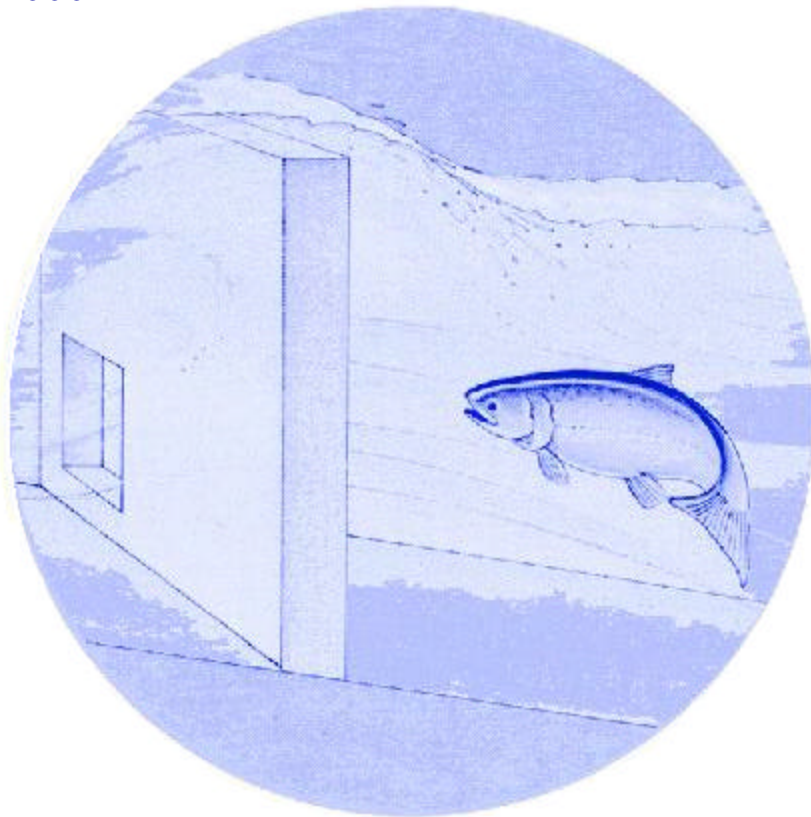


Development of an Index to Bird Predation of Juvenile Salmonids within the Yakima River

**Annual Report
2000**



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

Annual Report 2000

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ABSTRACT

Development of an Index to Piscivorous Bird Predation on Juvenile Salmonids in the Yakima River

Avian predation of fish is suspected to contribute to the loss of juvenile spring chinook salmon in the Yakima Basin, potentially constraining natural production. In 1997 and 1998, the Yakama/Klickitat Fisheries Project (YKFP) and the Washington Department of Fish and Wildlife (WDFW)--whose goal is to increase natural production historically present 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--conducted by Dr. Steve Mathews and David Phinney of the University of Washington--confirmed that Ring-billed Gulls and Common Mergansers were the primary avian predators of juvenile salmon, and that under certain conditions could impact migrating smolt populations.

Beginning in 1999, the Washington Cooperative Fish and Wildlife Research Unit (WACFWRU) was asked by the YKFP and the WDFW to continue development of avian consumption indices. Monitoring methods developed by Phinney et al. (1998) were adopted (with modifications) and monitoring of impacts to juvenile salmon along river reaches and at areas of high predator/prey concentrations (colloquially referred to as "hotspots") continued through 2000.

In 2000, 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; consumption by all other piscivorous birds was estimated using published dietary requirements and modeled abundance. Further development of the avian consumption index model provided an estimation of smolt consumption for the 2000 survey season. Seasonal patterns of avian piscivore abundance were identified, diurnal patterns of gull abundance at hotspots were identified, predation indices were calculated for hotspots and spring and summer river reaches, and the efficacy of aerial surveys for estimating bird abundance within river reaches was evaluated. The only change in survey methods in 2000 was the shortening (in river miles) of surveys on the North Fork of the Teanaway River and the shifting of start and stop dates for river drifts and hotspot surveys.

