Development of an Index to Bird Predation of Juvenile Salmonids within the Yakima River

Annual Report 2002

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ABSTRACT

The avian predation of fish is known to contribute to the loss of out-migrating juvenile salmonids in the Yakima River Basin, potentially constraining natural and artificial production. In 1997 and 1998, the Yakima Klickitat Fisheries Project (YKFP), whose goal is to increase the natural production of salmonids within the Yakima River, initiated investigations to assess the feasibility of developing an index to avian predation of juvenile salmon within the river. This research confirmed that Ring-billed Gulls and Common Mergansers were the primary avian predators of juvenile salmon on the Yakima River (Phinney et al. 1998), and that under certain conditions could significantly impact migrating smolt populations.

Beginning in 1999, the Washington Cooperative Fish and Wildlife Research Unit (WACFWRU) was asked by the YKFP to continue development of avian consumption indices. Monitoring methods developed by Phinney et al. (1998) were adopted with modifications and the monitoring of impacts to juvenile salmon along river reaches and at areas of high predator/prey concentrations, referred to here as "hotspots", has continued each year through 2002. Beginning in 2002, the YKFP Yakama Nation (YN) personnel joined the monitoring of avian predation, working cooperatively with the WACFWRU.

In 2001, WACRWRU developed two predation models, one to measure the number of fish consumed at hotspots, utilizing the modified survey methods begun that year, and one for the river reaches, to determine the number of kilograms of fish consumed throughout the Yakima River. The different survey methods between the hotspots and the river reaches account for the different units of the results. Revisions to the river reach model have continued since this time, to better incorporate the different fish populations thoughout the river.

In 2002, as in previous years, piscivorous birds were counted from river banks at hotspots and from a raft or drift boat along river reaches. Consumption by gulls at hotspots was based on direct observations of foraging success and modeled abundance while consumption by all other piscivorous birds was estimated using published dietary requirements and modeled abundance. Seasonal patterns of avian piscivore abundance were identified, diurnal patterns of gull abundance at hotspots were identified, and predation indices were calculated for hotspots and river reaches, for both the spring and summer. General survey methods used in 2002 were the same as those used in 2001. Changes to the survey schedule in 2002 included the addition of surveys on the Easton reach during the early spring, and in the Canyon during the summer. Methods for measuring gull feeding rates at hotspots were the same as those used in 2001.

The primary avian predators in 2002 were California and Ring-billed gulls at hotspots and Common Mergansers within the upper river reaches. Consumption on the lower reaches was distributed among a number of bird species. As in 2001, slightly more then half of all fish consumption in the lower reaches can be attributed to American White Pelicans. Estimated consumption by gulls at both hotspots combined, between April 11 to June 30, was 279,482 fish. Assuming a worst case scenario, that all fish taken were smolts, this represented approximately 10% of all smolts estimated passing or being released from the Prosser Dam area during the 2002 smolt migration season. Total gull abundances and estimates of consumption at the two hotspot sites showed an increase from that seen in 2001.

Total estimated take by Common Mergansers across all strata surveyed was 11,938 kg between April 8 and August 31, a decrease of 2,839 kg from 2001. Approximately 64 percent of that consumption was within the upper river reaches, where there is a known breeding population of mergansers.

INTRODUCTION

Note: For the purposes of this document the phrase "juvenile salmonids" refers to juveniles of the following stocks: spring chinook, (*Oncorhynchus tshawytscha*), fall chinook (*Oncorhynchus tshawytscha*), coho (*Oncorhynchus kisutch*), and summer steelhead (*Oncorhynchus mykiss*). Although the mountain whitefish (*Prosopium williamsoni*) is in the family *salmonidae*, it is not included in this study.

Avian Predation of Juvenile Salmon

Avian predation is suspected to be a significant constraint to salmonid production and has been shown to impact the survival of juvenile salmonids within river habitats and fish culture facilities (White 1936, 1939; Mills 1967; Sealy 1973; Alexander 1979; Packhurst et al. 1987; Wood 1987a,b; Pitt et al. 1998; Derby and Lovvorn 1997). The magnitude of impact to migrating smolts by avian predators is highly variable within and across river systems. Estimations of avian consumption of juvenile salmonids within specific river systems and specific years range between 1-66% of particular runs or releases (Alexander 1979; Mace 1983; Ruggerone 1986; Wood 1987b; Kennedy and Greer 1988; Roby et al. 1998; Phinney et al. 1998). As shown repeatedly by investigations throughout North America and Europe, avian predators can consume large number of juvenile salmonids when appropriate conditions for bird/fish interactions occur (Elson 1962; Feltham 1995a; Modde and Wasowicz 1996).

Bird predation of juvenile salmonids is particularly common throughout the Columbia River Basin (CRB) which supports some of the largest populations of piscivorous birds throughout North America and Europe (Ruggerone 1986; Roby et al. 1998). Most piscivorous birds within the CRB are colonial nesting birds, including Ring-billed, Mew, California and Glaucous-winged Gulls, Caspian Terns, Double-crested Cormorants, and Great Blue Herons, which are particularly suited to the exploitation of fluctuating prey fish densities (Alcock 1968; Ward and Zahavi 1996). Such prey fish density fluctuations can result from, but are not limited to, large migratory accumulations, hatchery releases, physical obstructions that concentrate or disorient, and other natural features and events which occur in complex river systems.

The advantage held by colonial birds under such conditions is hypothesized to result from unsuccessful foragers within a colony receiving cues from successful foragers as to prey type and location (Forbes 1986; Greene 1987). Such cues can lead to a rapid response by large numbers of avian predators to available concentrations of prey fishes. These behaviors, in combination with large nesting populations, can lead to high levels of consumption of migrating salmon smolts by avian predators. For example, in 1997, consumption of juvenile salmonids by a single species of avian piscivore, the Caspian Tern, from a single nesting colony within the Columbia River estuary, Rice Island, was estimated to be 6-25% of the 100 million out-migrating smolts that reached the estuary (Roby et al. 1998).

Salmon Supplementation in the Yakima and Klickitat Rivers

The Yakima/Klickitat Fisheries Project (YKFP) seeks 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 keeping adverse ecological interactions within acceptable limits" (Sampson and Fast 2000). This goal will be accomplished by a combination of salmon supplementation, hatchery rearing adjustments and habitat improvements targeting four principal species of salmonids: spring chinook, fall chinook, coho, and summer steelhead. At this time, stock specific supplementation programs are at different operational levels.

Intensive monitoring has been implemented in conjunction with the YKFP salmon supplementation efforts. This monitoring seeks to identify impacts of salmon supplementation on natural production, impacts on harvest, on genetic interactions between natural and supplemented stocks, and on ecological interactions among target and non-target species. Impacts of salmon supplementation on non-target species are being assessed by comparisons of non-target species population parameters (abundance, size-structure and distribution) and interaction indices before and after supplementation. Impacts of predators upon supplemented and naturally spawning salmonid stocks will be assessed by indices of predation.

It is anticipated that interactions between supplemented salmonid stocks and key fish-eating species may impact the ultimate success of the YKFP supplementation efforts (Busack et al. 1997; Pearsons 1998). Understanding such interactions has been identified as a high priority by the YKFP Monitoring Implementation Planning Team, leading to the research detailed within this document, the development of an index to bird predation of juvenile salmonids within the Yakima River.

Initial Assessment of Consumption of Juvenile Salmon by Avian Piscivores—1997-1998

In 1997, Dr. Steve Mathews and Dave Phinney of the University of Washington and the Washington State Department of Fish and Wildlife (WDFW),(Phinney et al. 1998), in collaboration with the YKFP, began investigations to assess the potential of avian piscivores to impact juvenile spring chinook populations within the Yakima River. This effort was focused upon broad scale assessments of piscivorous bird abundance within rearing areas preferred by juvenile chinook, as well as abundance and feeding behavior of piscivorous birds at localized areas of intense predation referred to as “hotspots”. In 1997 and 1998, Mathews and Phinney developed field methods, surveyed river reaches and hotspots, estimated piscivorous bird abundance along river reaches and hotspots, estimated piscivorous bird consumption of juvenile salmonids at the most significant hotspots, and investigated the relationship between water flow and avian predation at hotspots.

Mathews and Phinney found that gulls were the most abundant avian predator at the hotspots and that Horn Rapids Dam and the Chandler Canal Bypass Pipe were the hotspots with the most intense avian predation (Phinney et al. 1998). Common Mergansers were found to be the most abundant avian predator along river reaches and the Zillah reach contained the greatest number of avian predators. In 1998, gull abundance at hotspots was negatively correlated (-0.426, P<0.001 at Chandler and -0.385, P = 0.001 at Horn Rapids) with river discharge (Phinney et al. 1998).

Phinney et al. (1998) estimated total consumption of salmonids by birds congregating at Horn Rapids Dam and the Chandler Canal bypass to be 1.7% and 1.1%, respectively, of total salmon/trout passage. Based upon the assumption that all fish consumed by avian piscivores were salmon and that salmon were consumed in proportion to the relative number passing, 0.52% of all spring chinook passing Horn Rapids Dam and 0.20% of all spring chinook passing Chandler Canal bypass were consumed (Phinney et al. 1998). The authors also suggested that the relatively high flows in spring of 1998 were responsible for holding avian consumption of salmon and trout at hotspots to low levels. They suggested that unusually low water levels during spring smolt migrations may facilitate a much higher level of avian predation of migrating salmon and trout. During 1999, spring flows were again higher than average and combined take by avian predators at the hotspots was 2.7% of all salmonids passing over Prosser Dam (Grassley and Grue 1999), assuming all species taken were salmonids, very similar to the percentage taken the year before (Phinney et al. 1998).

Determination of species composition of fishes consumed by avian piscivores has proven problematic. Consumption estimates have relied principally upon observations of predation by gulls at hotspots, and daily energy requirements of avian piscivores enumerated on river reaches. Phinney et al. 1998 attempted a direct assessment of consumption for a single species of avian piscivores along river reaches, the Common Merganser, resulting in the collection of the contents of 20 bird stomachs. Prey species composition and percent of stomachs containing identified prey items only, percent by species, were obtained, but no length/mass estimates of prey items identified were reported.

Consumption of Juvenile Salmon by Avian Piscivores—1999

Beginning in 1999, the YKFP asked the Washington Cooperative Fish and Wildlife Research Unit (WACFWRU) to continue research efforts begun by Mathews and Phinney toward the development of an index to bird predation of juvenile salmonids. Monitoring methods developed by Mathews and Phinney for river reaches and hotspots were largely adopted, with the frequency of surveys increased and some methodological alterations implemented (Grassley and Grue 2001).

