years and during both spring and summer seasons.

Maximum potential consumption of fish in this Stratum by all birds during the spring survey season was 1,277.9 kg (±83.9) in 2001 and 1,515.7 kg (±122.5) in 2002. Total consumption in summer 2002 was 667.1 kg (±33.9). Consumption as a function of river kilometers is given in Figure 11**.** Consumption of fish in Stratum 2 was less dominated by common mergansers than it was in Stratum 1, but they still accounted for an average of 64% of total estimated take. Most of this occurred in the spring. Great blue herons accounted for most of the remaining potential take, averaging 23% across the three survey periods. Compared to common mergansers, total take by great blue heron's was greater in summer than in spring. As in Stratum 1, belted kingfishers were one of the most abundant species (the most abundant in summer 2002), but their low estimated daily food requirement (ca. 59 g/day) kept them from being a significant consumer of fish compared to some of the larger species.

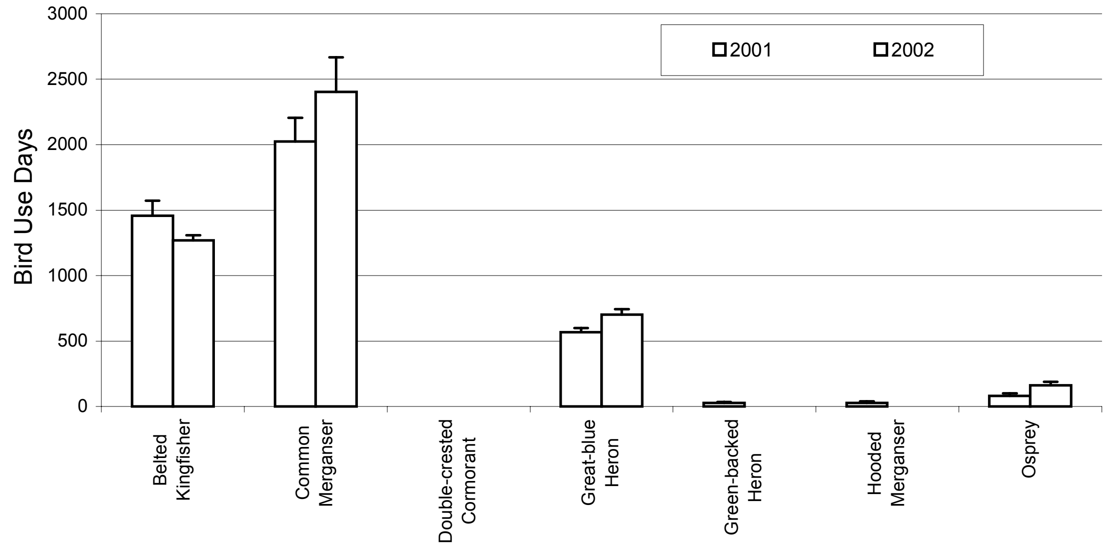

Figure 10. Abundance (Bird Use Days ± SE) of piscivorous birds in Stratum 2 during the spring survey season, 2001-2002.

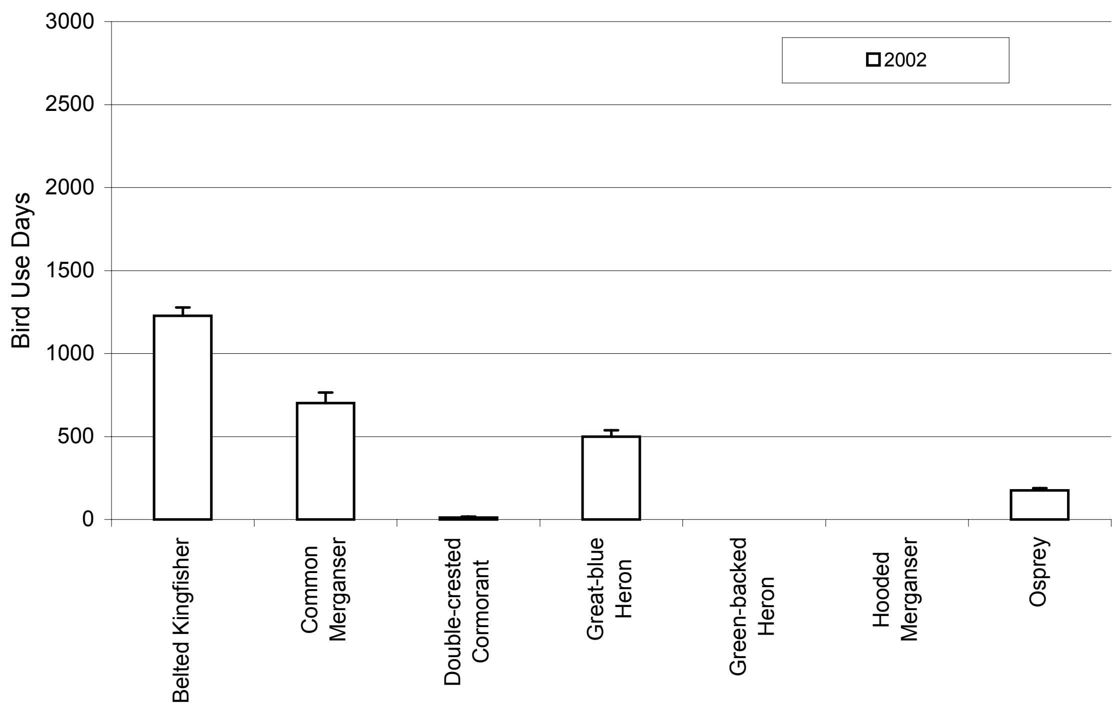

Figure 11. Abundance (Bird Use Days ± SE) of piscivorous birds in Stratum 2 during the summer survey season, 2002.

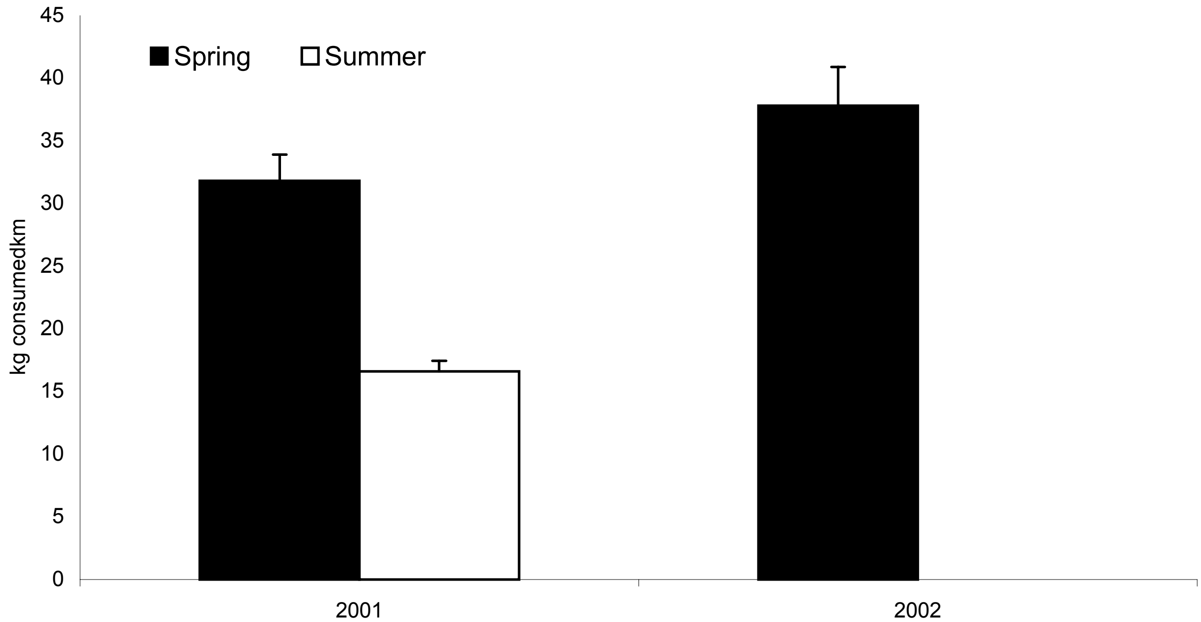

Figure 12. Estimated maximum total take (kg consumed/km ± SE) by piscivorous birds in Stratum 2, 2001-2002.

Stratum 3

Stratum 3 was surveyed during the spring season all 4 yrs. This Stratum supported the most diverse assemblage of avian piscivores (Figure 13). With the exception of hooded mergansers, these included all eleven recorded in Stratum 1 and Forster's tern *(Sterna forsteri)*, red-breasted mergansers *(Mergus serrator)*, great egrets *(Ardea alba)*, American bittern *(Botaurus lentiginosus)*, and American white pelicans *(Pelicanus erythrorhynchos)*. Of these 15, only 8 were seen during all 4 yrs: black-crowned night herons, belted kingfishers, common mergansers, double-crested cormorants, great blue herons, California and ring-billed gulls and osprey. American bitterns and red-breasted mergansers were only seen in 1 yr (2001 and 2002, respectively) and American White pelicans, and great egrets were seen in 2 yrs (2001 and 2002) and green-back herons were seen in 2000 and 2002.

Estimated maximum take by all birds was 5,202.8 kg (±491.6) in year 1999, 10,365.0 kg (±468.5) in 2000, 31,589.6 kg (±2,732.5) in 2001 and 28,721.1 kg (±2,924.0) in 2001. Take as a function of river kilometers is given in Figure 14. Great blue herons accounted for the greatest proportion of the estimated total take in 1999 and 2000, 29 and 36%, respectively. In 2001 and 2002, American white pelicans were the primary consumers, accounting for 53 and 55% of the total estimated take, respectively. The remaining estimated take was divided among common mergansers, double-crested cormorants, great blue herons (2001 and 2002) and gulls. These species combined accounted for 39 to 67% of the total estimated take across the 4 yrs. Take by common mergansers usually occurred early in the season (April and May) when breeding adults were migrating up-river. No merganser broods were observed in this stratum. The primary consumers in this stratum are all colonial nesters, but it is unclear whether the birds utilizing this portion of the river were breeding or non-breeding individuals. Colonies of great blue herons, gulls, American white pelicans and double-crested cormorants are all known to exist in the region (Thompson and Tabor 1981, Smith et al. 1997) and could potentially be within efficient foraging distance of this section of the Yakima River.