Primary avian predators in 2000 were 'gulls' (California and Ring-billed) at hotspots and Common Mergansers within upper river reaches. Estimated consumption by gulls at both hotspots combined (10 April - 30 June) was 163,475 fish. Assuming a worst case scenario (all fish taken were smolts) this represented 6.0% of all smolts estimated passing or being released from the Chandler Dam area during the 2000 smolt migration season. Total estimated take by Common Mergansers across all strata surveyed was 7,654 kg between 10 Apr and 30 Aug, 2000. Seventy-three percent of that consumption was within the upper river reaches (Stratum 1) 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*), rainbow trout and steelhead (*Oncorhynchus mykiss*). Although the mountain whitefish (*Prosopium williamsoni*) is of the family *salmonidae*, it was 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 1999). As shown repeatedly by investigations throughout North America and Europe, avian predators can consume large numbers 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 (Ring-billed, Mew, California and Glaucous-winged Gulls, Caspian Terns, Double-crested Cormorants, Great Blue Herons) which are particularly suited to the exploitation of fluctuating prey fish densities (Alcock 1968; Ward and Zahavi 1996). Such prey fish 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 habitats.

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 increase natural production of salmon and steelhead historically present within two eastern Washington State river basins, the Yakima and Klickitat Rivers (both of which are tributaries to the Columbia River). This goal will be accomplished by a combination of salmon supplementation and habitat improvements targeting four principal species of salmonids: spring chinook, fall chinook, coho, and steelhead. At this time, stock specific supplementation programs are at different operational levels. Currently the most intense supplementation effort organized under the YKFP focuses on upper Yakima River spring chinook.

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, competition, pathogens and changes in predator populations.

It is anticipated that interaction between supplemented salmonid stocks and key fish-eating species (biotic interactions) 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 (MIPT), leading to the funding of 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 David Phinney (University of Washington, School of Aquatic and Fishery Sciences), 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, Phinney et al. (1998) 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.

Phinney et al. (1998) found gulls were the most abun-

dant 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 1999). 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 at hotspots, gull abundance was negatively correlated (-0.426, $p < 0.001$ at Chandler and -0.385, $p = 0.001$ at Horn Rapids) with river discharge (Phinney 1999).

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) 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. Though flows were relatively normal during 1999, combined take by avian predators at the hotspots was 2.65% of all salmonids passing over Chandler Dam (assuming all species taken were salmonid); very similar to the percentage taken the year before.

The greatest uncertainty associated with past efforts to develop predation indices was determination of species composition of fishes consumed by avian piscivores along river reaches and at hotspots and estimating accurate consumption at high bird abundances. Consumption work conducted in 1998 relied principally upon behavioral observations of predation by gulls at hotspots, through which one can enumerate the number of fish captured. It was found, however, that measuring the number of successful takes at high bird densities is extremely difficult and inherently leads to an under estimate of consump-

tion. Direct assessment of consumption was attempted for a single species of avian piscivores along river reaches—the Common Merganser—resulting in the collection of gut contents of 20 birds. 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 (WACF-WRU) to continue research efforts begun by Phinney et al. (1998) toward the development of an index to bird predation of juvenile salmonids. Monitoring methods developed by Phinney et al. (1998) for river reaches and hotspots were largely adopted; the frequency of surveys was increased and some methodological alterations were implemented.

Continued were the abundance and consumption surveys of avian predation at two principal hotspots (Horn Rapids Dam and Chandler Canal bypass) and abundance surveys along five river reaches (Easton, Cle Elum, Zillah, Benton and Vangie). New efforts implemented in 1999 included monitoring of hatchery acclimation sites by 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 15 Mar to 30 May 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 at extreme low water events), a by-product of hatchery operations (such as open fish holding ponds), or the result of fish interacting with physical objects within the river channel (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 is 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 (e.g., increased/decreased flows, 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. 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 and shock. Under such circumstances, predation by avian predators can be highly efficient and intense.