The abundance and consumption surveys of avian predation at the two principal hotspots, Horn Rapids Dam and Chandler Canal bypass, and the abundance surveys along five river reaches (Easton, Cle Elum, Zillah, Benton, Vangie), were continued. New efforts implemented in 1999 included the monitoring of hatchery acclimation sites by Yakama Nation (YN) personnel at the Easton and Clark Flats facilities, monitoring of the North Fork Teanaway River associated with the Jack Creek acclimation facility, and the addition of aerial surveys along low and middle river reaches.

Hotspot Surveys—Spring

Hotspot surveys were conducted from March 15 to May 30 to assess the impact of localized areas of intense avian predation on the migrating spring chinook smolt population and other spring migrant juvenile salmon/trout. The abundance of avian piscivores was determined and behavioral based consumption of fish was estimated. These estimates were expanded across larger time frames in order to estimate seasonal impacts to migrating salmon smolts.

Hotspots were defined as any sustained and localized area of intense avian predation of fish. Hotspots can be caused by natural circumstances such as a pool of fish during extreme low water events, a byproduct of hatchery operations such as open fish holding ponds, or the result of fish interacting with physical objects within the river channel such as dams, irrigation and fish bypass structures. Although the hotspot surveys were designed to address the impact of smolt concentration and disorientation caused by dams and fish bypass structures, the definition was intentionally generalized to encompass any natural circumstance that may produce the same outcome. It was intended that this survey would be applicable to any hotspot which may emerge, especially as the physical parameters of the river change over time such as increases or decreases in flows, or new construction.

Within the Yakima River in normal flow years hotspots are most commonly the result of interactions between water flow and man-made structures which lead to local areas of intensely disrupted water. The movement through such areas by fish, such as migrating juvenile chinook, can lead to a temporary suspension of normal predatory avoidance behaviors due to disorientation, injury or shock. Under such circumstances, predation by avian predators may be highly efficient and intense.

River Reach Surveys—Spring and Summer

Spring river reach surveys were conducted from March 15 to May 30 on the Benton, Vangie, Zillah and Cle Elum reaches and focused on avian impacts to migrating spring chinook. Summer river reach surveys were conducted from June 1 to August 30 and consisted of the Cle Elum and Easton reaches, which are in the upper Yakima River. These surveys focused on impacts to coho and spring chinook parr and/or residualized coho and spring chinook. Selection of river reaches was based on a combination of factors including historical precedence (reaches utilized by Phinney et al. 1998), the degree of representation of typical habitats within the Yakima River, and the logistical constraints imposed by intermittent river access points and impassable obstructions such as dams and log-jams. River reach surveys were designed to estimate bird abundance and not directly measure consumption. Objectives related to estimating consumption by avian piscivores along river reaches were accomplished through a combination of bird abundance estimates and published daily caloric requirements for individual species.

Acclimation Site Survey—Spring

YKFP supplementation efforts utilize acclimation facilities to hold and imprint salmon smolts to different waters within the Yakima River system. Acclimation sites incorporate traditional and semi-natural raceways, artificial outer channels, and volitional release regimes to facilitate introduction of salmon smolts into waters targeted for natural production by returning adults. Acclimation site surveys were initiated in 1999 to assess the potential for avian piscivores to be attracted to acclimation sites. These surveys were designed by the WACFWRU and implemented in 1999 by YN hatchery personnel.

Aerial Surveys—Spring and Summer

Aerial bird surveys of the middle and lower Yakima River have been conducted regularly by the YN to provide broad scale census data for target species. Beginning in 1999, these surveys included all piscivorous bird species that could be dependably identified. These surveys provided abundance data and confirmation that hotspots chosen for intensive monitoring were the most active sites. Aerial surveys are a potential alternative to river drift surveys.

North Fork Teanaway River Surveys—Spring and Summer

The Teanaway River is a major tributary to the upper Yakima River, entering the river at kilometer 284. Approximately 26 kilometers up the Teanaway, along the North Fork Teanaway River, the Jack Creek acclimation facility was established in 1999 as part of the YKFP's supplementation effort with the release of 240,000 coho. Anticipating the potential for newly established acclimation facilities to attract avian piscivores, surveys were begun in 1999 to monitor any changes in piscivorous bird abundance and estimate consumption of salmonids along a reference reach of the North Fork Teanaway.

Summation

In 1999, piscivorous birds were counted from river banks at hotspots and from a raft or drift boat along river reaches. Consumption by gulls was based on direct observations of foraging success and modeled abundance. Consumption by Common Mergansers, which forage underwater, was estimated using published dietary requirements and modeled abundance. A second-order polynomial equation was used to interpolate gull and Common Merganser abundance on days when surveys were not conducted. Seasonal patterns of avian piscivore abundance were identified, diurnal patterns of gull abundance at hotspots were identified, predation indices were calculated for hotspots and summer river reaches, and the efficacy of aerial surveys for estimating bird abundance within river reaches was evaluated (Grassley and Grue 2001).

Primary avian predators were California and Ring-billed Gulls at hotspots and Common Mergansers within upper river reaches. The estimated take, presumed to be salmonids, by gulls at hotspots between April 22 and May 30 was 4,084 fish at the Chandler Bypass Outfall and 12,636 fish at Horn Rapids Dam. Combined take was 2.7% of the salmonids passing over Chandler Dam or 0.9 % of all smolts estimated passing or being released from the Chandler Dam area during the 1999 smolt migration season. Estimated take by Common Mergansers in the upper reaches of the Yakima River was 2,068 kg between 1 Jul and 30 Aug.

Consumption of Juvenile Salmon by Avian Piscivores—2000

In 2000, the YKFP asked the WCFWRU to continue its research efforts begun in 1999 (Grassley et al. 2002).

This effort was again organized into two specific time frames within which impacts of bird predation on juvenile salmon were assessed. The first time frame, April 8 to June 30, addressed impacts of avian predators on juvenile salmon during the spring migration of smolts out of the Yakima River. The second, July 1 to August 31, addressed impacts to coho and spring chinook parr and/or residualized coho and spring chinook in the upper reaches of the Yakima River.

These two time frames followed the basis of organization and methodological design set forward in the 1999 annual report (Grassley and Grue 2001) and are informally referred to within this document as “spring” and “summer”. This report and subsequent analysis is organized into these generalized time frames in an effort to focus on impacts to particular salmonid life histories considered important by fisheries researchers and management personnel. Compared to 1999, spring river surveys were begun approximately 1 month later and continued approximately three weeks longer. Hotspot surveys were also begun approximately one month later and lasted one month longer. The adjustments in survey dates was the result of trying to more effectively match survey efforts with seasonal bird abundances. The dates utilized in 2000 most likely better capture bird impacts to resident and migrating salmonid populations.

Hotspot Surveys—Spring
With the exception of the date shifts mentioned above, abundance and consumption surveys of avian predation at the two principal hotspots, Horn Rapids Dam and Chandler Canal Bypass, were continued in the same manner as 1999.

River Reach Surveys—–Spring and Summer
With the exception of the date shifts, abundance surveys along five river reaches, including Easton, Cle Elum, Zillah, Benton and Vangie, were continued in the same manner as 1999.

Acclimation Site Surveys—Spring
Acclimation site surveys were continued in 2000 in the same manner as 1999 to assess the potential for avian piscivores to be attracted to acclimation sites. These surveys were designed by the WACFWRU and implemented by the YN hatchery personnel.

Aerial Surveys—Spring
These surveys provided abundance data and confirmation that hotspots chosen for intensive monitoring were the most active sites. In 2000, aerial surveys were paired on four days with river drifts on the Benton reach in an effort to compare the two survey methods.

North Fork Teanaway River Surveys--Spring and Summer
As anticipated, spring chinook smolt production and acclimation were begun at the Jack Creek facility in 2000 with a release of smolts in spring, March 31 to June 2. Surveys were continued along the reference reach of the North Fork Teanaway below the acclimation facility in the same manner as 1999. The only modification was the shortening, in river miles, of the survey.

Summation
In 2000, piscivorous birds were counted from river banks at hotspots and from a raft or drift boat along river reaches. Consumption by gulls was based on direct observations of foraging success and modeled abundance. Consumption by Common Mergansers was estimated using published dietary requirements and modeled abundance. Seasonal patterns of avian piscivore abundance were identified, diurnal patterns of gull abundance at hotspots were identified, predation indices were calculated for hotspots and summer river reaches, and the efficacy of aerial surveys for estimating bird abundance within river reaches was evaluated (Grassley, et al. 2002).

Primary avian predators were California and Ring-billed Gulls at hotspots and Common Mergansers within upper river reaches. The estimated take, presumed to be salmonids, by gulls at hotspots between April 8 and June 30, was 30,340 fish at the Chandler Bypass Outfall and 133,135 fish at Horn Rapids Dam. Combined take was approximately 6% of the salmonids passing over or being released from the Chandler Dam area during the 2000 smolt migration season. Estimated take by Common Mergansers in Stratum 1, the uppermost river reaches, was 4,866 kg between July 1 and August 31.

Consumption of Juvenile Salmon by Avian Piscivores—2001

In 2001, the YKFP again asked the Washington Cooperative Fish and Wildlife Research Unit to continue the research efforts begun in 1999.

This effort was again organized into two specific time frames within which impacts of bird predation on juvenile salmon were assessed. The first time period, April 8 to June 30, addressed impacts of avian predators on juvenile salmon, principally spring chinook, during the spring migration of smolts out of the Yakima River. The second time period, July 1 to August 31, addressed impacts to coho and spring chinook parr and/or residualized coho and spring chinook in the upper reaches of the Yakima River. These dates allow for all future sampling efforts to be accomplished on even numbers of 2-week blocks to best fit the consumption model.

Hotspot Surveys—Spring

Hotspot survey methods were altered for the 2001 season in order to better estimate capture rates and consumption of smolts by gulls and to better deal with potential statistical bias. The new method involved acquiring time intervals between successful takes by gulls to determine consumption.

River Reach Surveys—Spring and Summer

With the exception of adding the Canyon reach to the spring survey schedule, all river reach surveys were continued in the same manner as previous years.

Acclimation Site Surveys—Spring

Acclimation site surveys were continued in 2001 in the same manner as 2000 to assess the potential for avian piscivores to be attracted to acclimation sites. These surveys were designed by the WACFWRU and implemented by YN hatchery personnel.

North Fork Teanaway River Surveys—Spring and Summer

Surveys for avian piscivores were continued in 2001 along the reference reach of the North Fork Teanaway below the acclimation facility in the same manner as previous years.

Summation

In 2001, piscivorous birds were again counted from river banks at hotspots and from a raft or drift boat along river reaches. Consumption by gulls was based on direct observations of foraging success and modeled abundance. Consumption by Common Mergansers was estimated using published dietary requirements and modeled abundance. Seasonal patterns of avian piscivore abundance were identified, diurnal patterns of gull abundance at hotspots were identified, predation indices were calculated for hotspots and summer river reaches, and the efficacy of aerial surveys for estimating bird abundance within river reaches was evaluated (Major et al. 2002).