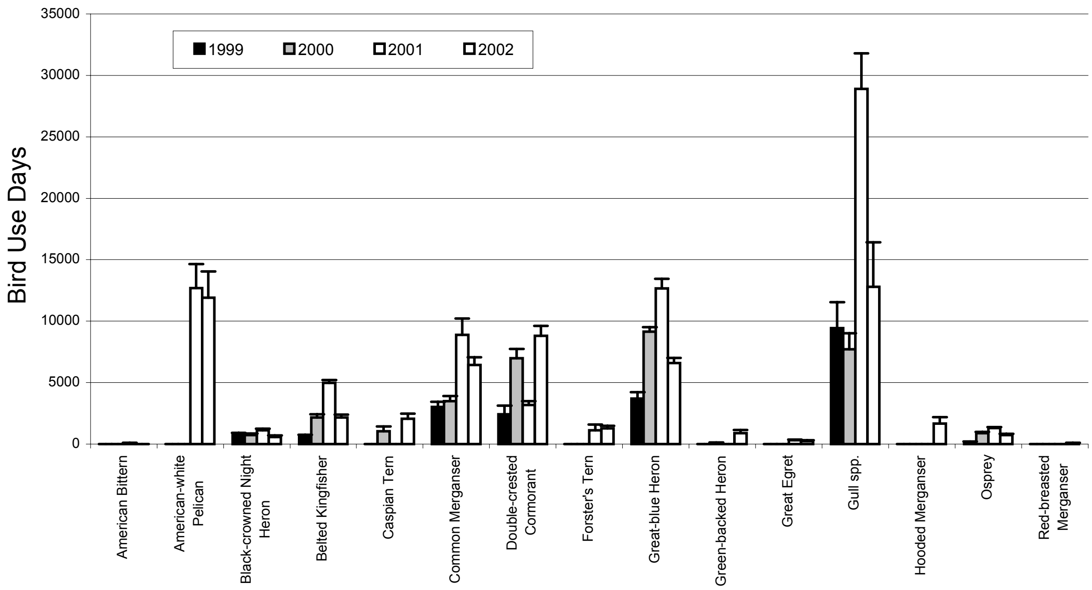

Figure 13. Abundance (Bird Use Days ± SE) of piscivorous birds in Stratum 3 during the spring, 2002.

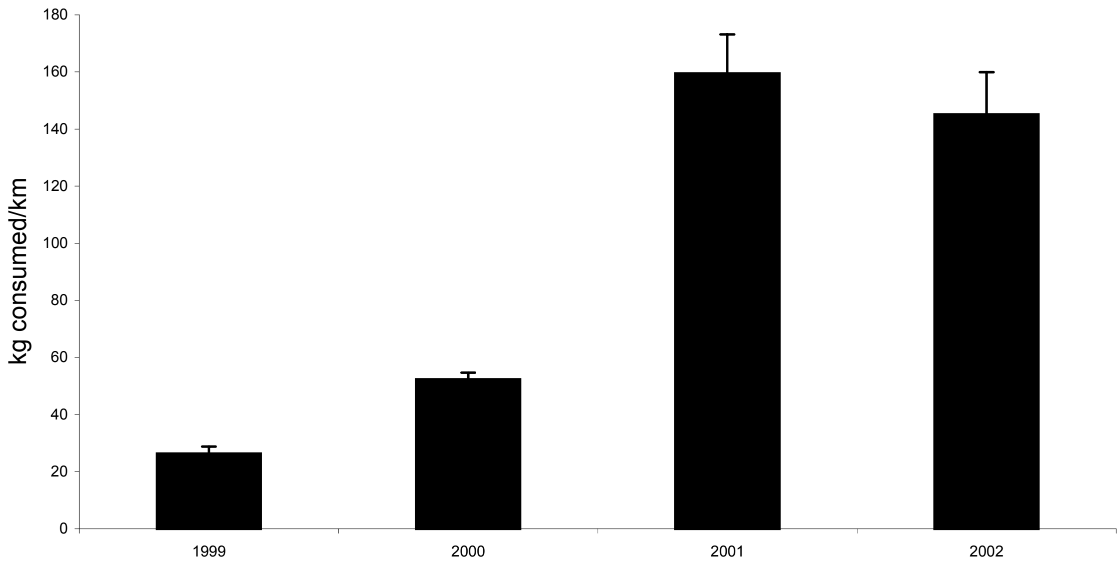

Figure 14. Estimated total maximum take (kg consumed/km ± SE) by piscivorous birds in Stratum 3, 1999-2002.

North Fork Teanaway

The North Fork Teanaway was surveyed by foot during the spring and summer all 4 yrs. There were very few piscivorous birds observed during any year or individual survey. Only three species were encountered: common mergansers, belted kingfishers and great blue herons (Figures 15 and 16). Estimated total maximum take by all species during both seasons combined across the 4 yrs ranged between 0.5 kg (±0.2) in 1999 to 1.3 kg (±0.4) in 2001. Take by great blue herons (3.3 kg ±0.9) accounted for approximately 90% of the estimated total.

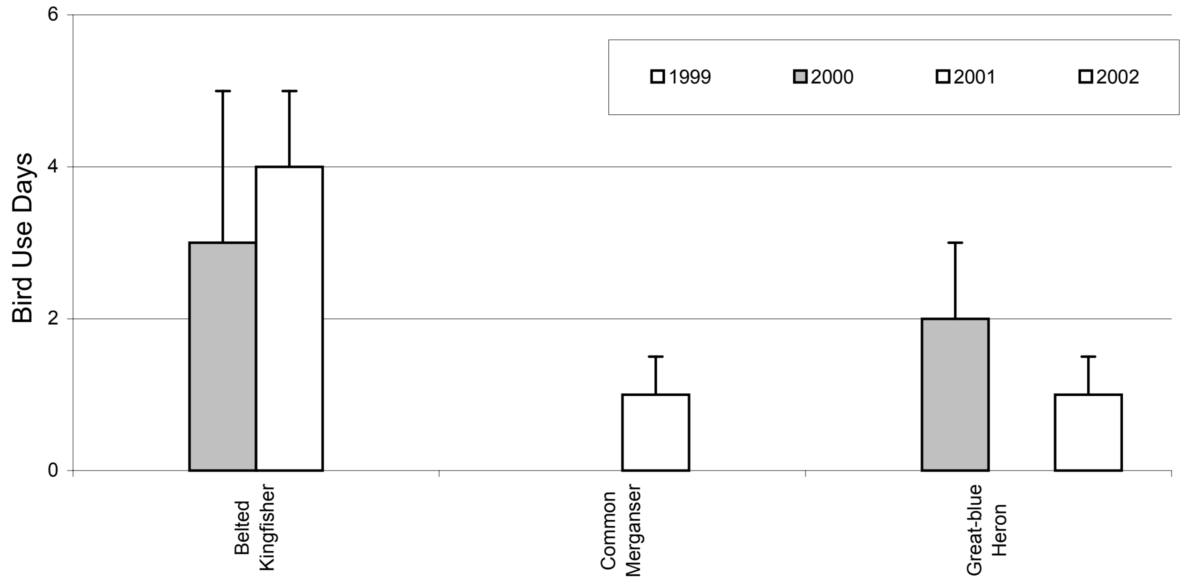

Figure 15. Abundance (Bird Use Days ± SE) of piscivorous birds observed on the North Fork Teanaway during spring.

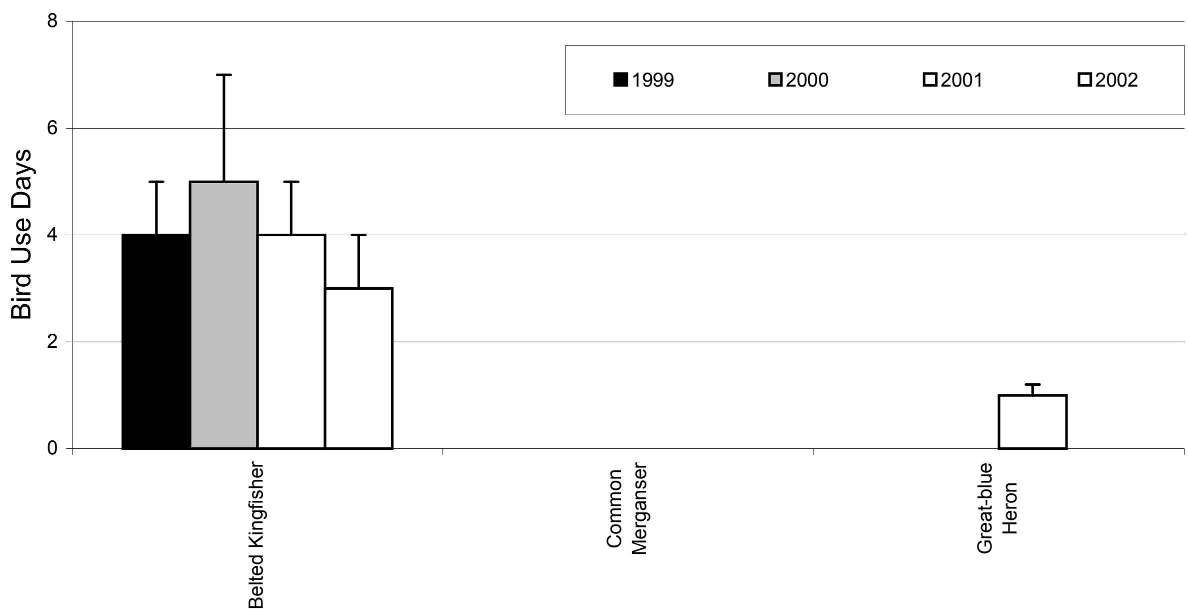

Figure 16. Abundance (Bird Use Days ± SE) of piscivorous birds observed on the North Fork Teanaway during the summer.

River-wide Bird Abundance and Consumption

Sixteen bird species were encountered across all strata over the 4 yrs of the study, but only half of these were observed in every year. Because bird abundance and consumption calculations within each Stratum and season involve separate temporal and spatial sampling fractions, estimates of total bird abundance and consumption across all seasons surveyed were converted to birds/km/day to enable comparisons across strata and among years (Figures 17 and 18). Average birds/km/day was greatest during the low flow year of 2001 in Strata 1 and 3 (4.44 b/km/day ±0.17 and 4.42 ±0.22, respectively). In Stratum 2, 2002 was greater than 2001 (2.29 ±0.11). Average kg consumed/km/day was highest across all three strata in 2001 (Stratum 1, 0.92 ±0.30: Stratum 2, 0.38 ±0.03: Stratum 3, 1.90 ±0.16). For both bird abundance (birds/km/day) and consumption (kg/km/day) in Strata 1 and 3, the last 2 yrs of survey data show an increase over the previous 2 yrs. These increases are most dramatic in Stratum 3.

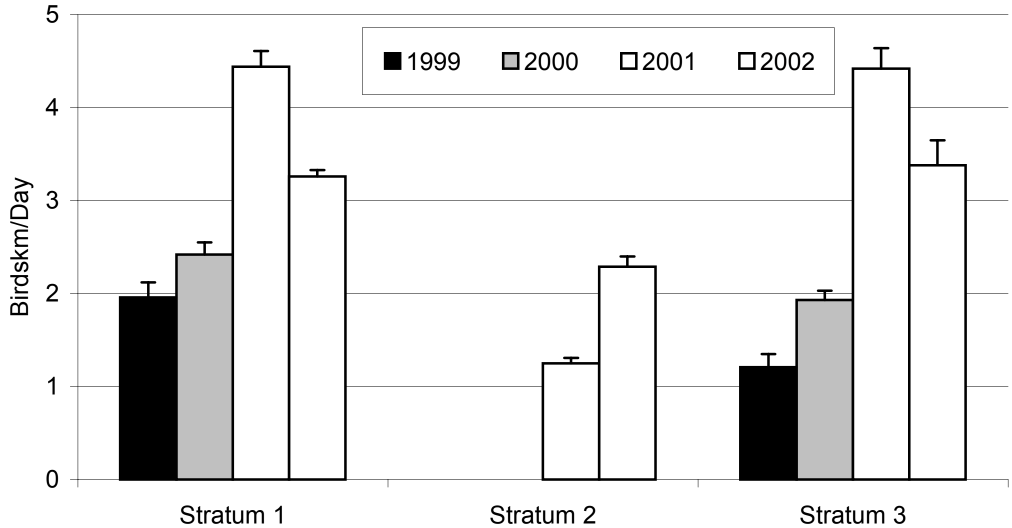

Figure 17. Average number of birds per kilometer per day (±SE) for Strata 1, 2 and 3 across all years and seasons.