River Reach Surveys—Spring and Summer

Spring river reach surveys were conducted from 15 Mar to 30 May 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 1 Jun to 30 Aug and consisted of the Cle Elum and Easton reaches. These reaches are in the upper Yakima and focused on impacts to coho parr and residual spring chinook. Selection of river reaches was based on a combination of factors including historical precedence (reaches utilized by Phinney et al. 1998), degree of representation of typical habitats within the Yakima River, and the logistical constraints imposed by intermittent river access points and impassable obstructions (dams, 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 experimental raceways, artificial acclimation streams, 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.

North Fork Teanaway River Surveys--Spring and Summer

The Teanaway River is a major tributary to the upper Yakima River, entering at river kilometer 284. Approximately 26 kilometers up the Teanaway, along the North Fork Teanaway River, the Jack Creek acclimation facility was established as part of the YKFP supplementation effort; beginning in 1999 with the release of 240,000 coho smolts on 10 May. Anticipating the potential for newly established acclimation facilities to attract avian piscivores, surveys were begun in 1999 to form a baseline for avian consumption of salmonids along a reference river reach of the North Fork Teanaway River.

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.

Primary avian predators were California and Ring-billed Gulls at hotspots and Common Mergansers within upper river reaches. Estimated take (presumed to be salmonids) by gulls at hotspots (22 April - 30 May) was 4,084 fish at the Chandler Bypass Outfall and 12,636 fish at Horn Rapids Dam. Combined take was 2.65% of the salmonids passing over Chandler Dam or 0.89 % 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 Stratum 1 was 2,068 kg between 1 Jul and 30 Aug.

Consumption of Juvenile Salmon by Avian Piscivores—2000

In 2000, the YKFP asked the Washington Cooperative Fish and Wildlife Research Unit to continue the research efforts begun in 1997

This effort was again organized into two specific time frames within which impacts of bird predation on juvenile salmon were assessed. The first, 10 April to 30 Jun addressed impacts of avian predators on juvenile salmon (principally spring chinook) during the spring migration of smolts out of the Yakima River. The second, 1 Jul to 30 Aug, addressed coho parr

and residualized spring chinook remaining in the upper sections of the Yakima River. These two time frames followed the basis of organization and methodological design set forward in 1999 and are informally referred to within this document as “spring” and “summer”. The report and subsequent analysis are 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 one 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 were an attempt to more effectively match survey efforts with seasonal bird abundances. We feel the dates utilized in 2000 better capture bird impacts to resident and migrating salmonid populations.

Hotspot Surveys--Spring

With the exception of the date shifts noted above, abundance and consumption surveys of avian predation at 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 (Easton, Cle Elum, Zillah, Benton, 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 Yakama Nation (YN) hatchery personnel.

Aerial Survey--Spring

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.

These surveys provided abundance data and confirmation that hotspots chosen for intensive monitoring were the most active sites. Aerial surveys are also considered a potential alternative to more expensive river drift surveys. 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. 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

This report summarizes data collection activities, methods, results, and topics of discussion for the 2000 field season—10 April to 30 Aug—by the Washington Cooperative Fish and Wildlife Research Unit. Except where noted, methodology and experimental design were consistent with that used during the 1999 season. This report is intended to satisfy the contractual requirement for annual report of activities by the Washington Cooperative Fish and Wildlife Research Unit toward the development of an index to bird predation of juvenile salmonids within the Yakima River for the Washington Department of Fish and Wildlife. All findings in this report should be considered preliminary and subject to revision until presented in a final report.