Consumption of Juvenile Salmon by Avian Piscivores—2002

In 2002, the Washington Cooperative Fish and Wildlife Research Unit worked in cooperation with the YKFP YN personnel to continue these monitoring efforts.

This effort was again organized into two specific time frames within which impacts of bird predation on juvenile salmon were assessed. The first, April 8 to June 30, addressed impacts of avian predators on juvenile salmon, principally spring chinook, during the spring migration of smolts out of the Yakima River. The second, July 1 to August 31, addressed impacts to coho and spring chinook parr and/or residualized coho and spring chinook in the upper reaches of the Yakima River. These dates followed the basic organization and methodological design first established in 1999 and modified in 2001. Time was again broken down into two time frames "spring" and "summer".

Hotspot Surveys—Spring

The survey methods used at hotspots in 2002 were the same as those used in 2001. This method involved acquiring time intervals between successful takes by gulls to determine consumption.

River Reach Surveys—Spring and Summer

River reach surveys were conducted in the same manner as in previous years, with the addition of more drifts on the Easton reach earlier in the spring than in 2001, and the addition of the Canyon reach in the summer.

Acclimation Site Surveys—Spring

Acclimation site surveys were continued in 2002, in the same manner as in previous years, to assess the potential for avian piscivores to be attracted to acclimation sites. These surveys were again designed by the WACFWRU and implemented by YN hatchery personnel.

North Fork Teanaway River Surveys—Spring and Summer

Surveys for avian piscivores were continued in 2002 along the North Fork Teanaway downstream of the acclimation facility in the same manner as 2001, with a shortening of the distance of the reference reach.

Secondary Hotspots—Spring

In 2002 surveys were conducted at additional dam sites identified by Phinney et al. (1998) to ascertain whether or not these sites could be hotspots.

Summation

In 2002, piscivorous birds were again counted from river banks at hotspots and from a raft or drift boat along river reaches. Consumption by gulls was based on direct observations of foraging success and modeled abundance, using the survey method established in 2001. Consumption by Common Mergansers was estimated using published dietary requirements and modeled abundance. Seasonal patterns of avian piscivore abundance were identified, diurnal patterns of gull abundance at hotspots were identified and predation indices were calculated for hotspots and summer river reaches.

This report summarizes data collection activities, methods, results, and topics of discussion for the field season 2002 conducted by the WACFWRU and the YN.

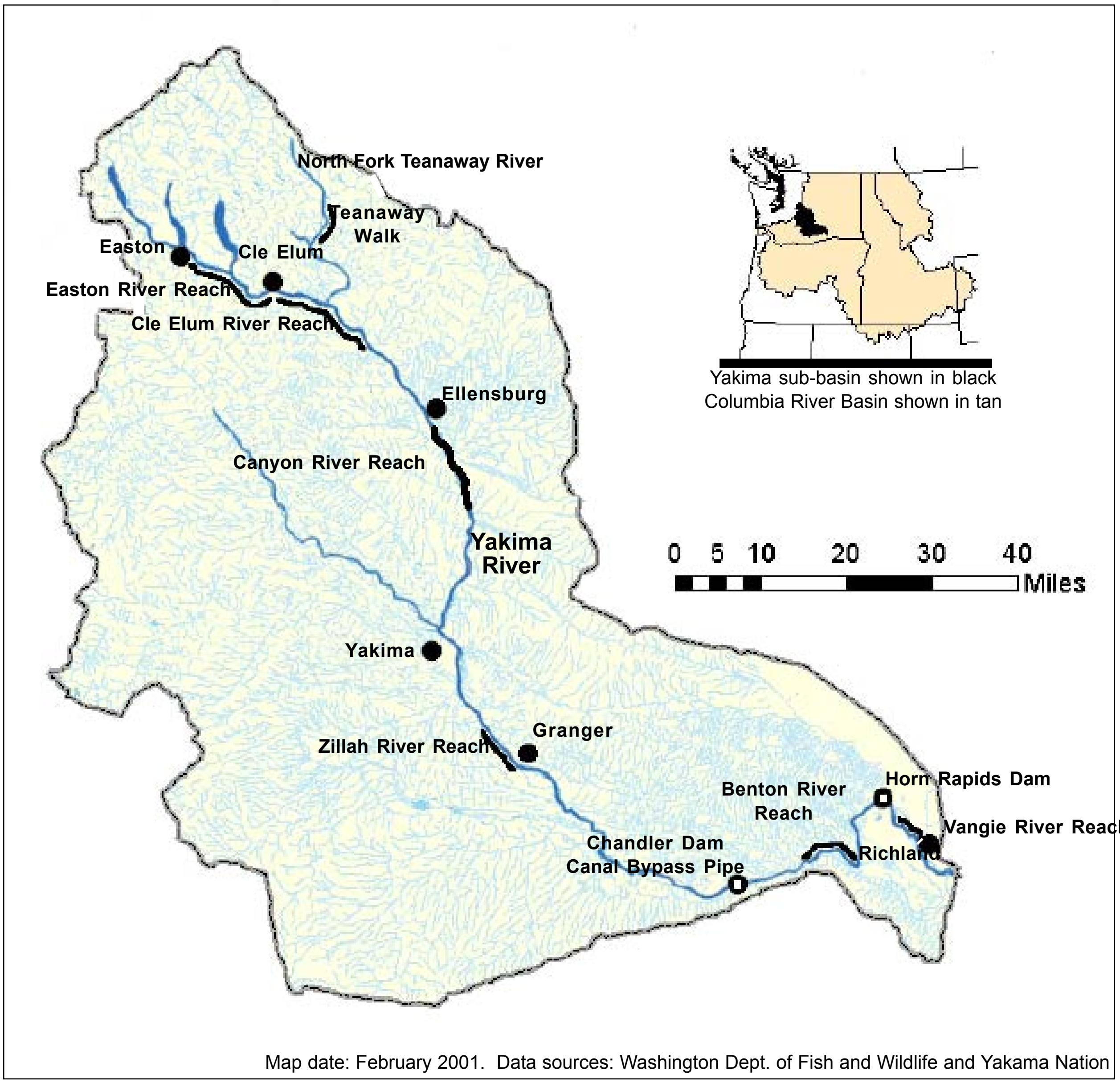
METHODS

Study Location

The Yakima River Basin encompasses a total of 15,900 square kilometers in south central Washington State along the eastern slopes of the Cascade mountain range, running a total length of approximately 330 kilometers (Figure 1). Terrain and habitat varies greatly along its length, which begins at 2,440 meters elevation at the headwaters and ends at 104 meters elevation at the mouth, prior to entering the Columbia River near the City of Richland, WA.

The upper reaches of the Yakima River, above the town of Cle Elum, are high gradient areas predominated by mixed hardwood/conifer forests in association with a high degree of river braiding, log jams and woody debris. Reaches from Cle Elum to Selah, WA are areas of intermediate gradient areas with less braiding and more varied terrain, including mixed conifer and hardwoods proximate to the river channel, frequent canyon type geography, and increasingly fre-

Figure 1. Map of the Yakima River Basin, Washington with approximate locations of the six river drift reaches (Easton, Cle Elum, Canyon, Zillah, Benton and Vangie) and the two hotspot locations (Horn Rapids Dam and Chandler Canal Bypass outfall).



quent arid steppe, sagebrush and irrigated agricultural lands. The middle and lower reaches, from Selah to the Columbia River, exhibit a low gradient, an infrequently braided river channel dominated principally by hardwoods proximate to the river channel with arid steppe and irrigated agricultural lands abutting the shoreline.

Data Collection Methods

Hotspot Survey—Spring

In 2002, hotspot surveys were conducted systematically, on Mondays, Wednesdays, and Fridays at Horn Rapids and Chandler Pipe, with two additional survey days at Horn Rapids during four of the survey weeks. During these four weeks at Horn Rapids, three different survey methods were used. These additional surveys were conducted to make comparisons between current and past survey methods. The data from the other survey methods are not included as part of this report. A total of 32 surveys were conducted at Chandler Pipe and a total of 41 surveys were conducted at Horn Rapids for the 2002 field season , which occurred between April 11 and June 28 (Table 1). Both sites were surveyed simultaneously by different personnel. Observations on survey days began on the nearest 15-minute interval after sunrise and ran for eights hours, or began at midday, eight hours after the nearest 15-minute interval after sunrise, and ended on the nearest 15-minute interval before sunset. This allowed for observations during all periods of the day, to account for the diurnal patterns of avian piscivores. Regionally calibrated tables obtained from the National Oceanic and Atmospheric Administration were used to determine sunrise and sunset times. Depending upon the length of day and start time, between seven and eight 2-hour periods existed within a single day.

The survey area for Horn Rapids Dam included 50 meters of river above the dam and 150 meters below the dam. Since the buoy located above the dam was not included within the survey area the birds resting upon the buoy were not included in abundance counts. The survey area for the Chandler Canal Bypass outfall included 50 meters of river above the outfall pipe and 150 meters of river below the outfall pipe. All

Table 1. Hotspot survey dates for Chandler Canal Bypass Pipe and Horn Rapids Dam in 2002.

Date	Chandler Pipe	Horn Rapids
11-Apr		X
12-Apr	X	
15-Apr	X	X
17-Apr	X	X
19-Apr	X	X
22-Apr	X	X
24-Apr	X	X
26-Apr	X	X
29-Apr	X	X
30-Apr		X
1-May		X
2-May		X
3-May	X	
6-May	X	X
7-May		X
8-May	X	X
9-May		X
10-May	X	X
13-May	X	X
14-May		X
15-May	X	X
16-May		X
17-May	X	X
20-May	X	
21-May		X
22-May	X	X
23-May		X
24-May	X	X
27-May		X
29-May	X	X
30-May		X
31-May	X	X
3-Jun	X	X
5-Jun	X	X
7-Jun	X	X
10-Jun	X	X
12-Jun	X	X
14-Jun	X	X
17-Jun	X	X
19-Jun	X	X
21-Jun	X	X
24-Jun	X	X
26-Jun	X	X
28-Jun	X	X

birds resting upon the shoreline lateral to the specified 50 meters of river above and 150 of river meters below both hotspots were included in abundance counts.

Observations at both sites were made from shore stations. At Horn Rapids Dam observations were made from either inside or outside an automobile. At Chandler Canal Bypass observations were made from a blind, to avoid disrupting normal bird activity. The bird blind at Chandler was used intermittently due to high water conditions. Binoculars (Leica, 10x42) were used to aid in identification. At Horn Rapids Dam, 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 the Chandler Canal Bypass outfall, 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 Dam, which improved the observer's ability to accurately monitor bird behavior.