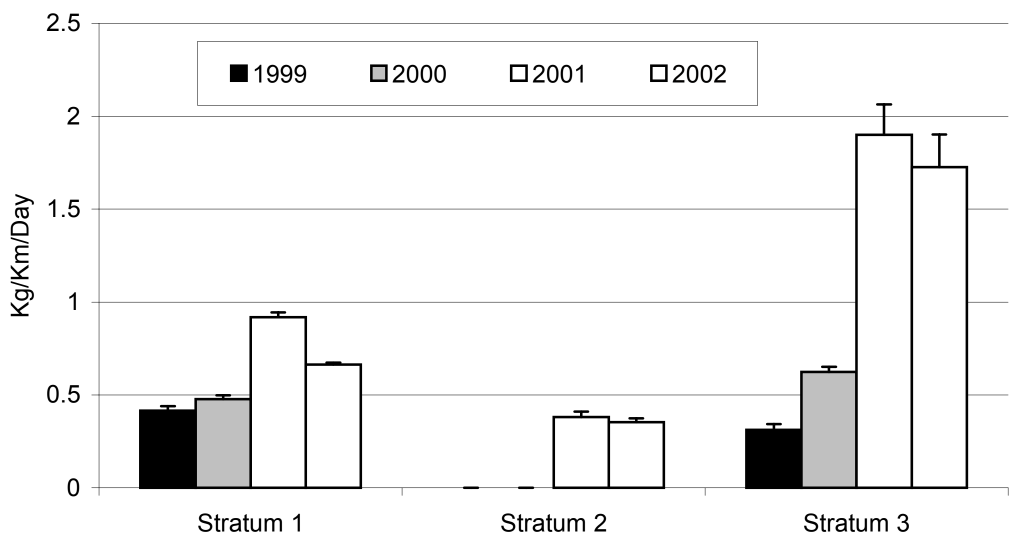

Figure 17. Estimated maximum kg of fish consumed per kilometer per day (±SE) by piscivorous birds in Strata 1, 2 and 3 across all years and seasons.

DISCUSSION

The Yakima River supports a diverse assemblage of piscivorous bird species. During the 4 yrs of our study (1999-2002), 16 species were recorded during at least 1 yr on at least one stratum surveyed. At least half of these species (including gulls) occurred commonly throughout most strata during all years. The physical structure of the river, flow conditions during the year and the surrounding landscape may play a more important role in determining the spatial and temporal distributions of piscivorous bird populations than current salmon supplementation efforts. Because piscivorous birds are commonly found to be opportunistic foragers (Knopf and Kennedy 1981, Dombeck et al. 1984), it is unlikely that these birds would prey disproportionately on out-migrating salmonids in this river system unless numbers of salmonids were significantly greater than other fish species present or more vulnerable to bird predation. A possible exception to this may be common mergansers.

Because they breed in cold-water streams in the western United States and Canada, common mergansers are often present in large numbers in areas with high salmonid production. As pursuit foragers, they have been known to aggressively feed upon salmonids, especially during large hatchery releases or in streams where wild production is high. Wood and Hand (1985a) found the average daily food requirement for a merganser can be satisfied at smolt densities of 0.02 – 0.30 per m^2. Wood (1984 and 1987) also found that time spent on a site by mergansers increased exponentially with fish density, decreased with searching time required until first capture of a fish and that during periods of smolt out-migration would forage almost exclusively on juvenile salmonids. Using doubly-labelled water, Feltham (1995a) estimated field metabolic rates of captive mergansers and applied his results to field observations. He concluded that annual predation of smolts was between 3 and 16% of annual production within two Scottish rivers. Feltham (1995b) also reports that the proportion of juvenile salmonids in the diet of mergansers changes over the season and is greatest (76-91%) early in the run. However, security from predators, factors affecting pair-formation and nesting habitat are also known to be important in the selection of breeding locations (Marquiss and Duncan 1994), possibly diminishing the importance played by salmonid availability as a food source. Gregory et al. (1997) found that river width and river gradient were positively and negatively correlated to the abundance of mergansers, respectively.

We do not know the fish community composition within the Yakima River, but might assume that with increased supplementation over the 4 yrs of our study and results derived from other studies, juvenile salmonids could be a significant food source for mergansers during all or part of the spring and summer season. In 1999, there were approximately 2.7 million salmonid smolts released into the Yakima River and available as food. This does not include hatchery releases or wild production in other rivers flowing into the Yakima within our study area except for the North Fork Teanaway. Salmonid supplementation increased slightly each year to approximately 4.7 mil fish released in 2002. The state of wild production over those four years is unknown.

The impacts to salmonid smolt survival by the foraging habits and food preferences of other piscivorous bird species encountered on the Yakima, especially in the lower reaches (Stratum 3) are more difficult to predict. The heron and egret species encountered are all stalkers, capturing prey in relatively shallow water by methodically hunting them and then spearing or capturing them with their beak. Terns, gulls and belted kingfishers are all plunge-divers and rely on good water clarity and prey within approximately 1 m of the surface. In the Yakima River, this translates to sections of relatively smooth water or situations that bring fish to the surface or make them more vulnerable to predation. A majority our sightings of terns and gulls were in flight along the course of the river and it is most likely that they were traveling between specific foraging locations such as dams or irrigation structures (Major et al. 2003, unpublished MS). Belted kingfishers, which are very territorial during breeding, occurred consistently in the same locations throughout the survey periods. Only belted kingfishers were consistently observed across all years, strata and seasons, but their small daily food requirement likely kept their impact on salmonids small even if one assumed 100 percent of their diet was salmonids.

Great blue herons accounted for a significant portion of consumption, especially in the lower sections of the river and were abundant all years and seasons. Great blue, black-crowned night and green-back herons and great egrets all methodically stalk their prey in shallow (usually slow-moving) water. Although all of these birds are known to be less than true piscivores, occasionally supplementing their diet with snakes, amphibians and even small mammals, they have repeatedly (with the exception of the green-back heron) been shown as predators of salmonid smolts in hatchery rearing facilities (Parkhurst et al. 1992, Pitt et al. 1998, Glahn et al. 1999). This would suggest that the juvenile salmonid size class is vulnerable to predation even by these large birds, provided they occur in the appropriate habitat. Current knowledge about salmonid presence in these areas in the Yakima River and their relative abundance to other available fish species is not known. During the surveys, we never encountered herons or egrets foraging in deeper or faster moving water or altering their traditional foraging strategies in a way that might suggest they were selecting specifically for salmonids.

The only other pursuit diver (except mergansers) encountered on the Yakima River was the double-crested cormorant. Although occurring in relatively small numbers and primarily limited to the lower river (Stratum 3), cormorants in eastern Washington are a growing concern among fisheries managers. They are known to breed locally (Smith et al. 1997) and research has shown them to prey upon juvenile salmonids under a variety of conditions. Within the Columbia River Basin, Collis et al. (2002) found that salmonids comprised between approximately 15 and 85% (by mass) of the diet of cormorants at different stages of the season. Cormorants have been also been shown to respond quickly to large inputs of hatchery reared salmonids, quickly shifting their diet to the available food source (Modde et al. 1996, Derby and Lovvorn 1997). Because of their opportunistic foraging habits and their occurrence primarily in the lower sections of the river where more fish species are available as prey, it is unlikely that cormorants are significantly impacting salmonid numbers. During our study we never encountered groups of more than 10 cormorants and never witnessed any response by these birds to large releases or movements of juvenile salmonids within the river.

The arrival of American white pelicans on the river in the last 2 yrs of the study (only in Stratum 3) inflates many of the consumption estimates for those years because of their large daily food requirement (~1339 g/day). American white pelicans dip their bills into the water while swimming along the surface in order to capture fish. This reduces their foraging impact below approximately 1 m. They have been shown to predate upon juvenile salmonids under certain conditions where large numbers of smolts are available within these water depths. Derby and Lovvorn (1997) found that like cormorants, American white pelicans shifted their diet to trout after a stocking event from 0.1 to 22% (by mass) of their diet. Recent work by Tiller and Welch (unpublished data, 2002) below McNary Dam on the Columbia River indicates that pelicans feed in the tailrace of the dam and may be responding to juvenile salmonid passage. In the 2 yrs that pelicans were encountered on the Yakima River in our study, they were consistently in one or two sections of Stratum 3. Until the relative abundance and out-migration timing of juvenile salmonid populations in these stretches of river are better understood, estimates of consumption in Stratum 3 should be carefully interpreted because the dietary requirements of the American white pelican heavily weight the results.

The Yakima River is highly varied in it's rate of flow, shoreline habitat and water quality as it runs from it's source to it's junction with the Columbia River. Because of this, the river supports a diverse assemblage of piscivorous birds. Our estimates of the distribution, abundance and maximum potential consumption of fish by these birds during 1999-2002 should give natural resource managers a picture of how these bird populations differ spatially and temporally along the Yakima and similar river systems and the extent to which they may impact fisheries. Our study was conducted within the context of increased salmonid supplementation. However, our estimates of fish take represent a worse case scenario, i.e. all of the dietary needs of the birds are met through consumption of fish taken from the Yakima River. The mathematical models we present for estimating take for each species incorporate the availability of salmonid stocks to each bird species based on fish size (g) as well as the proportion of salmonid stocks in the diet of each bird species through time. Unfortunately, data on the fish communities within the river are currently inadequate to partition take by piscivorous birds among different fish species or age classes. Fisheries managers can use our data and models as a framework for further investigations on the birds, fish communities and refinements in estimates of consumption.

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Chapter II: Piscivorous Bird Abundance, Fish Take and Flow Conditions at Artificial Structures within the Yakima River in Washington State

Abstract - Consumption of fish by piscivorous birds may be a significant constraint on efforts to enhance salmonid populations within tributaries to the Columbia River in Washington State. During 1999-2002, we determined the abundance of fish-eating birds, primarily ring-billed (*Larus delawarensis*) and California (*L. californicus*) gulls and monitored their behavior at two man-made structures within the Yakima River in eastern Washington: Horn Rapids Dam, a low-head irrigation dam, and the return pipe for the Chandler Juvenile Fish Handling Facility. Earlier observations of congregations of gulls at these structures suggested an increased likelihood of predation of out-migrating juvenile salmonids. We estimated the number of fish consumed and examined the relationship between river flow and gull numbers and fish taken. Numbers of gulls at the structures varied daily between their arrival in Late March-early April and departure in late June (mean (±SE) - Horn Rapids: 11.7 (±2.0), Chandler: 20.1 (±1.5)). During the 4-yr study, numbers at Horn Rapids peaked dramatically during the last 2 weeks in May (between 132.9 (±4.2) to 36.6 (±2.2) gulls/day) and appeared to the associated with the release of > 1-mil hatchery juvenile fall chinook (*Oncorhynchus tshawytscha*) above the 2 study sites. A comparable peak in gull abundance was not observed at Chandler. Diurnal patterns of gull abundance also varied among years and sites. The relationship between foraging efficiency and gull numbers was not consistent among years or sites. Gull numbers were not correlated with river flow when year was considered. However,

variations in flow among years appeared to be associated with average gull numbers at each site, but trends were not consistent between sites. Low seasonal flows were associated with increased predation at Chandler, whereas high seasonal flows were associated with increased predation at Horn Rapids. Assuming all fish taken were salmonids, we estimate gulls consumed between 0.1 – 10.3 % of the juvenile salmonids passing or being released from the Chandler Juvenile Fish Monitoring Facility located above the two structures. Staggered releases of hatchery fish, nocturnal releases of fish entrained in the Chandler facility, changes in the orientation of the outflow from the facility, and physical deterrents (e.g., sprinklers or overhead wires) may significantly reduce take by gulls at these sites.