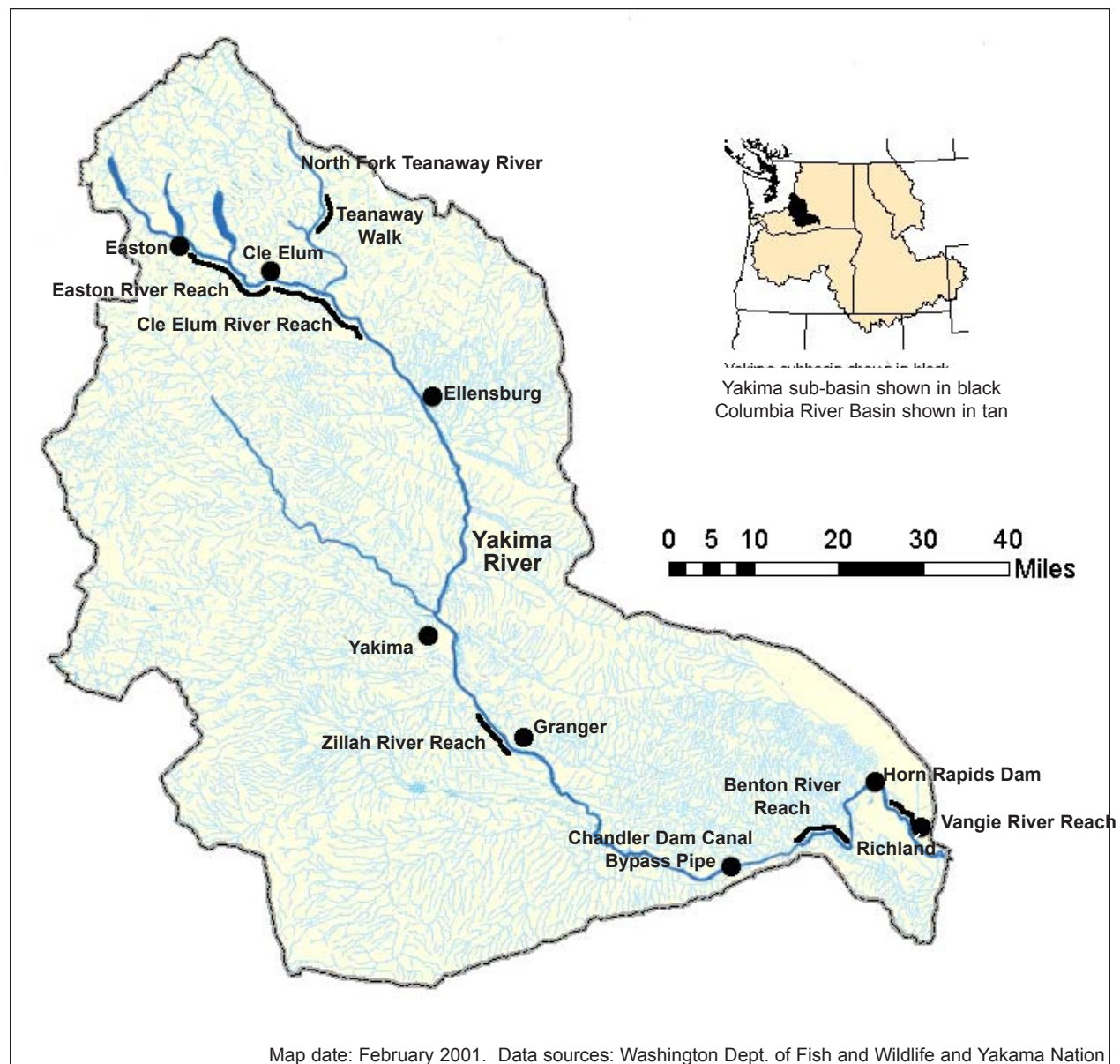
METHODS

Study Locations

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 it's length, beginning at 2,440 meters elevation at the headwaters and ending 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 (Cle Elum, WA 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 from Cle Elum to Selah, WA 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

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



agricultural lands. Middle and lower reaches (Selah to the Columbia River) 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.

Data Collection Methods

Hotspot Survey--Spring

In 2000, hotspot surveys were conducted systematically on a 2-week cycle which included a total of five day-long surveys within each 2-week period, totaling approximately 30 surveys at each site for the 2000 field season; 10 Apr to 30 June (Table 1). In 2000, sites were not always surveyed simultaneously (on the same day) due to logistical constraints. The survey schedule still required two personnel which alternated between the sites to reduce observer bias.