The hotspot survey design for 2002 followed the method used in 2001. Each day was divided into 2-hour survey 'windows', consisting of three, 15-minute abundance/feeding 'blocks'. Each of these blocks was divided by a 15-minute period of no observation, unless a feeding interval was still being measured, in which case the observation period was extended into the next 15 minutes. This 75-minute cycle of 'blocks' was followed by a 45-minute rest period before beginning a new 2-hour 'window'. Within the 15-minute survey 'blocks', abundance of all piscivorous birds, foraging ratios, the number feeding to total number present, and foraging rates, fish consumed/min, of gulls were determined (Table 2). Gulls flying within the study area were considered foraging. Gulls within

Table 2. Hotspot survey period design

Window	Block	Activity
1	1 Observation (15-minute)	Abundance of all piscivorous birds and ratio of gulls present to gulls foraging determined at beginning of block. First gull observed successfully capturing a fish followed continually until second successful capture. Time of foraging interval recorded. Abundance of all piscivorous birds and ratio of gulls present to gulls foraging determined at end of block
1	Rest (15-minute)	Any ongoing foraging interval was continued into this period until a second successful capture or the end of the 15-minute rest period. If there was no interval ongoing then no data were collected.
1	2 (15-minute)	Same activities as block 1.
1	Rest (15-minute)	Same as previous rest period.
1	3 (15-minute)	Same as blocks 1 and 2.
1	Rest (45-minute)	Any ongoing foraging interval was continued into the first 15-minutes of this period and ended according to the above criteria. The observer then rested for 30 minutes with no data collection activity.
2	1 (15-minute)	Repeat as Window 1.

the study area foraging on terrestrial prey items—such as insects, seeds, plants—were not considered feeding, but were included in total abundance counts. Gulls sitting or standing on rocks emerging from the river or along the river edge were not counted as part of the foraging fraction. Although gulls sometimes utilized such rocks as fishing platforms, more frequently such platforms were used for loafing and other non-foraging activities. In addition, it was not feasible to distinguish foraging gulls standing on rocks from those loafing.

The gull chosen to be observed for foraging rate was the first individual observed consuming a fish within the study area. Once a gull was chosen it was followed continuously until a second successful capture occurred or a maximum of 30 minutes had passed. Initial successful feeding attempts were those in which a foraging bird captured a fish by plunging from the air into the water. Second takes were counted regardless of the means of capture. This accounted for the very rare instance in which the second successful take by a gull was accomplished by stealing from another bird or jumping from an exposed rock or log into the water to catch a fish.

River Reach Surveys—Spring and Summer
Spring river surveys included six river reaches. Each reach was surveyed approximately once every 2 weeks, from April 15 through June 28 (Table 3). These reaches included Benton, Vangie, Zillah, the Canyon, Cle Elum and Easton. During the summer, river surveys included only the Canyon, Cle Elum and Easton reaches, which were surveyed every week from July 1 through August 28. The Canyon was an additional drift in the summer in 2002, compared with previous years, when only Cle Elum and Easton were surveyed during this time of year. All reaches surveyed in both the spring and summer were identical in length and location to those conducted in previous years.

All river reach surveys were conducted by a two-person survey team from either a 5.2 m aluminum drift boat or a two-person raft, depending upon water conditions. Most surveys began between 0800 and 0900 and lasted between 2.5 to 5.5 hours, depending upon length of reach, water flow and wind speed. All surveys were preformed while actively rowing the drift boat or raft down stream to decrease the interval of time required to traverse the reach.

Of the two-person survey team, one person was responsible for rowing the boat while the other was responsible for identifying and recording birds. Team members alternated between rowing and bird identification duties approximately every hour. All piscivorous birds detected visually or aurally were recorded, including time of observation, species, and sex and age if they were distinguishable. Binoculars (Leica, 10x42) were used to aid in identification. All birds positively identified by the rower were included, although the team member responsible for bird identification at the time of the encounter made final decisions for uncertain or potential repeat identifications, that is, double counting.

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. Birds being pushed were usually kept in sight until passed by the survey boat. Passage usually occurred when the river widened sufficiently to let the pushed bird pass to the side of the survey boat.

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 1000 meters of river was assumed to be the pushed bird. If a bird of the same species/age/sex was not encountered in the subsequent 1000 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.

Table 3. River reach start point, end point and total length (km) surveyed for piscivorous birds.

Name	Start	End	Length	Strata
Vangie	1.6 km above Twin Bridges	Van Giesen St Hwy Bridge	9.3	3
Benton	Chandler Canal Power Plant	Benton City Bridge	9.6	3
Zillah	US Hwy 97/St. Hwy 8 Bridge	Granger Bridge Ave Hwy Bridge	16.0	3
Canyon	Ringer Road	Lmuma Recreation Site	20.8	2
Cle Elum	South Cle Elum Bridge	Thorp Hwy Bridge	28.3	1
Easton	Easton Acclimation Site	South Cle Elum Bridge	29.3	1
North Fork Teanaway	Mouth of Jungle Creek	3.5 km downstream	3.5	5

Acclimation Site Surveys—Spring

Beginning February 1 and continuing until May 29, YN hatchery personnel at the Clark Flat, Jack Creek and Easton acclimation sites conducted piscivorous bird surveys. Jack Creek was surveyed from February 22 to May 23, Easton from March 1 to May 17, and Clark Flat from February 1 to May 29. In addition, a few observations were made at the Cle Elum Hatchery site from February 13 to April 3. Surveys were conducted at various times throughout the day. In general, each site had at least three surveys conducted, one in the morning, one around noon, and one later in the afternoon. All piscivorous birds within the acclimation facility, along the length of the artificial acclimation stream, and 50 meters above and 150 meters below the acclimation stream outlet, into the main stem of the Yakima River or N. Fork Teanaway, were identified and recorded within their respective zones. Surveys were conducted on foot by hatchery personnel.

North Fork Teanaway River Surveys—Spring and Summer

The survey reach included the river and its banks from the Jungle Creek/North Fork Teanaway confluence down river past the Jack Creek acclimation site continuing downstream for approximately 3.5 km. One surveyor moved down from Jungle Creek, noting the presence of piscivorous birds. If navigation of the river-bank was not possible, the river was crossed and surveys were continued on the opposite bank. If it was not possible to cross the river, detours were taken away from the river-bank, down stream, and paths through the underbrush were located to enable periodic return to the river-bank. Once there, a visual search up and down the stream was conducted. All piscivorous birds detected visually were recorded including time of observation, species of bird, and sex and age if distinguishable. A pair of Leica (10x42) binoculars was utilized to aid in identification. This area was surveyed seven times between May 2 and August 21, 2002, approximately once every two weeks.

Secondary Hotspot Surveys—Spring

Additional surveys were conducted in 2002 at four dam sites along the Yakima River. These surveys were conducted to ensure that potential hotspot sites were not being overlooked. These sites, in addition to others, were initially identified by Phinney et al. (1998) as areas for potential heavy predation and were also surveyed in 2000, but not in 2001. Sites surveyed in 2002 included Prosser Dam, Sunnyside Dam, Wapato Dam and Roza Dam. Each site was visited approximately nine times, once every one to two weeks between April 16 and June 25. Wapato Dam was only visited seven times due to high water conditions, which made the road to one part of the dam inaccessible. Observations were made for one hour at each site, with birds present noted every 15 minutes. Bird species, time, number and location, either above or below the dam, or at the canal intake at Prosser Dam, were all noted.

In addition, checks were made at Prosser Dam when time permitted, to determine if there was a significant number of birds feeding at the head of the canal, where

Table 4. River reach survey dates for spring and summer, 2002. Dashed line demarcates spring and summer survey periods.

DATE	ZILLAH	BENTON	VANGIE	CANYON	CLE ELUM	EASTON
15-Apr	X					
16-Apr		X	X			
17-Apr				X		
18-Apr					X	
19-Apr						X
29-Apr	X					
30-Apr		X	X			
1-May				X		
2-May					X	
3-May						X
13-May	X					
14-May		X	X			
15-May				X		
16-May					X	
17-May						X
27-May	X					
28-May		X	X			
29-May				X		
30-May					X	
31-May						X
10-Jun	X					
11-Jun		X	X			
12-Jun				X		
13-Jun					X	
14-Jun						X
24-Jun	X					
25-Jun		X	X			
26-Jun				X		
27-Jun					X	
28-Jun						X
1-Jul						X
2-Jul					X	
3-Jul				X		
9-Jul						X
10-Ju					X	
11-Jul				X		
16-Jul						X
17-Jul					X	
18-Jul				X		
23-Jul						X
24-Jul					X	
25-Jul				X		
29-Jul						X
30-Jul					X	
31-Jul				X		
5-Aug						X
6-Aug					X	
7-Aug				X		
13-Aug						X
14-Aug					X	
15-Aug				X		
20-Aug						X
21-Aug					X	
22-Aug				X		
27-Aug				X		
28-Aug					X	
29-Aug						X incomplete

fish are susceptible to predation due to upwelling.

Statistical Modeling Methods

Estimates of smolt predation from the survey data were calculated by dividing the river into three spatial strata and two hotspot locations. Each stratum reflected differences in species abundance, distribution and geography. Hotspot surveys differ from river reach surveys in both the type of survey data collected, and the survey effort. The three strata were 1) the upper Yakima River (84 km), 2) the Canyon (40 km), and 3) the river below the Canyon to the mouth (198 km). The two hotspot locations were Horn Rapids Dam and the Chandler Canal Bypass Pipe. In addition, seven foot surveys along the North Fork Teanaway River were included. Estimates of biomass consumed were calculated for the three strata, however, a lack of data on fish community composition and size prevented calculations of the number of fish taken. Numbers of fish taken were calculated for the hotspots. 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, are slightly different for each area. A stratified approach to the estimation 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 observed by boat. River reach surveys encompassed approximately 35% of the Yakima River. In addition, feeding rates and bird abundance data were collected at the two hotspots on the river. Assumptions common to both strata and hotspots were: 1) that all birds observed were correctly counted and identified to species, 2) that observing the birds did not effect their behavior, 3) that the behavior and abundance of birds during the time of observation was representative of birds at all times, and 4) that predation only occurred between the hours of dawn and dusk.

The total number of smolts taken from the river during the outmigration season *M*, was estimated by summing the estimates across strata. An estimate of *M*, is given by:

$$\hat{M} = \sum_{i=1}^{4} \hat{M}_i$$

Where,

$\hat{M}$ = the estimated total number of smolts consumed,

$\hat{M}_i$ = the estimated number of smolts consumed in the

i^{th} stratum (i = 1,...,4).

*for summation purposes, hotspots are defined as the 4th strata.