INTRODUCTION

Consumption by avian predators is known to affect salmonid survival rates within unaltered (Alexander 1979; Wood 1987a,b; Feltham 1995; Derby and Lovvorn 1997) and altered (Ruggerone 1986; York et al. 2000; Collis et al. 2001, 2002;) river systems. This predation, primarily upon out-migrating juvenile salmonids, is highly variable because of the opportunistic foraging habits of most piscivorous birds allowing them to quickly consume large numbers of juvenile salmonids when appropriate conditions occur. Conditions which congregate fish and/or increase the susceptibility of juvenile salmonids to predation by fish-eating birds may occur at dams, irrigation structures, and in-system fish handling facilities and release sites (Ruggerone 1986, Modde and Wasowicz 1996, Scheel and Hough 1997).

Bird predation of out-migrating juvenile salmonids at dams and sites of salmon smolt release from hatchery rearing sites or downstream transport is particularly common throughout the Columbia River Basin. The Basin supports some of the largest populations of piscivorous birds in North America and Europe (Thompson and Tabor 1981, Ruggerone 1986, Collis et al. 2001). Most piscivorous birds within the Basin are colonial nesters including ring-billed gulls (*Laurus delawarensis)*, California gulls *(Laurus californicus)*, glaucous-winged gulls (*Laurus glaucescens)*, Caspian terns *(Sterna caspia),* double-crested cormorants *(Phalacrocorax auritus)* and great blue herons *(Ardea herodias)*. As such, they are particularly suited to the exploitation of prey that fluctuate in density (Alcock 1968, Ward and Zahavi 1973). The advantage held by colonial birds under these conditions is hypothesized to result from colony members receiving cues from successful foragers as to prey type and location (Forbes 1986, Greene 1987). Or, alternatively, the close proximity of colonies to sources of prey such that all birds are alerted to sudden increases in prey abundance.

These factors, in combination with large concentrations of salmon smolts, can lead to high levels of consumption by avian predators. In one study, 74% (by mass) of the diet of Caspian terns — from a single nesting colony within the Columbia River estuary on Rice Island — was estimated to be salmonids (Collis et al. 2002). Ruggerone (1986) estimated that gulls consumed 50 to 562 fish/h (assumed to be salmonids) below Wanapum Dam on the Columbia River. Another study, York et al. (2000) found peak consumption (percent frequency of food items in stomachs) of salmonids by gulls below Priest Rapids Dam on the Columbia River coincided with peak salmonid out-migration.

Colonies of piscivorous birds have historically been present throughout the Columbia River as far upstream as the Hanford Reach (Jewett et al. 1953). However, colonies of gulls in the Basin have increased in number and size during the last 50 yrs (LaFave 1965, Thompson and Tabor 1981, Smith et al. 1997, Collis et al. 2002). Breeding Bird Survey (BBS) data for Washington State, show ring-billed and California gulls have increased approximately 7% from 1966 to 1991 (Sauer et al. 2002). As a result of increasing numbers of piscivorous birds in the Basin, in combination with increasing salmon supplementation efforts and intensified water management programs, losses of juvenile salmon from avian predation has become a concern on several tributaries of the Columbia River. The Yakima River, entering the Columbia River at the city of Richland, Washington, has been identified as one of several rivers where avian predation could negatively impact supplemation efforts.

Salmonid management within the Yakima River is currently guided by the Yakima/Klickitat Fisheries Project (YKFP). Initiated in 1998, the Yakima/Klickitat Fisheries Project combines hatchery rearing, salmon supplementation, and habitat improvement projects targeting four species of salmonids: spring and fall chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and summer steelhead (*O. mykiss*). In conjunction with these efforts, the impacts of predators upon supplemented and naturally spawning salmonid stocks are being assessed through indices of predation, competition, and changes in predator populations.

It is anticipated that interactions between salmonid stocks and principal fish-eating birds may impact the ultimate success of the YKFP supplementation efforts (Pearsons 1998). Numerous man-made structures exist on the Yakima River that may hinder fish movement downstream, and/or concentrate or disorient out-migrating fish sufficiently to increase their vulnerability to avian predators. Quantifying the response of fish-eating birds to these structures, identifying the factors governing the response of the birds, quantifying fish losses, and identifying ways to mitigate losses are important in maximizing the benefits of conservation and enhancement efforts. The objectives of our study were to (1) identify sites within the Yakima River where predation by fish-eating birds may be significant, (2) determine diurnal and seasonal patterns in abundance, (3) determine the relationship between numbers of fish-eating birds and river flow, and (4) estimate take of fish by the birds at these sites.

METHODS

Study Areas

Two primary locations were chosen for monitoring avian piscivore abundance and fish take. Horn Rapids Dam (hereafter Horn Rapids) is a low-head diversion dam with a 159.4 m face that spans the width of the river. The dam is approximately 25-30 km upriver from the confluence with the Columbia River and approximately 15 km west of Richland, WA. The river below the dam contains turbulent rapids, varying in intensity and depth with river flow for approximately 1 km. The pool above the dam extends for approximately 1 km upriver and is approximately 1.5 m deep at the dam head. The survey area for Horn Rapids included the width of the river to 50 m above, and 150 m below the dam.

The Chandler Canal Bypass outfall (hereafter, Chandler) is the return pipe from the Chandler Juvenile Fish Processing Facility located approximately 500 m below the

Prosser Dam in Prosser, WA. This facility utilizes an upstream diversion canal to direct fish off the river to monitor various aspects of juvenile salmonid life history, health and out-migration patterns. Diverted fish are eventually returned to the river by way of a 66.0 cm diameter, 114.3 m bypass pipe that expels fish into the river. Depending upon river flow, the pipe can be at different depths below the water's surface, greatly varying the exposure of fish to avian predators. The survey area for Chandler included the width of the river to 50 m above, and 150 m below the outfall.

Other locations along the Yakima River were monitored less frequently throughout each season and the monitoring effort varied among years depending on availability of personnel. The purpose of this secondary monitoring was to ensure that other areas of significant predation were not being overlooked. Aerial flights of the river were conducted in 2 of the 4 yrs to assist in this effort. All of the secondary sites were dams ranging in size from that described for Horn Rapids to the Roza Diversion Dam (the largest on the Yakima), which is a concrete weir structure 20.4 m high and 148.1 m long its crest.

Estimates of Bird Abundance and Consumption

At the two locations, observations were made from the shore in either an automobile (Horn Rapids) or bird blind (Chandler) to avoid disrupting normal bird activity. Binoculars (Leica 10x42) were used to aid identification. At Horn Rapids, survey personnel stationed themselves on the windward bank of the river such that the preferred orientation of feeding birds (primarily gulls) was towards the observer. At Chandler, altering the side of the river from which observations were made was not feasible. However, the distance from one side of the river to the other was considerably less than at Horn Rapids, which improved the observer's ability to accurately monitor bird behavior.

It became clear during the preliminary field seasons (1997 and 1998) that gulls (ring-billed and California) were the primary avian piscivores at these sites and therefore methods to survey abundance and estimate consumption were developed to quantify gull abundance and monitor gull foraging behavior.

Two methods were used for quantifying gull abundance and fish take during the course of the study. Methods used in 1999 and 2000 were modified for 2001 and 2002 in an effort to address concerns that the method used initially may underestimate fish take. In both methods, daily surveys were conducted for 8 h, either from 30 min after sunrise or to 30 min before sunset. Start times and personnel were alternated daily, providing an equal distribution of survey times throughout the season at each site and eliminating personnel bias. In 1999, surveys began in mid-March and were conducted until the end of May, and in 2000-2002, from the first week of April until the end of June. It was determined after the first year that surveys from April through June would better capture the overlap between regional gull breeding phenology and the out-migration of juvenile salmonids salmonid.

In 1999 and 2000, each day was divided into 2-h survey windows. At the beginning of each survey window, all piscivorous birds in the study area were counted at 1-min intervals for 5 min. Immediately following the total abundance count, the ratio of actively foraging gulls (those in the air hovering within the study area) to total number within the study area was determined and an individual gull was selected for 5-min of observation. The gull selected was the first individual present to attempt to capture a fish in the study area. Once a bird was chosen, successful and unsuccessful feeding attempts were recorded. Successful feeding attempts were those in which the observed bird consumed a fish, regardless of the means of acquisition. Unsuccessful feeding attempts were defined as any clear and sudden movement towards the water resulting in contact with the water, but not resulting in a fish being taken. This 5-min individual observation period was repeated twice more with different birds (assumed) followed by another 5-min abundance count of all piscivorous birds present. Counts and observations continued for a total of 45 min followed by a 75-min rest period for the observer.

Estimates of daily bird abundance were calculated by,

$$\hat{N}_{lm} = \frac{24}{6}\sum_{n=1}^{P}\sum_{r=1}^{6} A_{lmnr}$$

where A_{jmnr} = the number of active birds feeding in the r^{th} 5 min period (r = 1, 2,...,6), of the n^{th} survey period (n = 1, 2, ...,p), on the m^{th} day (m = 1, 2, ...,t_l), for the l^{th} hotspot (l = 1,2),

There are 24 5-min periods in 2 h, and only 6 these periods were sampled for foraging rate, giving a sampling fraction of 6/24. The number of fish taken in the six, 5-min periods was expanded by the sampling fraction (24/6). Estimates of fish consumed was calculated by,

$$\hat{M}_4 = \sum_{j=1}^{B_4}\sum_{l=1}^{2}\left[\frac{T_{4l}}{t_{4l}}\cdot\frac{24}{6}\cdot\sum_{m=1}^{t_{4l}}\sum_{h=1}^{H} p_{mh}\sum_{n=1}^{P}\sum_{r=1}^{6} A_{jmnhr}\cdot R_{jmnhr}\right]$$

where A_{jmnr} = the number of active birds feeding in the r^{th} 5 min period (r = 1, 2,...,6), of the n^{th} survey period (n = 1, 2, ...,p), on the m^{th} day (m = 1, 2, ...,t_l), for the j^{th} species (i = 1, 2, ...,B_i),

R_{jmnr}= the number of fish taken in the r^{th} 5 min period (r = 1, 2,...,6), of the n^{th} survey period (n = 1, 2, ...,P), on the m^{th} day (m = 1, 2, ...,t), for the j^{th} bird species (i = 1, 2, ...,B_i),

p_{mh} = the proportion of the h^{th} salmonid species in the run on the m^{th} day,

t_{4l} = the number of days visited the l^{th} hotspot (l = 1,2),

T_{4l} = the total number of days in the out-migration season,

In the second method, each day was also divided into 2-h survey windows, but consisted of three, 15-min observation blocks. Each of these blocks was separated by a 15-min period of no observation. A 45-min rest period followed the 75-min cycle before beginning a new 2-h window. Within each 15-min survey block, abundance of all piscivorous birds and the foraging ratios (number feeding to total number present) and foraging rates (fish taken/min) of the gulls present were determined. Total abundance of all piscivorous birds was determined once at the beginning and end of each block. The first gull observed taking a fish within the study area was chosen for observation. This bird was observed continuously until a second successful capture occurred or a maximum of 30 min had passed. The time interval between successful takes was recorded. If time remained in the 15-min block, another foraging gull (assumed) was selected for observation and was observed until another successful take or the end of the subsequent 15-min rest period. When the latter occurred, the time between the first successful take and the end of the rest period was recorded and considered a minimum foraging interval in subsequent analyses.