The survey area for Horn Rapids Dam included the width of the channel, 50 meters of above and 150 meters below the dam. The buoy located above the dam was not included within the survey area; birds resting upon the buoy were not included in abundance counts. The survey area for the Chandler Canal Bypass outfall included the width of the river, 50 meters above and 150 meters of below the outfall pipe. All 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 were made from shore stations in either an automobile (Horn Rapids Dam) or bird blind (Chandler Canal Bypass) to avoid disrupting normal bird activity. Binoculars (Leica, 10x42) were used to aid 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 ob-

servers ability to accurately monitor bird behavior. Each hotspot-survey day was divided into 2-hour survey periods, the first began at sunrise, the last ending near, or soon after sunset (to the nearest fifteen-minute interval). Regionally calibrated tables obtained from the National Oceanic and Atmospheric Administration were used to determine the time of sunrise and sunset. Depending upon the length of day and start time, seven or eight 2-hour periods existed within a single day.

Table 1. Hotspot survey dates for Chandler Canal Bypass Pipe and Horn Rapids Dam in 2000.

Chandler	Horn Rapids
14-Apr	13-Apr
16-Apr	15-Apr
18-Apr	18-Apr
21-Apr	20-Apr
23-Apr	22-Apr
25-Apr	25-Apr
28-Apr	27-Apr
1-May	30-Apr
3-May	3-May
6-May	5-May
8-May	10-May
10-May	12-May
13-May	14-May
15-May	17-May
17-May	19-May
20-May	21-May
22-May	24-May
24-May	26-May
27-May	28-May
31-May	31-May
3-Jun	2-Jun
4-Jun	5-Jun
7-Jun	7-Jun
10-Jun	9-Jun
12-Jun	11-Jun
14-Jun	14-Jun
17-Jun	16-Jun
19-Jun	18-Jun
21-Jun	21-Jun
28-Jun	23-Jun

Each 2-hour period consisted of a 45 minute abundance/feeding survey cycle, followed by a 75 minute period without data collection. Within the 45 minute abundance/feeding survey cycle, bird abundance, foraging ratios and foraging success of individuals were determined (Table 2). All piscivorous birds within the 200 meter study area were counted, including those on the bank. Gulls flying within the study area were considered foraging. Birds within

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

Table 2. Hotspot survey period design.

Minutes	Activity	Conditional Factor
1-5	One abundance count per minute (total 5) for each species present, including sex and age if possible.	None
6-10	Determine abundance and foraging ratio of all birds. Count unsuccessful and successful feeding attempts of a single bird for 5 minutes.	First bird of the most abundant piscivorous bird species present which makes an aggressive attempt to capture a fish
11-15	Determine abundance and foraging ratio of all birds. Count unsuccessful and successful feeding attempts of a single bird for 5 minutes.	First bird of the most abundant piscivorous bird species present which makes an aggressive attempt to capture a fish
16-20	Determine abundance and foraging ratio of all birds. Count unsuccessful and successful feeding attempts of a single bird for 5 minutes	First bird of the most abundant piscivorous bird species present which makes an aggressive attempt to capture a fish
21-25	One abundance count per minute (total 5) for each species present, including sex and age if possible.	None
26-30	Determine abundance and foraging ratio of all birds. Count unsuccessful and successful feeding attempts of a single bird for 5 minutes	First bird of the most abundant piscivorous bird species present which makes an aggressive attempt to capture a fish
31-35	Determine abundance and foraging ratio of all birds. Count unsuccessful and successful feeding attempts of a single bird for 5 minutes	First bird of the most abundant piscivorous bird species present which makes an aggressive attempt to capture a fish
36-	Determine abundance and foraging ratio of all birds. Count unsuccessful and successful feeding attempts of a single bird for 5 minutes	First bird of the most abundant piscivorous bird species present which makes an aggressive attempt to capture a fish
41-45	One abundance count per minute (total 5) for each species present, including sex and age if possible.	None
46-120	No survey activity.	

other non-foraging activities. In addition, it was not feasible to distinguish foraging gulls standing on rocks from those loafing.

The bird chosen to be observed for the 5-minute observation interval was the first individual of the most abundant species of avian piscivore present to make an aggressive attempt to capture a fish in the study area. Because of the inability to truly select foraging birds at random in the context of our hotspots, the "first attempt" method was chosen. This differs from the method utilized by Phinney et al. (1998) where an attempt to enumerate all takes within the observation period was made. As mentioned previously, this method likely underestimates consumption, especially at high bird abundances.