River Reaches

Surveys in Stratum 1 were conducted by river drifts at regular intervals throughout the survey period on two reaches, Easton (29.3 km) and Cle Elum (28.3 km). These two reaches were surveyed throughout the season, from April to August. Each drift was surveyed on a different day. The Cle Elum section was surveyed one more time than the Easton reach during the summer, due to equipment failure. The reach surveyed was assumed to be representative of the entire stratum. Smolt consumption was estimated by the following:

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

where

T_1= number of possible days in survey for Stratum 1

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

Km_1 = the total length of river in the 1st stratum (84 km stratum)

km_{1ks} = the number of river miles drifted on the s^{th} river section, in the k^{th} block, in the 1st stratum (28.3 km for Cle Elum and 29.3 for Easton),

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 1st stratum,

B_1 = the number of bird species in the 1st stratum,

W_j = daily dietary food consumption rate for the j^{th} (j = 1,2,…,B) bird species in terms of grams per day,

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.

$$I = \begin{cases} 1 & \text{indicator when calculations of } \hat{M}_i \text{ in terms of the number of smolts eaten} \\ 0 & \text{when } \hat{M}_i \text{ expressed in terms of grams of salmonid smolts eaten} \end{cases}$$

The survey season was divided into blocks of approximately 2 weeks, centered on a river reach drift. Blocks were constructed to account for changes in species composition of juvenile salmonids during the outmigration season. 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. The temporal sampling fraction was calculated by the following:

$$\frac{T_{1k}}{\sum_{s=1}^{n} t_{1ks}}$$

and the spatial sampling fraction was,

$$\frac{Km_1}{\sum_{s=1}^{n} km_{1ks}}$$

When the reaches were floated on consecutive days, they were treated as one survey, and sampling fractions were calculated accordingly, i.e., t_{1ks} for each block, however the number of days in each block, T_{1ks} varied.

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.

In cases where river reaches were floated twice in a 2-week period, it was possible to evaluate the variability within the period.

Consumption rates for birds are usually given in terms of the number of grams consumed per day. The number of grams per day can be converted into the number of fish per day consumed using 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 Stratum 1, and from the abundance of resident salmonids estimated by river surveys done in the fall by WDFW. The salmonid species consisted of two outmigrating species, spring chinook, coho salmon and one resident species, rainbow trout. Although estimates of rainbow trout are calculated from fall survey data, they can serve as an index of resident salmonid abundance. 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 (size) in the k^{th} block.

The abundance of both spring chinook and coho can be calculated using the number of each species released from the hatcheries and rearing ponds during the survey block. It can be 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 in Stratum 1 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. Equation 2 then sums over all bird species to obtain an estimate of total fish consumption in the first stratum.

The estimator includes the following assumptions:

1. Birds are detected with probability 1,
2. Birds are stationary targets throughout the day over the course of the survey,
3. All birds predating on fish are observable from the river,
4. The fraction of the river surveyed is a random sample of the reach (stratum),
5. Consumption rates, grams per day, are the same across all days regardless of the number of hours of daylight,
6. All outmigrating fish released into the river during an survey block exit before the start of the next survey block,
7. The abundance of resident salmonids observed in the fall are an index of residents available to birds in the spring.

Calculations for Strata 2 and 3 are same as Stratum 1, except that the Benton reach was floated the same day as the Vangie reach, so these two reaches were treated as one. The Zillah reach was always floated by itself but in the same week as the Benton and Vangie reaches. Therefore, blocks were generally 1-week in length, centered on a survey of either the Zillah or Benton/Vangie reach.

North Fork Teanaway River Surveys

Bird abundance data were also collected during seven foot surveys along a reference reach of the North Fork Teanaway River. These were conducted periodically between May 2 and August 21. This area included the Jack Creek Acclimation Site. No data on the total length of the Teanaway River were included in the survey, so the estimate of biomass consumption for this stratum is for the survey reach only, between the time of the first and second survey. Biomass (M_5) of fish consumed was calculated by,

$$M_5 = W_j P_j \left[\frac{T_5}{t_5} \sum_{s=1}^{n} b_{5jk} \right]$$

where

T_5 = the length of the survey season in days for stratum five,
t_5 = the number of survey days for stratum five
b_{1jk} = the number of birds observed on the k^{th} survey, of the j^{th} species in stratum five,
B_1 = the number of bird species in the third stratum,
W_j = daily dietary food consumption rate for the j^{th} (j = 1,2,…,B) bird species in terms of grams per day,
P_j = the proportion of the diet consisting of the j^{th} (j = 1,2,…,B) comprised of the h^{th} salmonid species (h = 1,2,…,H)

Hotspots

Horn Rapids Dam and the Chandler Canal Bypass Outfall were defined as hotspot locations due to high levels of avian predation, primarily by gulls, due to the physical obstructions at these sites that concentrate and/or disorient the fish. To estimate predation we used two pieces of information collected during the survey, the number of birds actively foraging, and the average time between successful feeding attempts by a bird. Surveys were conducted in 2-hour windows. Within each window there were two 15-minute blocks, each followed by a 15 -minute rest period, then a 15-minute block followed by a 45-minute rest period. Foraging intervals, the time between successful takes by a gull, in addition to instantaneous counts of the number of foraging gulls were taken at the beginning and end of each 15-minute block.

The time between each successful take was recorded by the surveyors, and the data used in the calculations were the interval lengths, or t_{ijklm}. The average number of fish per bird-minutes per survey block was calculated by,

$$\overline{t}_{ijkl} = \frac{\sum_{m=1}^{M} t_{ijklm}}{M} = \frac{\text{bird} \times \text{min}}{\text{fish}}$$

where, t_{ijklms} = the number of minutes between successful fish takes for the sth (s = 1, 2,…,S) bird, for the mth forage block (m = 1,2,3) for the lth survey window (2-hour period) (l = 1,2,…,L) of the kth (k = 1,2,…,K) survey for the jth (j = 1,2,…,J) bird species on the ith (i = 1,2) hotspot.

The number of birds actively foraging was defined as in previous years. The number of bird-minutes for the survey block was calculated by,

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

where, y_{ijklmr} = the number of bird-minutes in the s^{th} (s = 1, 2) count, the m^{th} survey block (m = 1,2,3), for the l^{th} survey window (2-hour 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 taken in the m^{th} survey block of the l^{th} survey window, f_{ijklm}, was,

$$f_{ijklm} = \frac{\overline{y}_{ijklm}}{\overline{t}_{ijklm}} = \frac{\text{bird}\times\text{min}}{\text{bird}\times\text{min}/\text{fish}} = \text{fish}$$

where f_{ijkl} = the number of fish taken in the m^{th} survey block (m = 1,2,3), for the l^{th} survey window (2-hour 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 total number of fish taken for the year, f, is calculated by expanding fish counts by sampling fractions and summing across survey days, bird species and hotspots,

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

Variances for f_{ijkl} were calculated using the delta method, and the overall variance was calculated using the variance for a multi-stage sampling design (Cochran 1977).

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RESULTS & DISCUSSION

2002 Survey Season

River Reach Surveys

Avian Piscivore Abundance—Spring
After combining the two gull species into a single group, 'gulls', 13 species of avian piscivores were identified, including: Common Mergansers, Belted Kingfishers, Great Blue Herons, gulls, Osprey, Double-crested Cormorants, American White Pelicans, Caspian Terns, Forster's Terns, Bald Eagles, Hooded Mergansers, Black-crowned Night Herons, and Great Egrets.

Inclusive of gulls, avian piscivore abundance during spring surveys ranged from a low of 1.36 birds/km on the Canyon reach to a high of 3.61 birds/km on the Zillah reach (Figure 2). The peak abundance of all piscivorous birds for any single survey day was 8.17 birds/km on May 28 on the Vangie reach. If gulls are excluded, mean bird abundances drop significantly on the Benton and Vangie reaches to 1.35 and 1.86 birds/km, respectively. Gulls were not sighted on the Easton, Canyon or Cle Elum drifts, and only one was sighted on the Zillah drift, so the total avian piscivore abundance does not decline when gulls are excluded from those calculations. Of the 13 species encountered, only the Great Blue Heron and Common Merganser occurred on all six reaches during the spring. The Belted Kingfisher and Osprey were identified on five of the six survey reaches. The Belted Kingfisher was absent only on the Vangie reach and the Opsrey was absent only on the Benton reach.

Common Mergansers, which are of particular importance because of their known utilization of salmon smolts as forage (White 1957; Wood 1985) and their relatively high abundance within the upper reaches of the Yakima River, were encountered most frequently on the Easton and Cle Elum reaches, 1.99 birds/km and 1.54 birds/km respectively (Figure 3). They represented approximately 85% of all piscivorous birds counted within the Easton reach and 84% of all piscivorous birds counted within the Cle Elum reach during spring. In the Canyon, Common Mergansers accounted for over half, 53%, of all piscivorous birds observed. In the lower three reaches, Common Mergansers accounted for only 2% of birds observed on Vangie, 3% on Benton, and 22% on Zillah, of all avian piscivores observed.

The distribution of bird species over all six reaches during the spring was highly variable (Figures 4 to 8). The lower sections of the river had a greater diversity of species with ten species occurring on Vangie, and eight on Benton and Zillah. Seven species were found on Easton, five on Cle Elum, and only four species were seen in on the Canyon. The Vangie reach had the greatest diversity of birds observed on any reach, with ten of the 13 species, including gulls, occurring at some point during the spring survey season.

Figure 2. Spring abundance of all avian piscivores by reach including gull sightings, April 8 to June 30. Error bars represent standard deviation.

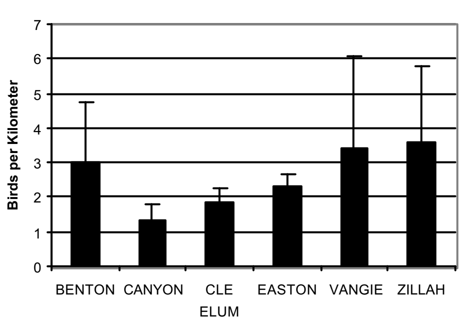


Figure 3. Spring abundance of Common Mergansers by reach, April 8 to June 30. Error bars represent standard deviation.

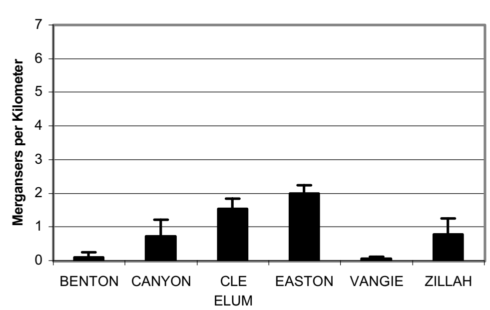


Figure 4. Average spring avian piscivore abundance per kilometer on the Benton river reach, April 8 to June 30. Error bars represent standard deviations. Bars without errors represent a single observation.