Gull abundance, expressed as gull-use-minutes, for the observation period is calculated by,

$$\bar{y}_{ijklm} = \left(\frac{y_{ijklm1} + y_{ijklm2}}{2} \right) \cdot 15,$$

where, y_{ijklmr} = the number of gull-use-min in the s^{th} (s = 1, 2) count the m^{th} forage interval (m = 1,2,3) for the l^{th} survey period (2-hr period) (l = 1,2,…,L) of the k^{th} (k = 1,2,…,K) survey for the j^{th} (j = 1,2,…,J) bird species on the i^{th} (i = 1,2) hotspot.

The number of fish take within each observation period is calculated by,

$$\bar{t}_{ijkl} = \frac{\sum_{m=1}^{M} t_{ijklm}}{M}$$

where, t_{ijklms} = the number of minutes between successful fish takes for the s^{th} (s = 1, 2,…,S) bird, for the m^{th} forage interval (m = 1,2,3) for the l^{th} survey period (2-h period) (l = 1,2,…,L) of the k^{th} (k = 1,2,…,K) survey for the j^{th} (j = 1,2,…,J) bird species on the i^{th} (i = 1,2) hotspot.

This is then used to calculate the number of fish taken in the m^{th} observation period of the l^{th} survey period, f_{ijklm} by the equation,

$$f_{ijklm} = \frac{\bar{y}_{ijklm}}{\bar{t}_{ijklm}}:$$

where f_{ijkl} = the number of fish taken in the m^{th} forage interval (m = 1,2,3) for the l^{th} survey period (2-hr period) (l = 1,2,…,L) of the k^{th} (k = 1,2,…,K) survey for the j^{th} (j = 1,2,…,J) bird species on the i^{th} (i = 1,2) hotspot.

Finally, the total number of fish taken for the year, f, is calculated by expanding fish counts by sampling fractions and summing across survey days, and hotspots,

$$f = \sum_{i=1}^{2}\sum_{j=1}^{J}\frac{K}{k}\sum_{k=1}^{K}\frac{L}{l}\sum_{l=1}^{L}\frac{8}{3}\sum_{m=1}^{3} f_{ijklm} .$$

Statistical Analyses

Relationships between gull abundance and daily river flow conditions were examined across the 4 yrs, whereas the relationship between fish take and flow was analyzed separately across the 2 yrs of similar sampling methodology (1999-2000 and 2001-2002). Analysis of covariance (Neter et al. 1996) was used for both comparisons. Foraging efficiency (time between successful takes) relative to foraging gull abundance was examined using linear regression and data from 2001 and 2002. A significance level of $P \leq 0.1$ was used in all analyses.

RESULTS

Abundance of Fish-eating Birds

Across the 4 yrs (1999-2002), 12 species (not including gulls) were observed at Horn Rapids and Chandler combined (Figs. 1 and 2). Numbers for these species averaged less than 3 birds per day, except for common mergansers (*Mergus merganser)*

(3.0 ±1.6) at Chandler in 1999. In comparison, abundance of gulls averaged between 11 (±2.7) to 47 (±1.4) and 10 (±1.2) to 22 (±4.9) birds per day in years 2000-2002 at Chandler and Horn Rapids, respectively (Fig. 3). Gulls were observed on all survey days.

Total gull abundance was highly variable among days, but peak gull abundance at Horn Rapids (Fig. 4) was distinct and consistent across all 4 yrs, occurring during the last 2 wks of May. A comparable consistent peak in gull abundance was not observed at Chandler. Gulls at Chandler tended to arrive during the last weeks of April and numbers remained relatively constant until the first or second week of June.

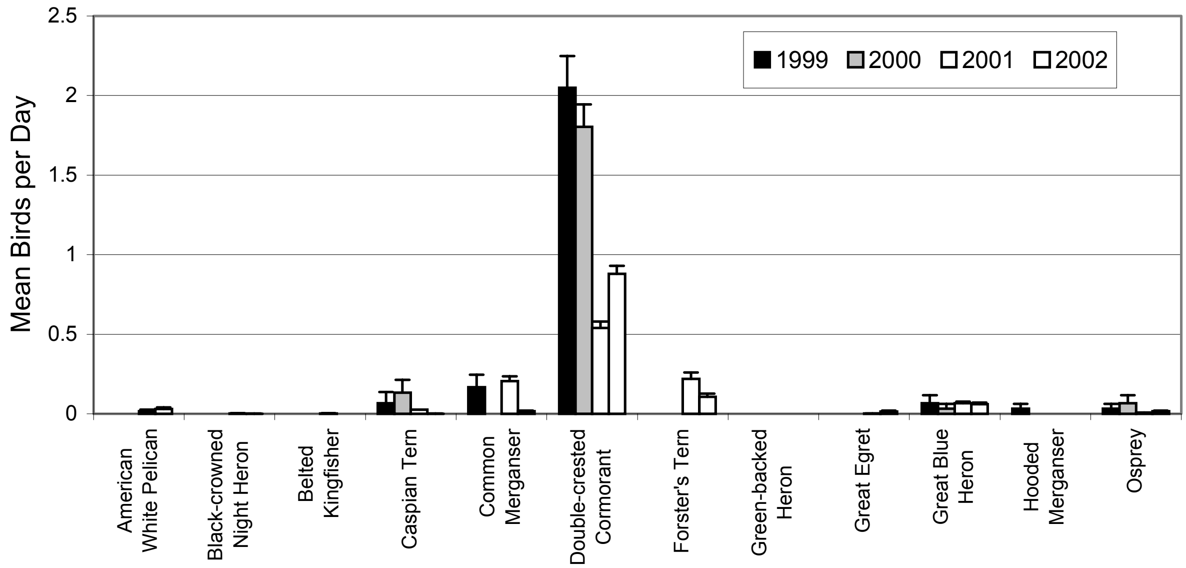

Figure 1. Mean (± SE) daily abundance of piscivorous birds excluding gulls at Horn Rapids, 1999-2002.

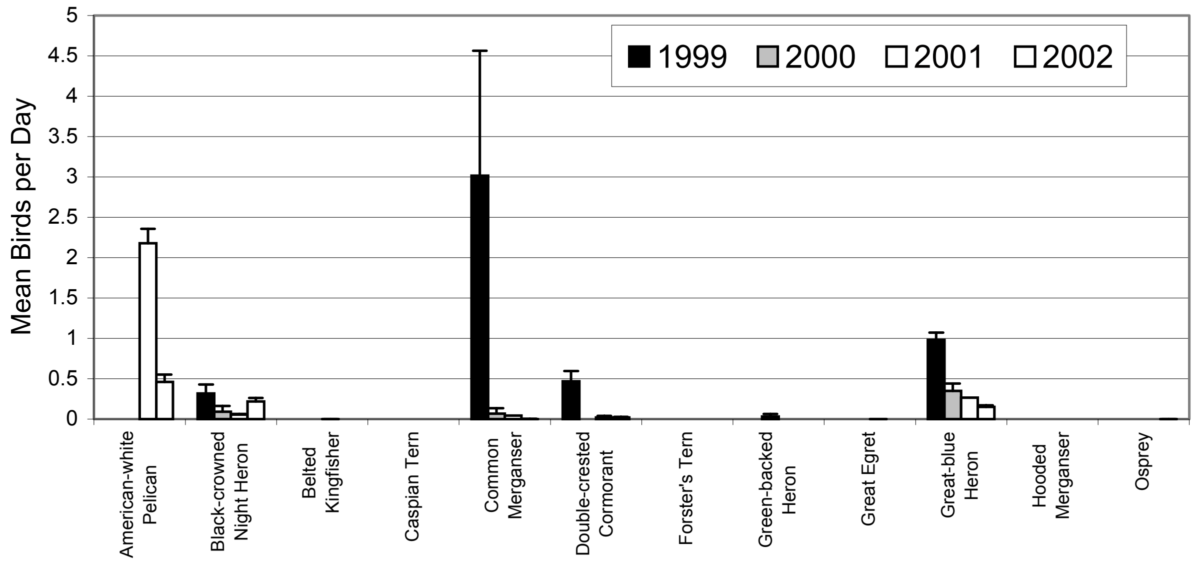

Figure 2. Mean (± SE) daily abundance of piscivorous birds at Chandler, 1999-2002.

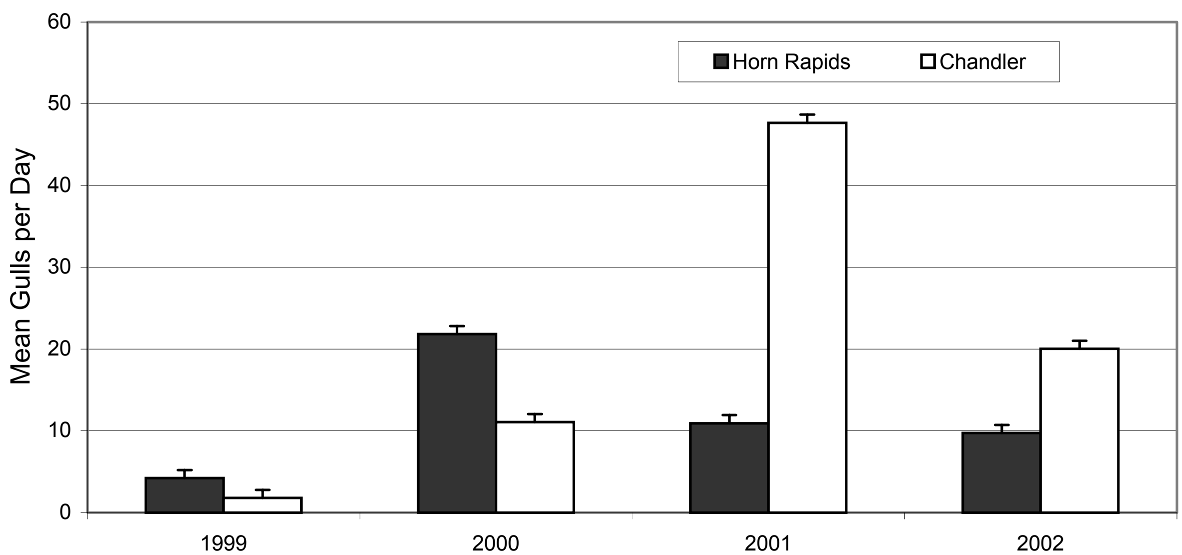

Figure 3. Mean (± SE) daily abundance of gulls at Chandler and Horn Rapids, 1999-2002