Once a bird was chosen, the number of attempts and successful attempts at fish capture were recorded. Successful feeding attempts were those in which the bird being observed consumed a fish, regardless of the means of acquisition. For gulls, aggressive (but 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 consumed. Some examples of unsuccessful attempts include:

1. The observed gull dives towards and touches the water with wing, bill, or foot and does not capture and consume a fish.
2. The observed gull captures a fish but drops the fish prior to consuming it.
3. The observed gull captures a fish, but the fish is stolen away by another gull who consumes it.
4. The observed gull steals a fish from another gull, loses control of the fish, and does not consume it.

Although all piscivorous birds within the survey area were counted and recorded, foraging and feeding behavior assessments were focused upon gulls due

to their overwhelming abundance. When gull numbers or viewing conditions did not allow for determination of gulls to 'species', sightings were described as 'gull' for purposes of modelling abundance and consumption.

River Reach Surveys--Spring and Summer

Spring river surveys included four river reaches, each surveyed approximately every 2 weeks from 10 Apr to 30 Jun (Table 3). These reaches included Cle Elum, Zillah, Benton and Vangie. Summer surveys occurred once each week on the Easton and Cle Elum reaches from 1 Jul to 30 Aug. Table 4 details start/stop points and total length for these reaches. All reaches surveyed in both spring and summer were identical in length and location as those in 1999.

All river reach surveys were conducted by a two-person survey team from 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 between 2.5 to 5.5 hours, depending upon length of reach, water flow and wind speed. All surveys were performed while actively rowing the drift boat/raft down stream to decrease the interval of time required to traverse the reach.

Of the two-person survey team, one was responsible for navigation while the other was responsible for identifying and recording birds (team members alternated rowing and bird identification duties approximately every hour). All 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 birds positively identified by the navigator 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 (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

Table 3. River reach survey dates for spring and summer 2000. Line demarcates spring and summer survey periods.

Date	Easton	Cle Elum	Zillah	Benton	Vangie	Teanaway
10-Apr			X			
12-Apr		X				
17-Apr					X	
24-Apr			X			
26-Apr		X				
02-May				X	X	
09-May			X			
11-May		X				
16-May				X	X	
18-May	X					
19-May		X				X
23-May			X			
25-May	X	X				X
30-May				X	X	
01-Jun	X					
02-Jun		X				X
06-Jun			X			
08-Jun	X	X				X
15-Jun	X			X	X	X
16-Jun		X				
20-Jun			X			
22-Jun	X	X				
27-Jun				X	X	
30-Jun		X				X
03-Jul	X					
06-Jul	X					
07-Jul		X				
13-Jul		X				X
14-Jul	X					
20-Jul		X				
21-Jul	X					
27-Jul		X				X
28-Jul	X					
03-Aug	X					
04-Aug		X				
10-Aug						X
11-Aug		X				
17-Aug	X					
18-Aug		X				
24-Aug	X					

Table 4. Start point, end point and total length (km) of river reaches surveyed for piscivorous birds.

Name	Start	End	Length
Vangie	1.6 km above Twin Bridges	Van Giesen St Hwy Bridge	9.3
Benton	Chandler Canal Power Plant	Benton City Bridge	9.6
Zillah	US Hwy 97/St. Hwy 8 Bridge	Granger Bridge Ave Hwy Bridge	16.0
Cle Elum	South Cle Elum Bridge	Thorp Hwy Bridge	28.3
Easton	Easton Acclimation Site	South Cle Elum Bridge	29.3
Teaway	Jungle Creek	Dickey Creek Bridge	5.8

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 passage 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.

Acclimation Site Surveys--Spring

Beginning on 11 Apr and continuing to 30 May, YN hatchery technicians at the Clark Flats, Jack Creek and Easton acclimation sites conducted piscivorous bird surveys. Surveys were conducted approximately every 2 hours beginning 1 hour before sunrise on even numbered days and at sunrise on odd number days. At the beginning of each 2-hour period, 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 Teaway) were identified and recorded

within their respective zones. Surveys were conducted on foot by hatchery technicians who utilized a pair of 8x binoculars to aid in species identification.