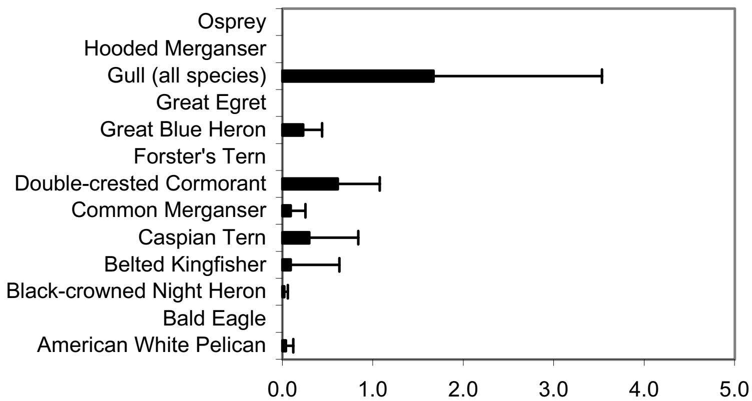


Figure 5. Average spring avian piscivore abundance per kilometer on the Vangie river reach, April 8 to June 30. Error bars represent standard deviations. Bars without errors represent a single observation.

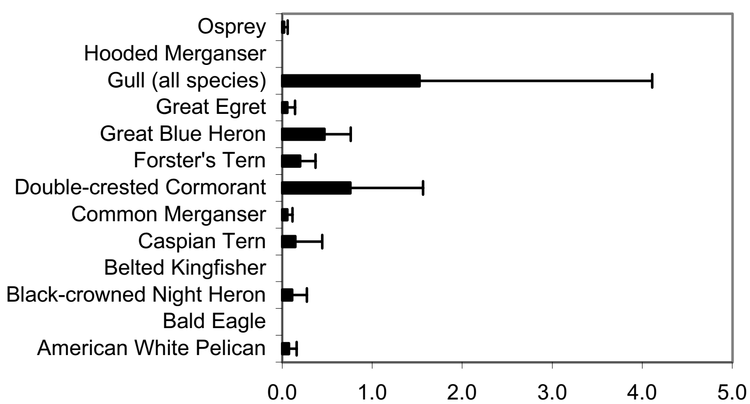


Figure 6. Average spring avian piscivore abundance per kilometer on the Zillah river reach, April 8 to June 30. Error bars represent standard deviations. Bars without errors represent a single observation.

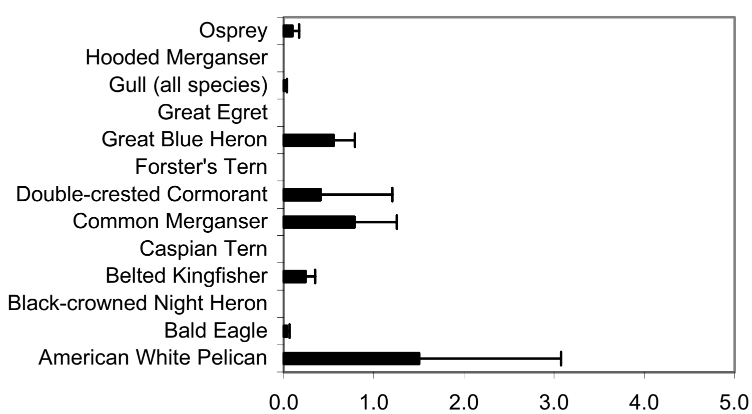


Figure 7. Average spring avian piscivore abundance per kilometer on the Canyon river reach, April 8 to June 30. Error bars represent standard deviations. Bars without errors represent a single observation.

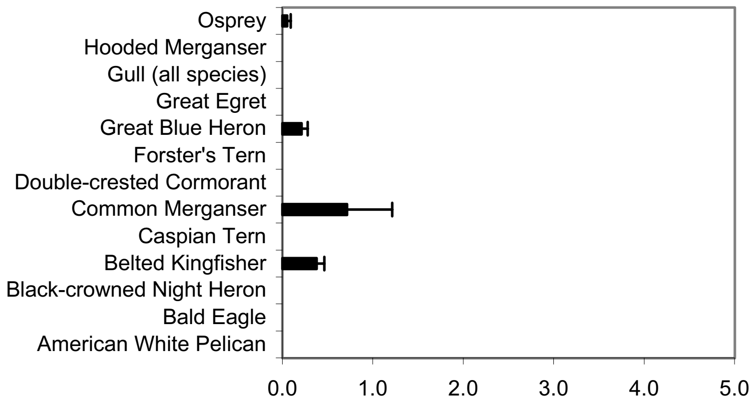


Figure 8. Average spring avian piscivore abundance per kilometer on the Cle Elum river reach, April 8 to June 30. Error bars represent standard deviations. Bars without errors represent a single observation.

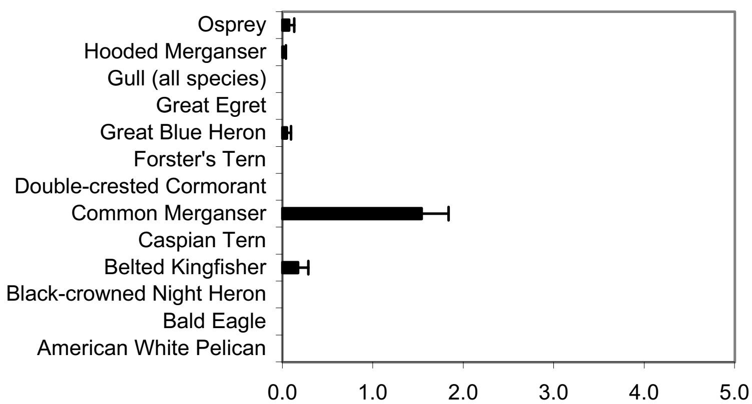
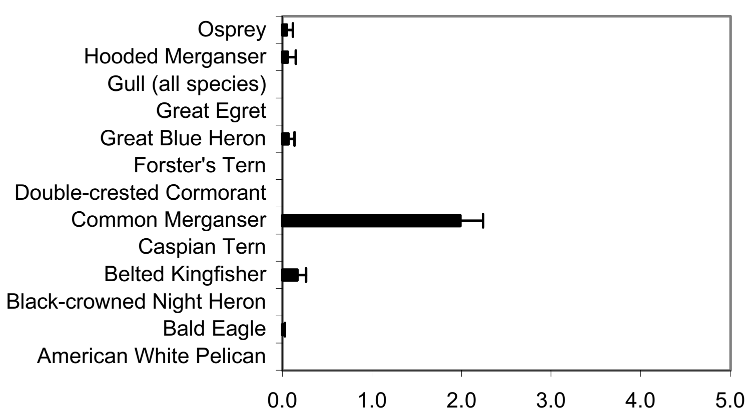


Figure 9. Average spring avian piscivore abundance per kilometer on the Easton river reach, April 8 to June 30. Error bars represent standard deviations. Bars without errors represent a single observation.



Avian Piscivore Abundance—Summer

Due to increasing water temperatures in the lower sections of the Yakima River and a shift in priority of monitoring efforts to summer parr and resident salmonid smolts, drifts during the summer survey period were limited to the Easton, Cle Elum and Canyon reaches, with the Canyon being a new summer survey in 2002. After combining Ring-billed and California Gulls into a single group, gulls, eight species of avian piscivores were identified across all reaches. These included: Belted Kingfishers, Common Mergansers, Great Blue Herons, gulls, Osprey, Bald Eagles, Double-crested Cormorants and Black-crowned Night Herons. Inclusive of gulls, avian piscivore abundance during the summer surveys was 1.45 birds/km on the Easton reach, 1.14 birds/km on the Cle Elum reach, and .96 birds/km on the Canyon reach (Figure 13). The peak abundance of all piscivorous birds for any single survey day was 2.56 birds/km on July l on the Easton reach. Gulls were not found on the Canyon or Cle Elum reaches, and only one was seen on the Easton reach (0.03 gulls/km), so that excluding them from the counts creates a negligible difference in mean or peak numbers of birds observed. Four of the eight species, Belted Kingfishers, Common Mergansers, Ospreys and Great Bule Herons, were encountered on all three reaches. Double-crested Cormorants were found on the Canyon and Cle Elum reaches, Black-crowned Night Herons were only observed on the Easton reach, and Bald Eagles were only seen on the Cle Elum reach. Mergansers were the most predominant species on two of the three reaches, averaging .92 birds/km on Easton, .74 birds/km on Cle Elum, and .27birds/km on the Canyon (Figure 14). This represented 64%, 65%, and 28% of all piscivorous birds counted on the Easton, Cle Elum, and Canyon reaches, respectively. Mergansers breed extensively in the upper Yakima and many of the birds recorded during the summer survey period were young of the year. Belted Kingfishers were the most abundant species on the Canyon reach, with .43 birds/km, which accounted for 45% of the birds on that reach. The Great Blue Heron and Osprey were the other two species that occurred most often during the summer survey period on these reaches.

Avian Piscivore Consumption—Spring

In the years prior to 2001, Bald Eagles were included in biomass estimates of consumption on river reaches. Reviewing the literature more closely regarding this species' food habits, however, has led us to conclude they have little impact on migrating smolts or summer parr. While Bald Eagles do utilize fish for a certain proportion of their diet, it is primarily larger carcasses or warmer, shallow-water fishes. The remainder of their diet (up to 85%) consists of waterfowl and other bird species (Fielder 1982; Lang, et al. 1999; Mabie, et al. 1995). Bald Eagles are only included in the abundance estimates in this report. Osprey remain in the biomass estimates because it is widely accepted that their diet is comprised almost entirely of live fish and prey size selection by Osprey could include parr, steelhead, or rainbow trout populations of interest. However, it should be noted that Osprey primarily feed on fish weighing between 150-300 g (Cramp and Simmons 1977;) or 25-35 cm (Green 1976; Swenson 1978). Van Daele and Van Daele (1982) found this size class to constitute nearly 90% of the Osprey diet in Idaho. Therefore, impacts to fishes outside these length and weight ranges by Osprey could be adjusted accordingly if the length distribution of the fish community were known.

Mean biomass consumption for the spring survey season was greater within Stratum 3, 145.1 kg/km, than within Stratum 1, 72.7 kg/km, or Stratum 2, 37.6 kg/km. The primary consumer within Stratum 1 was the Common Merganser, accounting for 92.9% of total biomass consumed. The next species of significance within Stratum 1 during spring were the Great-blue Heron and Osprey which together accounted for 4.9% of the total biomass consumed. Though present in substantial numbers in Stratum 1 during the spring, Belted Kingfishers consumed only 1% of the total biomass taken.