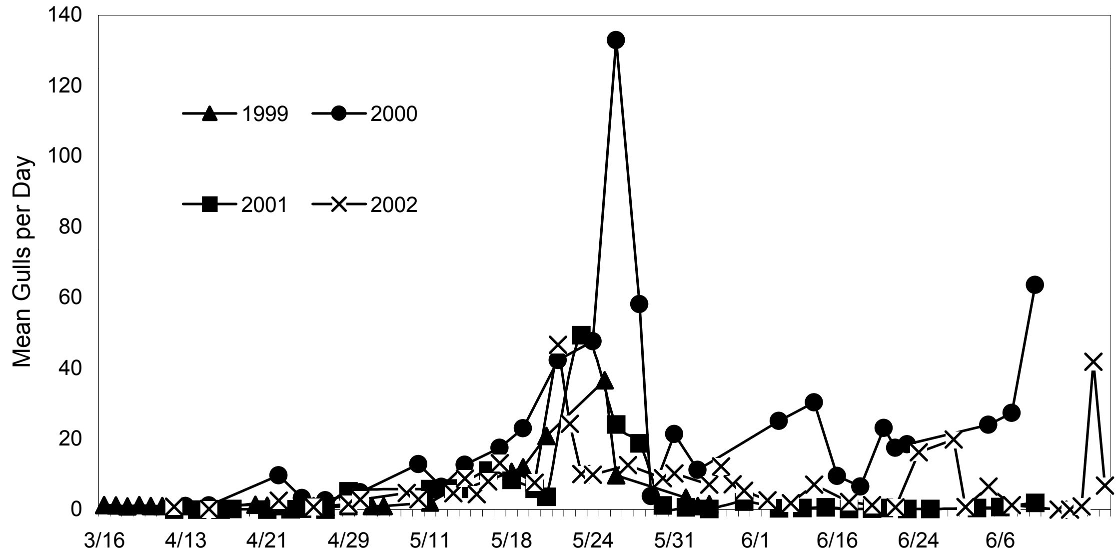

Figure 4 . Mean daily gull abundances for all survey days at Horn Rapids, 1999-2002.

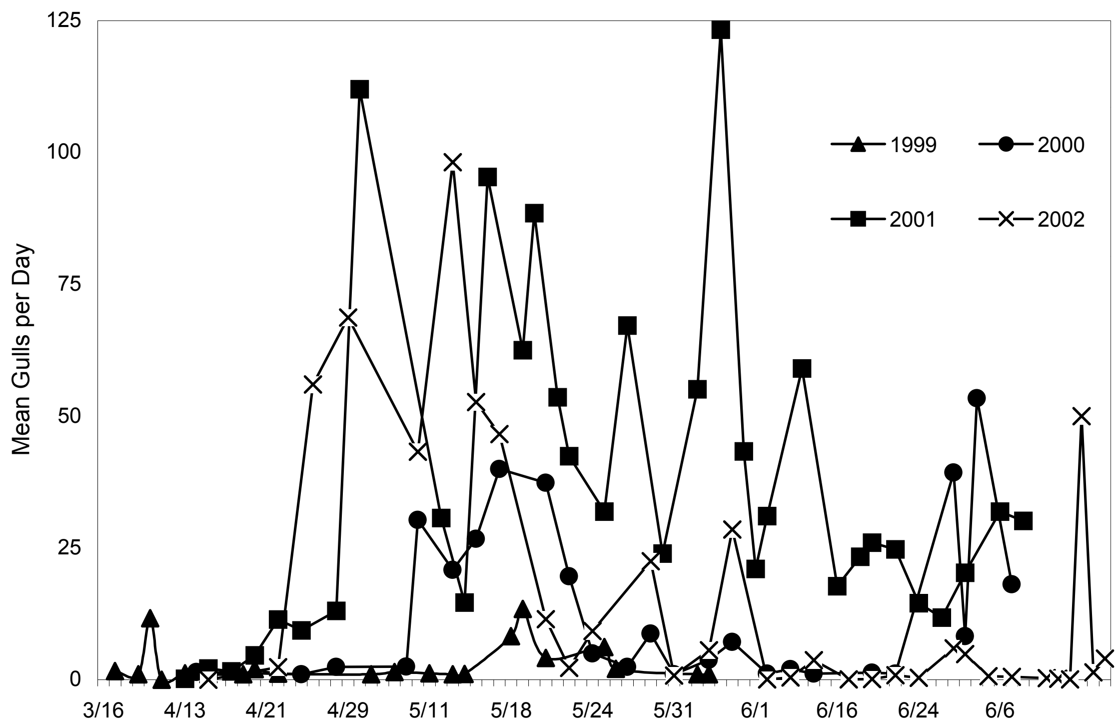

Figure 5. Mean daily abundance of gulls on all survey days at Chandler, 1999-2002.

Numbers of foraging gulls (defined as those gulls in flight and searching for food within the study areas) were nearly identical to total gull numbers at Horn Rapids and Chandler except for 2001. During this year at Chandler, foraging gull numbers were often less than total abundance during low flow conditions that provided birds with numerous in-river locations to loaf between foraging efforts.

Diurnal patterns of gull abundance also varied between years and sites. In 1999 and 2000, gull abundance peaked in the 5th or 6th hour after sunrise at both sites, though the patterns leading to the peak and after the peak varied. In 2001 and 2002, abundance at Chandler and Horn Rapids peaked in the 10th and 12th, and 4th and 10th hours after sunrise, respectively. In both of these years at Horn Rapids, gull numbers increased to the peak and then declined, whereas at Chandler, the pattern was less inconsistent leading to the peak and after the peak.

Fish Take by Gulls

Consumption by gulls across the 4 yrs (Table 1) was directly related to gull abundance and therefore reflects many of the patterns previously discussed. If all fish consumed by gulls were out-migrating juvenile salmonids, then 0.1, 5.9, 7.3 and 10.3 % of all salmonids passing through, or being released from the Chandler Juvenile Fish Monitoring Facility were consumed at both hotspots combined from 1999-2002, respectively. Take includes spring and fall chinook, coho and steelhead stocks. While it is not known if one or more of these stocks is disproportionately vulnerable to predation by gulls, the input of hatchery-reared fall chinook (> 1 million fish per year) up-river was likely associated with the peak in gull abundance at Horn Rapids (Figs. 6-9).

Table 1. Number of fish captured by gulls at Horn Rapids and Chandler, 1999-2002.

	Chandler Pipe				Horn Rapids Dam Dam			
	1999	2000	2001	2002	1999	2000	2001	2002
Estimate (±SE)	2,157 (±1,164)	30,340 (±6,950)	211,914 (±49,206)	195,279 (±67,509)	19,406 (±8,448)	133,135 (±33,271)	36,258 (±9,224)	84,202 (±17,355)

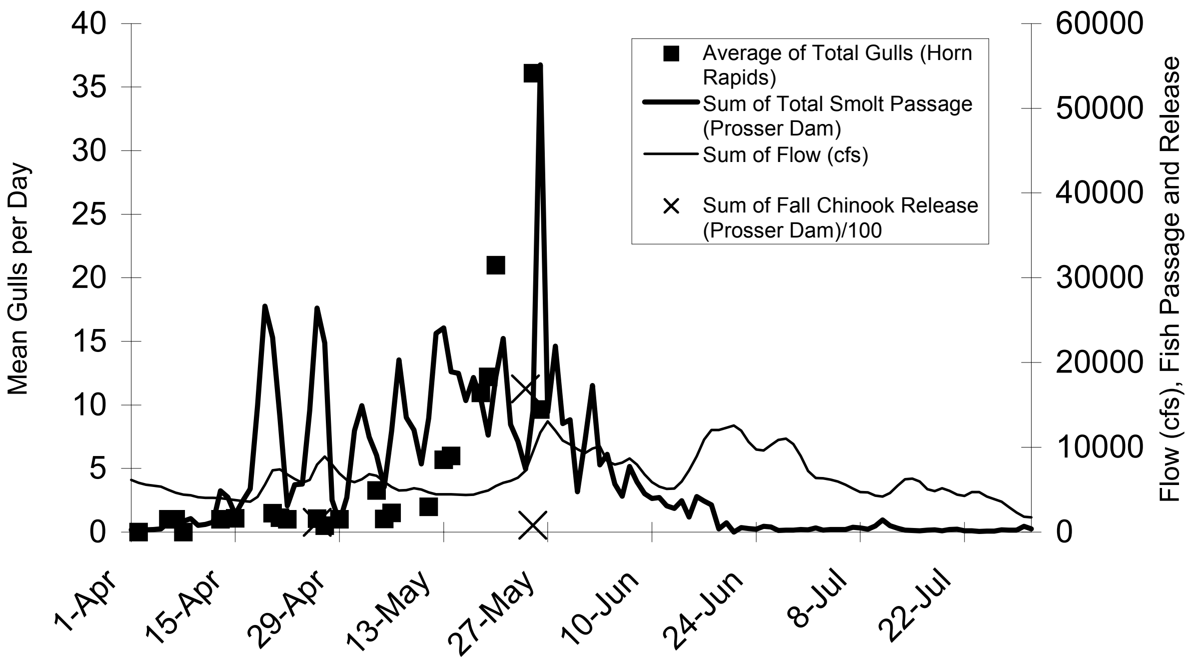

Figure 6. Temporal relationships of fish passage, gull abundance, river flow and inputs of hatchery reared fall chinook in 1999. Gull abundance is for Horn Rapids Dam. Fish passage and fall chinook inputs calculated approximately 25 km upstream from Horn Rapids. Flow measured at Kiona gauging station.

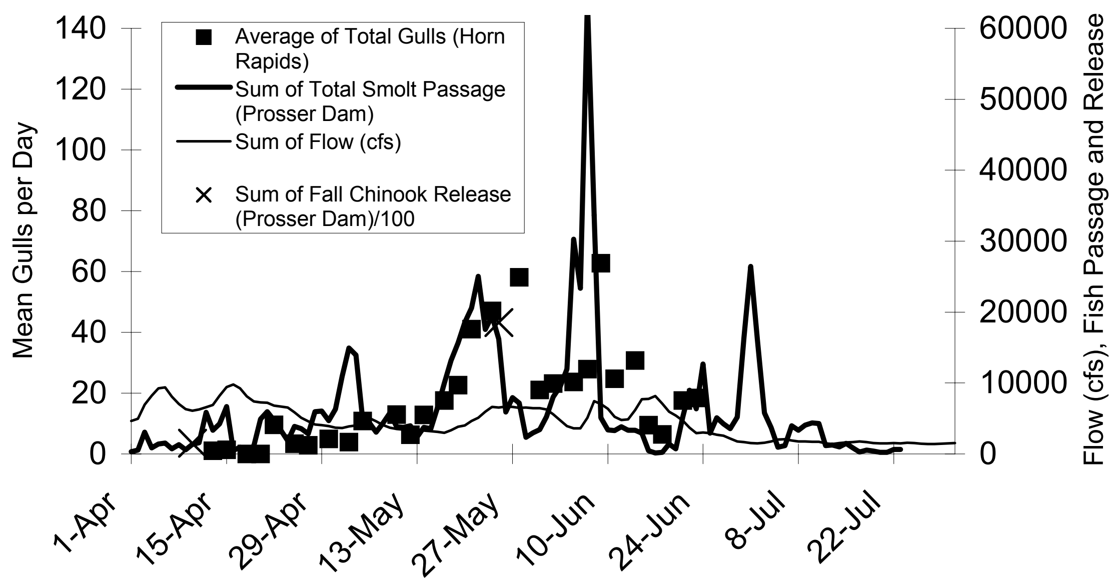

Figure 7. Temporal relationships of fish passage, gull abundance, river flow and inputs of hatchery reared fall chinook in 2000. Gull abundance is for Horn Rapids. Fish passage and fall chinook inputs calculated approximately 25 km upstream from Horn Rapids. Flow measured at Kiona gauging station

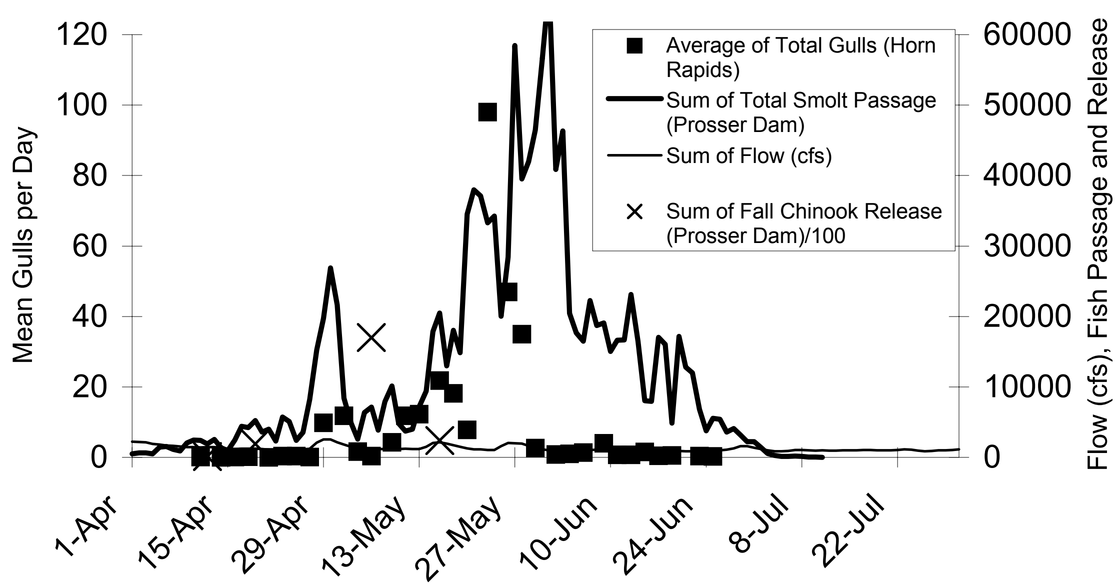

Figure 8. Temporal relationships of fish passage, gull abundance, river flow and inputs of hatchery reared fall chinook in 2001. Gull abundance is for Horn Rapids. Fish passage and fall chinook inputs calculated approximately 25 km upstream from Horn Rapids. Flow measured at Kiona gauging station

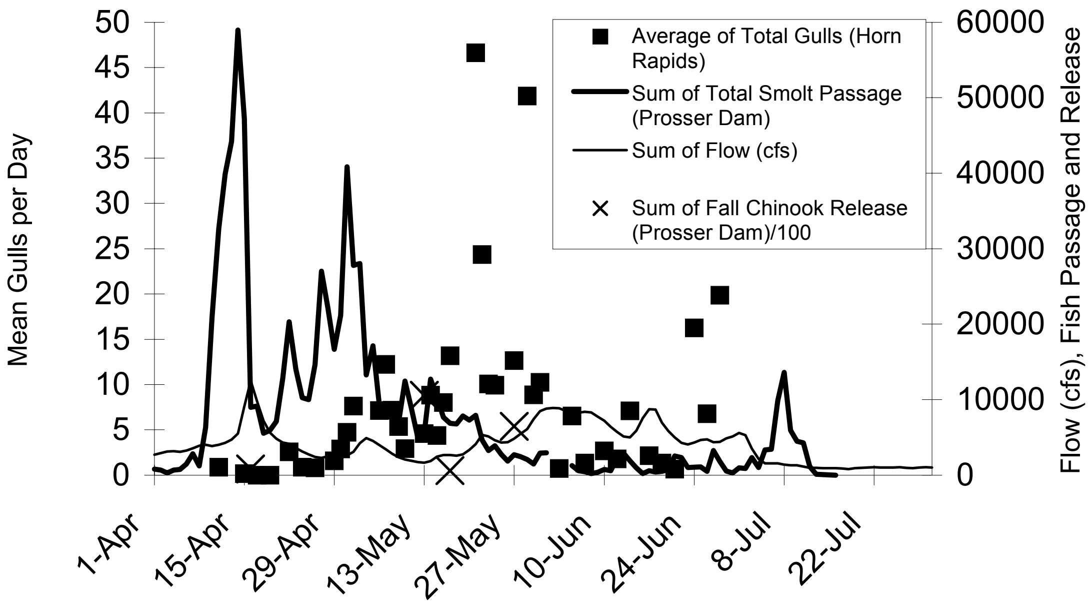

Figure 9. Temporal relationships of fish passage, gull abundance, river flow and inputs of hatchery reared fall chinook in 2002. Gull abundance is for Horn Rapids Dam Dam. Fish passage and fall chinook inputs calculated approximately 25 km upstream from Horn Rapids Dam Dam. Flow measured at Kiona gauging station

Relationship of Abundance of Foraging Gulls and Fish Take with River Flow

The numbers of foraging gulls for the period 1999-2002 were regressed against flow and year (Table 2). Results are supported by the scatter plot shown in Figure 10. In this analysis there was no significant interaction (P=0.244), meaning that the relationship between flow and foraging abundance was similar among years. Further, there was no significant relationship between flow and the number of foraging gulls when year is taken into account (P=0.154). However, when no adjustment is made for year, foraging abundance is associated with flow. This relationship is most likely attributable to the conditions observed in 2001; differences in foraging gull abundance between 2001 and the other years account for most of the variability in the data. Any association between flow and foraging is most likely an artifact of these between year differences as indicated by the significant year effect ($P < 0.001$).

Table 2. ANCOVA for testing the relationship between foraging gull abundance at Horn Rapids and river flow conditions for the 4 yrs, 1999-2002.

Effect	Df	Sum of squares	Mean Squares	F-value	Pr(F)
Year	3	225891561	75297187	13.306	<0.001
Flow	1	11633400	11633400	2.056	0.154
Interaction	3	23863167	7954389	1.406	0.244
Residuals	122	690360591	5658693		

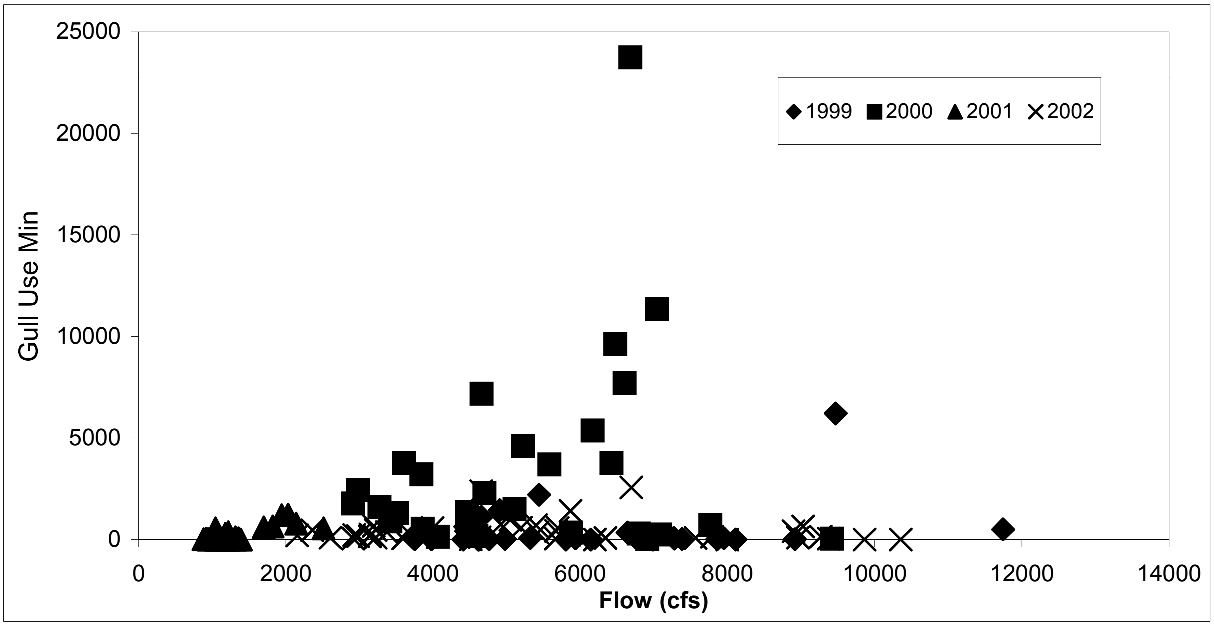

Figure 10. Scatter plot showing the relationship between foraging gull abundance at Horn Rapids and river flow conditions during the four year study, 1999-2002.

Testing for a relationship between fish take by gulls at Horn Rapids and river flow conditions was separated into years with similar survey methodologies (1999-2000 and 2001-2002). The results of these analyses indicate that there was no association between flow and fish consumption for either 1999-2000 or 2001-2002 (Tables 3 and 4). This is supported by the associated scatter plots (Figs. 11 and 12).

Table 3. ANCOVA for testing the relationship between fish take by gulls at Horn Rapids and river flow conditions for the 4 yrs, 1999-2002.

Effect	Df	Sum of squares	Mean Squares	F-value	Pr(F)
Year	1	33118431	33118431	7.626	0.008
Flow	1	9571278	9571278	2.204	0.143
Interaction	1	5519684	5519684	1.271	0.265
Residuals	54	234522224	4343004		

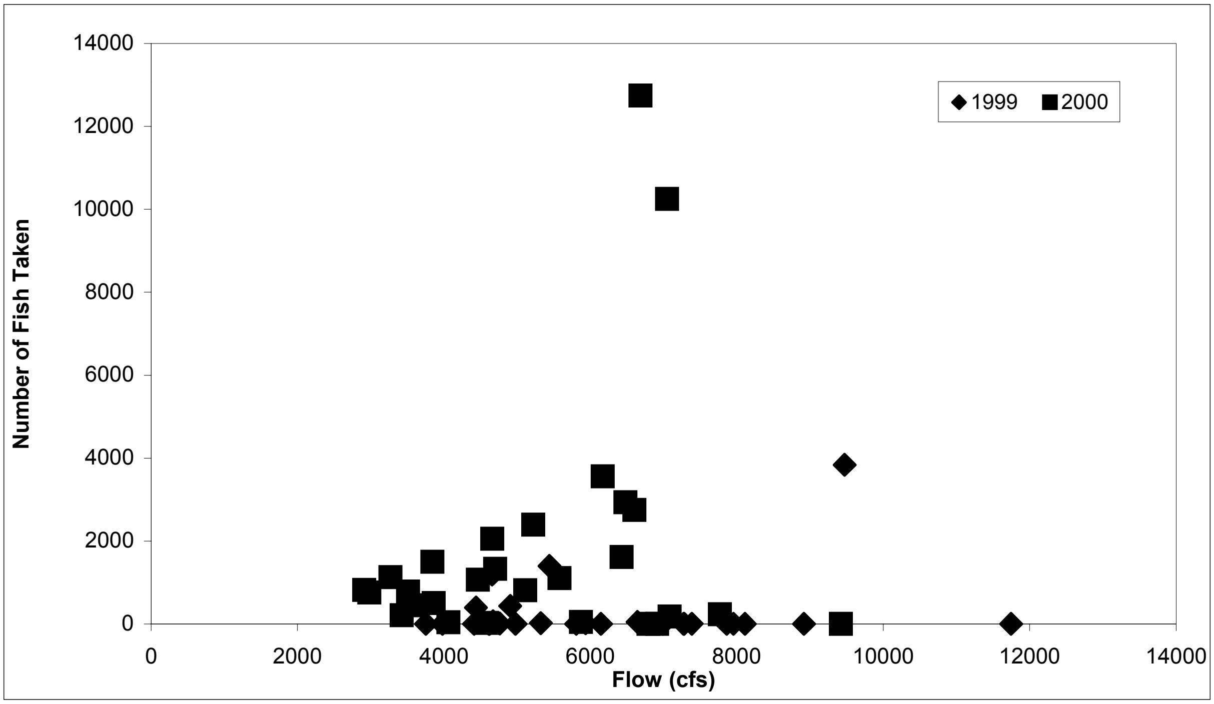

Figure 11. Scatter plot of the relationship between fish take by gulls at Horn Rapids and river flow conditions for 1999 and 2000.