In the Canyon, Stratum 2, Common Mergansers accounted for the greatest consumption, 72.1%. Great Blue Herons and Belted Kingfishers accounted for 19.2 % and 4.9% of fish biomass consumed in Stratum 2.

Stratum 3 had the greatest diversity of avian piscivores.

Figure 10. Average summer abundance of all avian piscivores per river kilometer by drift on the Canyon river reach, July 1 to August 31. Error bars represent standard deviations. Bars without errors represent a single observation.

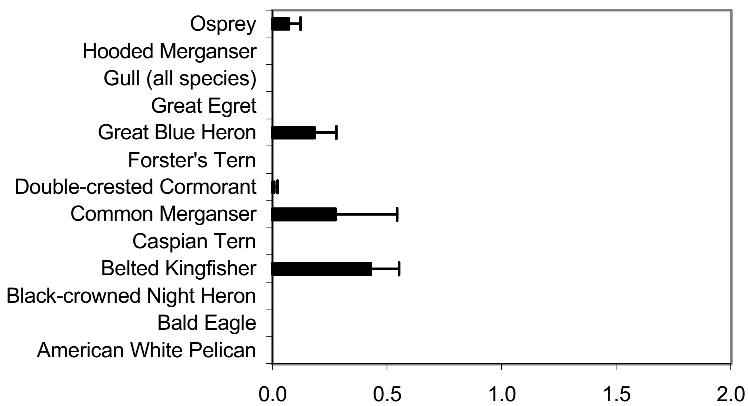


Figure 11. Average summer abundance of all avian piscivores per river kilometer by drift on the Cle Elum river reach, July 1 to August 31. Error bars represent standard deviations. Bars without errors represent a single observation.

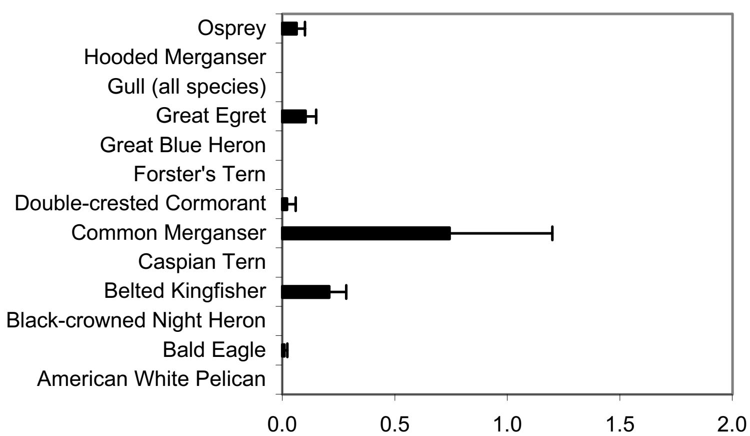


Figure 12. Average summer abundance of all avian piscivores per river kilometer by drift on the Easton river reach, July 1 to August 31. Error bars represent standard deviations. Bars without errors represent a single observation.

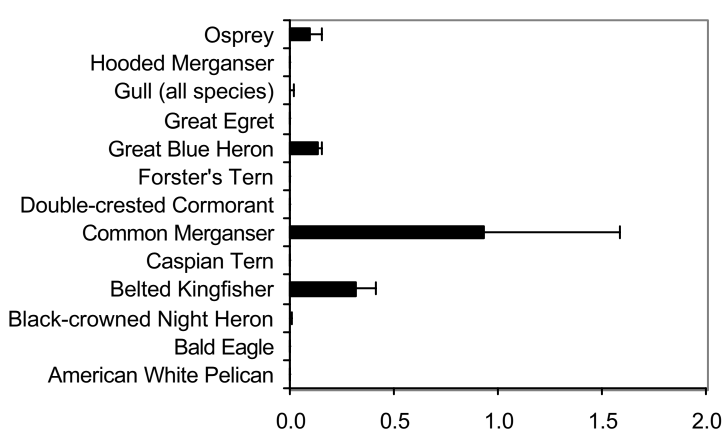


Figure 13. Average summer avian piscivore abundance per km on the Canyon, Cle Elum and Easton reaches, July 1 to Aug 31. Error bars represent standard deviation.

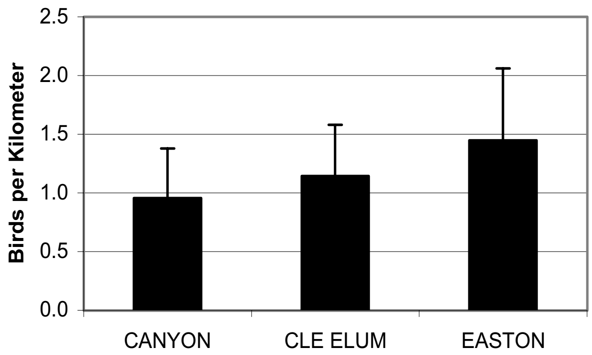
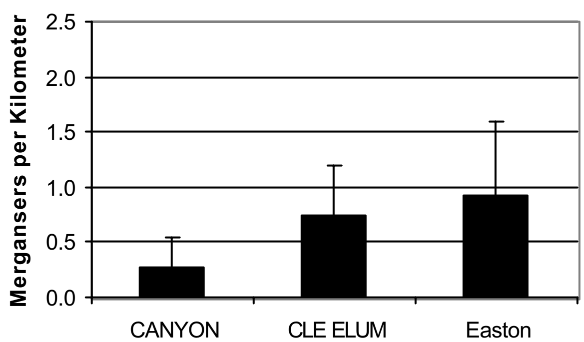


Figure 14. Average summer Common Merganser abundance per km on the Canyon, Cle Elum and Easton reaches, July 1 to Aug 31. Error bars represent standard deviation.



This included: American White Pelicans, Bald Eagles, Black-crowned Night Herons, Belted Kingfisher, Caspian Terns, Common Mergansers, Double-crested Cormorants, Forster's Terns, Great-blue Herons, Great Egrets, gulls, and Osprey. Of this group, American White Pelicans were estimated to have consumed the largest percentage of fish biomass, 55.5%, while Great Blue Herons, Common Mergansers and Double-crested Cormorants consumed 9.5%, 10.2% and 15.3%, respectively. Although present in greater numbers in Stratum 3 than any other stratum during the spring, Belted Kingfishers consumed less than 1% of the total biomass taken.

Avian Piscivore Consumption—Summer

Because water temperatures in the lower river are too high for salmon smolts to survive, summer surveys were conducted only within Stratum 1, the upper most reaches of the Yakima River, and Stratum 2, the Canyon. During this time of year, salmonids are represented by residualized spring chinook, summer parr, steelhead and rainbow trout in the upper river which are still vulnerable to avian predation.

Species diversity in Stratum 1 and 2 remained relatively the same between spring and summer. The only difference was the addition of one Black-crowned Night Heron in Stratum 1 and one Double-crested Cormorant in Stratum 2 in the summer. Mean biomass consumed within Stratum 1 in summer was 29.5 kg/km. This represented less than half, 28.8%, of all the estimated biomass consumed within Stratum 1 for the entire season. Common Mergansers accounted for the greatest proportion of the take, 77.7%, during the summer period. During this time period, Common Mergansers are usually in their highest numbers because broods have moved onto the river to feed, but in 2002 there were less Common Mergansers seen in the summer than in the spring. Although Great Blue Herons are not known to breed within the upper reaches, they were observed more frequently during the summer within Stratum 1 than during the spring. Their estimated consumption was approximately 11.2% of total estimated biomass consumed, second to that of Common Mergansers . Belted Kingfishers numbers also increased in abundance from the spring survey period, yet only accounted for 3.6% of the total estimated take.

Hotspot Surveys

Avian Piscivore Abundance

In 2002, hotspot surveys were conducted on 32 days at Chandler Canal Bypass (Chandler) and 41 days at Horn Rapids Dam (Horn Rapids). Surveys occurred between April 11 and June 28. Although other piscivorous birds were identified, gulls, California and Ring-billed, were by far the most numerous. At Chandler mean gull abundance was consistently low, less than five per day, until late April, when numbers went up and dropped again briefly in early May. After peaking in mid-May, numbers dropped off and were consistently low from late May till the end of June.

At Horn Rapids, numbers were low all through April, less then five per day, and remained moderately low, less then 15 per day, until they peaked in the third week of May. Numbers dropped again, came up at the end of May, and stayed below ten per day through June, until rising again at the end of the month.

Within the time period surveyed, the maximum number of gulls at Chandler occurred on May 13 with an average of 98 gulls per day (Figure 15) while at Horn Rapids the maximum occurred on May 21 with 46.6 gulls (Figure 16). This represented a decrease in maximum gull abundance at the two sites from the previous year, when there were an average of 125 birds at Chandler, and 49 birds at Horn Rapids.

Species other than gulls identified at Chandler included: Black-crowned Night Herons, Great Blue Herons, Common Mergansers, American White Pelicans, Osprey and Double-crested Cormorants. Species identified at Horn Rapids included all those sighted at Chandler as well as Caspian Terns, Forster's Terns and Great Egrets.

Diurnal patterns of gull abundance have been difficult to discern because of low gull numbers early in the season. As gull numbers increased, patterns of diurnal abundance became more apparent. To resolve these patterns, survey periods were numbered sequentially one to eight. Each period was two hours long with seven or eight occurring per day depending upon survey start time and length of day. Each period was then averaged across the entire survey season, April 11 to June 28. For each survey period mean gull abundances were averaged across all of the survey days.

Mean daily abundance patterns at Chandler showed a general, steady increase in gulls from sunrise to a mean daily peak 32.94 gulls in period five (Figure 17). This is within approximately the 9th or 10th hour after sunrise. The pattern of gull abundance after the peak shows a consistent decline over the last three periods. By Period 8, the last of the surveys, gull numbers were still averaging around four birds, but observations after sunset were not possible. It is assumed that there was insufficient light for effective foraging after this point and most remaining gulls were loafing or sleeping on rocks. Quite often, the last count of the 2-hour window was near zero, though higher counts early in the window produced a mean abundance of approximately 4.4 birds.

Figure 15. Average gull abundance at Chandler Canal Bypass April 11 to June 28. Error bars represent standard deviation.