Table 4. ANCOVA for testing the relationship between foraging gull abundance at Horn Rapids and river flow conditions in 2001-2002.

Effect	Df	Sum of squares	Mean Squares	F-value	Pr(F)
Year	1	6174203	6174203	3.048	0.085
Flow	1	2003944	2003944	0.989	0.323
Interaction	1	11510622	11510622	5.682	0.020
Residuals	69	139774662	2025720		

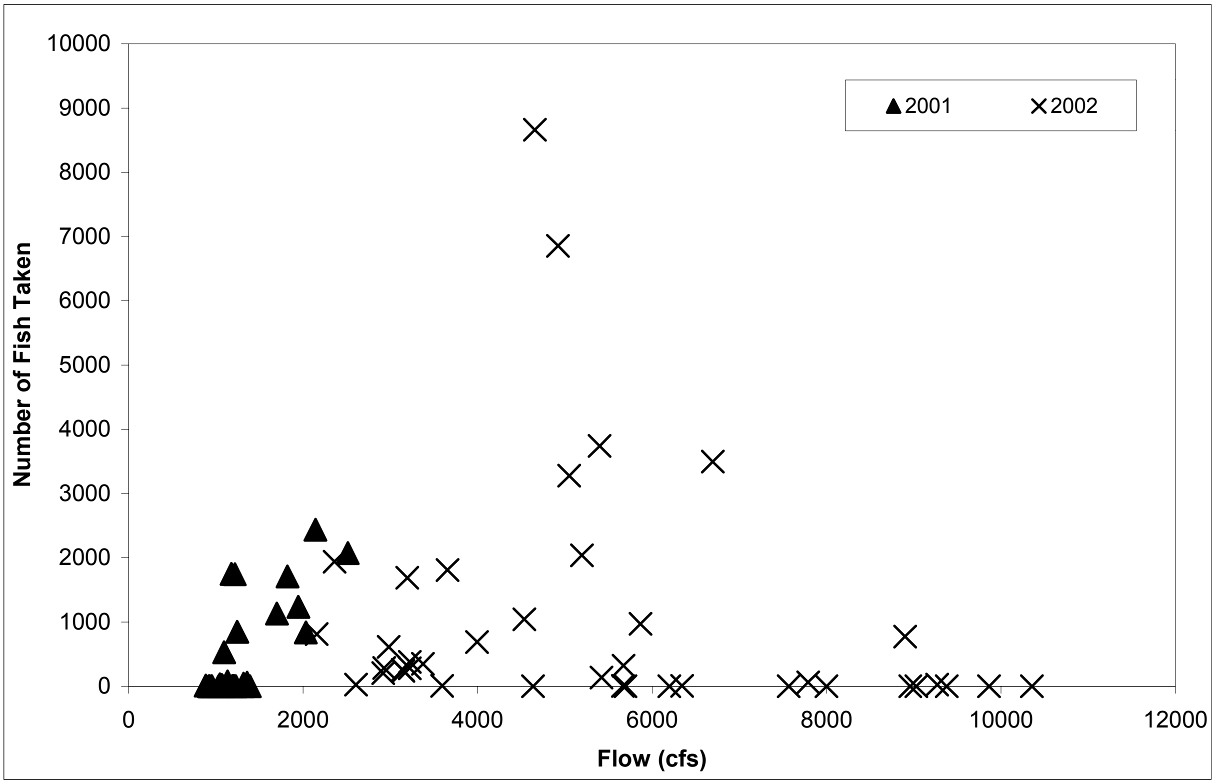

Figure 12. Scatter plot of the relationship between fish take by gulls at Horn Rapids and river flow conditions for 2001 and 2002.

DISCUSSION

We determined the abundance of avian piscivores and estimated fish take by the most abundant species (California and ring-billed gulls) at two artificial structures within the Yakima River. We consider the results of investigations at the outfall pipe from the juvenile fish monitoring facility (Chandler) less applicable to other systems because of its unique features and because releases from this facility were heavily managed (and therefore less indicative of actual fish movements down river). Therefore, we concentrated our efforts towards understanding the relationships between bird numbers, fish take and river flows at Horn Rapids Dam. However, patterns of piscivorous bird use did emerge by comparing the two structures within and across years. Early data collection efforts (Phinney et al. 1998) indicated that gulls were the primary avian piscivores at both of these structures and this continued during the four subsequent years of our study. At no time did the abundance of another avian piscivore exceed that of gulls. Whether this is indicative of the latter's greater ability to exploit these two sites more efficiently than other species or simply reflects their greater numbers in the area is unclear. Most other bird species observed at these structures breed locally (Thompson and Tabor 1981). Many are colonial nesters sharing the same advantages provided by their nesting strategy. The exception was the occasional occurrence of common mergansers at these sites. Common mergansers are known to breed in the upper reaches of the river and likely use these sites only during migration up-river in the spring. Based on surveys of the lower river outside the hotspots, only gulls seemed to occur at the hotspots disproportionate to their abundance in proximate stretches of the river (Major et al. 2003). This would suggest they exploit some advantage at these sites that other piscivorous birds cannot.

We did not find a statistical association between river flow and gull abundance or fish take at Horn Rapids when year was taken into account. However, comparison of gull numbers and fish take to river flow between the two sites show a general tendency for Chandler to attract more gulls during low and moderate flow years than Horn Rapids. This is true across all 4 yrs, including the 1999-survey season, which started and ended approximately 1 month earlier than the other three seasons. Estimates of fish take within years of similar sampling methodology also support this relationship with flow. Salmonids emerging from the pipe at Chandler during low to moderate flows are much more vulnerable to avian predation because the depth of the pipe opening relative to the water surface is less. During low flows, fish are expelled at or above the surface of the surrounding river and are easy prey to waiting birds circling above. The opposite occurs during high flows. At Horn Rapids, low flow conditions likely created less turbulence beneath the dam and subsequently less stress and disorientation to fish passing over the dam and into the backwash below where most of the gull foraging occurs. Phinney et al. (1998) reported a predation threshold at Horn Rapids based on river flow rates greater than 8,000 cfs. Their study hypothesized that at the threshold, there was "a breakdown in the recirculating motion of the water at the base of the dam", making conditions more favorable to safe fish passage. Our data from Horn Rapids supports this threshold hypothesis. Because of the greater vulnerability of fish to predation at Chandler during low and moderate flows, numbers of gulls at the outflow consistently exceed those at Horn Rapids. Excluding 1999 (early survey season), the highest mean gull abundances for a year (2001) at Chandler was more than twice that calculated for the highest year at Horn Rapids (2000).

At Horn Rapids, the seasonal peak of gull abundance was temporally consistent across all 4 yrs, occurring during the last 2 wks in May. In addition, the peak was very distinct in magnitude, rising sharply above prior and subsequent gull abundances. Neither of these phenomena occurred at Chandler. At Chandler, gull numbers were more consistent across the season, although variable among years. Reasons for these different seasonal abundance patterns are not known. Plots of gull abundance at Horn Rapids against fish passage (as measured ca. 25 km up-river) and the dates of large releases of fall chinook above the dam suggest peak gull abundance is associated with increased numbers of fall chinook, but not passage of other salmonids. In all 4 yrs of our study, peak gull numbers occurred within 8 to 10 days of the release of > 1 million fall chinook. In comparison, the period of greatest overall fish passage tended to occur after peak gull abundance (2000 and 2001) or well before (ca. 3-4 wks) peak gull abundance (2002). Only in 1999, could we detect a consistent pattern of increasing gull numbers with increasing passage of juvenile salmonids. The lack of accurate measurements of fish passage more proximate to Horn Rapids and fish travel times, make the understanding of these associations qualitative at best. Gull breeding phenology could also be a significant factor in governing peak gull abundance or seasonal use of the hotspots. Thompson and Tabor (1981) found that California and ring-billed gulls nesting along the upper Columbia River were feeding young beginning in the second to third week of May, the same time as our peak gull numbers. It is possible that the feeding of young requires adult gulls to shift to a more nutritious food source such as fish or at least makes expenditure of energy associated with the travel and capture of smolts profitable versus other sources of food.

Our limited surveys of secondary structures similar to Horn Rapids would also suggest that the releases of hatchery fall chinook and possible production from wild fish was responsible for gull numbers at Horn Rapids. At these other sites, which are well within the foraging distances for gulls associated with nearby colonies, we did not observe any piscivorous birds—including gulls. It is likely that all of these structures provide similar difficulties for out-migrating smolts and thus a similar foraging opportunity for birds. The discernible difference being that none of them have a hatchery release upstream of the same magnitude as the fall chinook release above Horn Rapids. Most of the wild production of fall chinook in the Yakima River also occurs above Horn Rapids. The run timing of wild chinook may coincide with that of hatchery fish, potentially increasing the numbers migrating over the dam.

Our study examined the relationships between the abundance of piscivorous birds (primarily gulls), out-migrating salmonid smolts, and river flow conditions at two artificial structures within the Yakima River. We found no statistical association between river flow and gull abundance or consumption of fish at Horn Rapids when year was considered. However, across year comparisons do reveal patterns that should help guide managers in mitigating losses of smolts to fish-eating birds at the two sites. Greater than 60% of all consumption over the 4 yrs occurred at Chandler with approximately 93 percent of that occurring in years with low to moderate flows. At Horn Rapids, where slightly less than 40% of the total consumption occurred, approximately 80 percent of the fish were taken in years with high or moderate flows. At Horn Rapids, there is also the possible response by gulls to large inputs of hatchery fall chinook.

Given moderate to high flow conditions, managers may want to stagger releases of fall chinook to reduce foraging opportunity for gulls downstream at Horn Rapids. During low flow conditions, managers may want to adjust release times of large numbers of smolts entrained for sampling purposes. These releases could be shifted to non-daylight hours. Alterations to the orientation of the outflow pipe itself or physical deterrents (e.g., sprinklers or overhead wires) may also be effective in reducing the vulnerability of smolts irrespective of flow conditions.

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