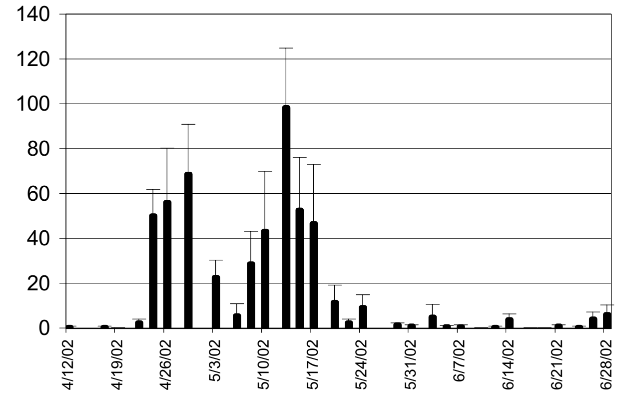
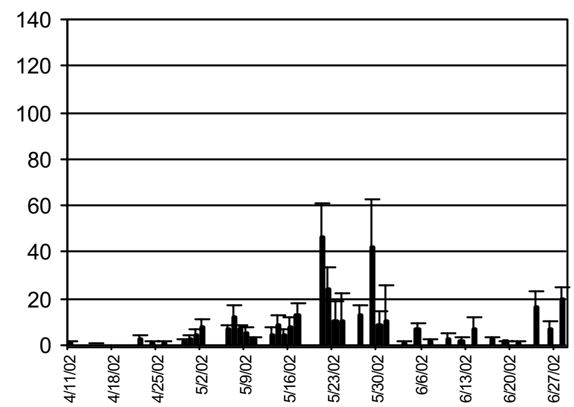
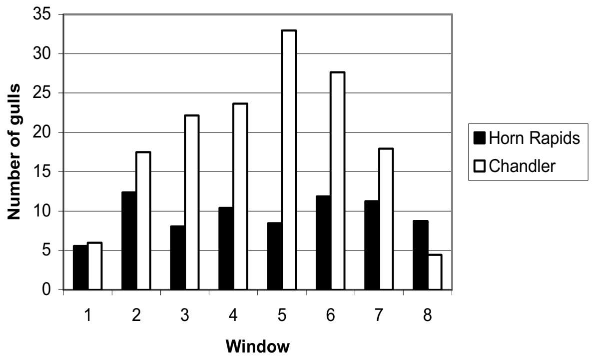


Figure 16. Average gull abundance at Horn Rapids April 12 to June 28. Error bars represent standard deviation



A similar analysis at Horn Rapids shows a pattern not consistent with that found at Chandler. Horn Rapids also had a proportionately smaller number of birds than Chandler. Gull numbers at Horn Rapids showed an increase earlier in the day than at Chandler. Peak numbers occurred in period two at 12.36 birds. This is within approximately the 3rd or 4th hour after sunrise. Numbers were also up in the 6th and 7th periods. Gull numbers at Horn Rapids remained more consistent throughout the day than

Figure 17. Diurnal pattern of gull abundance at Horn Rapids and Chandler Canal Bypass. Numbers 1 through 8 represent 2-hour survey periods beginning the first 15 minutes after sunrise.



at Chandler. By the last period, mean gull abundance had decreased to less than ten birds.

The pattern of increase to the peak in gull numbers or subsequent decline has not been consistent over the last four years.Unlike survey results from 1999 and 2000, neither site showed a daily peak in the 3rd period in 2002. In 2001 gull numbers peaked during the fifth period at Horn Rapids, and the sixth period at Chandler. This brings into question utilizing the daily peak or other parameters associated with diurnal abundance as an index for determining mean daily gull abundance with less intensive monitoring as was suggested in the 1999 and 2000 annual reports (Grassley and Grue 2001; Grassley et al. 2002).

Consumption by Gulls

Modeled average rates of successful fish capture by gulls at both hotspots resulted in consumption estimates for these sites of 84,203 (SE=17,356) fish at Horn Rapids and 195,279 (SE=67,510) fish at Chandler. If the release of approximately 1.85 million fall chinook smolts from below Chandler Dam are taken into account, 82,985 smolts in April and 1,763,726 smolts in May, then our combined consumption estimate of 279,482 fish represents 10.3% of all smolts estimated passing or being released from the Chandler Dam area during the 2002 smolt migration season. These estimates do not include consumption by gulls at hotspots before surveys began on April 11 or after surveys ended on June 30 and assume that all fish taken were hatchery released smolts.

Acclimation Site Surveys

Piscivorous bird surveys were conducted at the three spring chinook acclimation sites from late February until late May. Surveys were conduced at Jack Creek from Feb. 22 to May 23, at Easton from March 1 to May 17, at Clark Flat from March 25 to May 29, and a few additional surveys were conducted at the Cle Elum Hatchery during the same general time frame. Surveys were conducted on a daily basis several times throughout the day, however the survey times and frequencies often varied between and within sites. About two thirds of the surveys at all sites were conducted between 6:00 am and noon, with most of the remainder surveys conducted between noon and 6:00 pm. Piscivorous birds observed at all the sites included: Great Blue Herons, Belted Kingfishers, Osprey, Bald Eagles, Golden Eagles, Common Mergansers, and Hooded Mergansers. Of the three acclimation sites, Clark Flat had the greatest diversity of piscivorous birds with only Osprey not being observed there. Jack Creek and Easton each had four different species observed. No Bald Eagles or Osprey were sited at Jack Creek, and no Hooded Mergansers or Great Blue Herons were seen at Easton. Belted Kingfishers were the most frequently occurring species at Clark Flat and Jack Creek where they accounted for 72% and 75% of the total number of birds observed at each sites, respectively. Common Mergansers were the most commonly observed species at Easton, accounting for 80% of all birds observed at that site. On days that were surveyed in common with all three sites, Easton had the greatest number of birds relative to the number of observations made, 1.15 birds per observations. Jack Creek had the least number of birds per observation, at only .49, while Clark Flat had .91 birds per observations on the days that were surveyed in common with the other sites. The differing survey time periods and irregularities of the daily survey schedule at the different sites made it difficult to compare bird abundances among the sites or make any additional quantitative statements. Efforts will be made in the following field season to ensure more consistency in surveying methods between the three acclimation sites.

North Fork Teanaway River Surveys

There were a total of seven surveys along the North Fork Teanaway, conducted between May 2 and August 21, approximately one survey every two weeks. The only birds encountered on the North Fork Teanaway within this time frame were one Great Blue Heron and three Belted Kingfishers. Average spring abundance was .10 birds per km, and average summer abundance was .21 birds per km, both very low abundances. Total biomass consumerd in the spring, between April 22 and June 30, was 415g (SE 208), and total biomass consumed in the summer, between July 1 and August 30, was 592g (SE 220). If fish at release are approximately 18 fish per pound and consumption is assumed to be 100 percent salmonids, this would represent only .2% of the 285, 270 spring chinook released from the Jack Creek acclimation facility in the spring.

Figure 18. Average spring avian piscivore abundance per kilometer on the North Fork Teanaway foot survey, May 2 to 30 June. Bar without error represents a single observation.

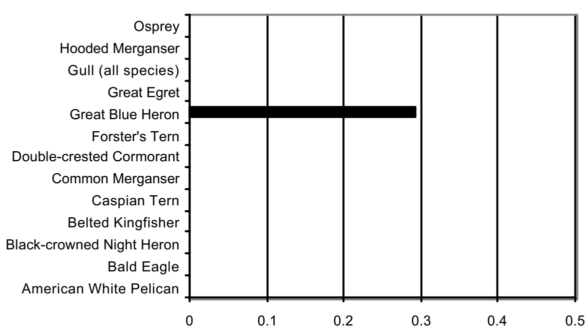
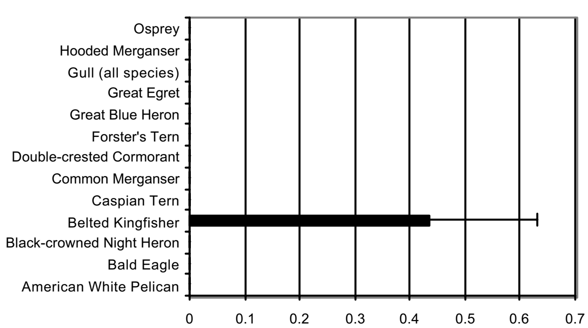


Figure 19. Average summer avian piscivore abundance per kilometer on the North Fork Teanaway foot survey, July 1 to Aug 31. Error bar represents standard deviation.



Secondary Hotspot Surveys

Four additional sites, Prosser Dam, Roza Dam, Sunnyside Dam and Wapato Dam, were surveyed to ascertain the level of predation at these sites. Out of these four sites, Sunnyside Dam had the greatest diversity of bird species, including the American White Pelican, Belted Kingfisher, Great Blue Heron, Osprey and gull species. Black-crowned Night Herons, Great Blue Herons and gulls were seen at Prosser Dam, while only Great Blue Herons and Osprey were found at Wapato Dam, and only Great Blue Herons at Roza Dam. During the additional checks that were conducted at the head of the canal at Prosser Dam, only gulls were seen foraging, with the exception of one Great Blue Heron flying overhead.

Each of the four dam sites was visited nine times, with the exception of Wapato Dam, which was only visited seven times, due to water conditions. There was also a difference in the number of observations made at each visit. Prosser Dam had the greatest number of birds per observation, at 4.38, with 99% of the birds being gulls. There were .57 birds per observation at Sunnyside Dam, with 37% of the birds being Great Blue Herons, 33% being Osprey, and 22% being American White Pelicans. At Wapato Dam there were .37 birds per observation, with 70% being Great Blue Herons, and 30% being Osprey. Roza Dam had only .13 birds per observation, 100% of which were Great Blue Herons seen below the dam. During the additional checks made at the head of the canal at Prosser dam, 6.27 birds were seen per observation, with 99% of them being gulls. Based on these numbers, these sites do not appear to be "hotspots", compared to the numbers of birds, particularly gulls, seen at either Horn Rapids or Chandler. Prosser Dam and the head of the canal may warrant future surveys

Table 6. Piscivorous bird species encountered during surveys on the Yakima River 2002

American White Pelican (*Perecan erythrorhynchos*)
Bald Eagle (*Haliaeetus leucocephalus*)
Belted Kingfisher (*Ceryle alcyon*)
Black-crowned Night Heron (*Nicticorax nicticorax*)
California Gull (*Larus californicus*)
Caspian Tern (*Sterna caspia*)
Common Merganser (*Mergus merganser*)
Double-crested Cormorant (*Phalacrocorax auritus*)
Forster's Tern (*Sterna forsteri*)
Great Blue Heron (*Ardea herodias*)
Great Egret (*Ardea alba*)
Hooded Merganser (*Laphodytes cucullatus*)
Osprey (*Pandion haliaetus*)
Ring-billed Gull (*Larus delawarensis*)

though, especially if spinklers are run at the Chandler pipe outlet to deter birds in the future.

Summary

During 2002, piscivorous bird surveys were again conducted on the Yakima River, both at 'hotspots' and along river reaches. Gulls were again the major predator feed at the hotspots, Horn Rapids Dam and the Chandler Pipe, while the Common Merganser was again the main species feeding in the upper river reaches in both the spring and summer. Monitoring of bird predation on the Yakima River will continue in much of the same manner in 2003.

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