Aerial Surveys-Spring

Five aerial surveys were conducted by the YN between 2 May and 27 Jun (Table 5). Surveys began at the mouth of the Yakima River and progressed up river as far as weather and flight conditions permitted. All piscivorous birds seen were recorded within reaches defined by physical objects and structures detectable from the plane. Start point, end point and length of aerial survey sections are detailed in Table 6.

Miscellaneous Surveys--Spring and Summer

In order to minimize the possibility that unexpectedly intense predation of fish by avian piscivores was occurring in areas outside scheduled hotspot, river drift and acclimation surveys, periodic surveys were conducted in 1999 at locations previously identified by others (Phinney et al. 1998) as potentially attractive to piscivorous birds. These areas included Chandler Dam (Prosser), Parker Dam, Roza Dam, Sunnyside Dam, Union Gap Dam, Thorp Diversion, Easton ponds and the Cle Elum Hatchery acclimation slough. Of these areas, only the Easton ponds and Cle Elum slough were considered a priority for monitoring in 2000. The other sites having low or no piscivorous bird activity. In 2000, surveys at the Easton ponds and Cle Elum slough were done five times each between 10 Apr and 30 Jun with one 45-minute observation survey being conducted as de-

Table 5. Dates and reaches surveyed by air in 2000.

Reach	2-May	16-May	30-May	13-Jun	27-Jun
Mouth of Yakima River to Horn Rapids Dam	X	X	X	X	X
Horn Rapids Dam to Benton City Bridge	X	X	X	X	X
Benton City to Prosser Dam	X	X	X	X	X
Prosser Dam to Mabton Bridge	X	X	X	X	X
Mabton Bridge to Union Gap	X	X	X	X	X
Union Gap to Selah Gap	X	X	X	X	X
Selah Gap to South end of Ellensburg Canyon	X	X	X	X	X
Ellensburg Canyon	*	*	*	*	*
North End of Ellensburg Canyon to Clark Flat	*	*	*	*	*
Clark Flat to Indian John Hill (Power Lines)	*	*	*	*	*
Indian John Hill to Cle Elum Hatchery	*	*	*	*	*
Cle Elum Hatchery to Easton	*	*	*	*	*

* Sections not flown due to safety considerations.

Table 6. Start location, end location and length of aerial surveys.

River Reach Name	Start River km	End River km	Total km
Mouth of Yakima River to Horn Rapids Dam	0.0	28.8	28.8
Horn Rapids Dam to Benton City Bridge	28.8	47.6	18.8
Benton City to Prosser Dam	47.6	75.3	27.6
Prosser Dam to Mabton Bridge	75.3	95.6	20.3
Mabton Bridge to Union Gap	95.6	171.3	75.6
Union Gap to Selah Gap	171.3	187.3	16.0
Selah Gap to South end of Ellensburg Canyon	187.3	197.9	10.5
Ellensburg Canyon	197.9	238.2	40.3
North End of Ellensburg Canyon to Clark Flat	238.2	267.8	29.6
Clark Flat to Indian John Hill (Power Lines)	267.8	279.0	11.2
Indian John Hill to Cle Elum Hatchery	279.0	292.9	13.9
Cle Elum Hatchery to Easton	292.9	322.2	29.2

scribed in Table 2.

North Fork Teanaway River Surveys--Spring and Summer

The survey reach included the river and it's banks from the Jungle Creek/North Fork Teanaway confluence down river past the Jack Creek acclimation site to the Dickey Creek bridge (5.8 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 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, sex and age if distinguishable. A pair of Leica 10x42 binoculars was utilized to aid in identification. This river reach was surveyed nine times between 19 May and 10 Aug 2000.

Modelling Methods

Estimates of smolt predation from the survey data were calculated by dividing the river into four spatial strata. Each stratum reflected differences in species abundance and distribution, geography and most importantly differences in both the type of survey data collected, and survey effort. The four strata were 1) the upper Yakima River, 2) the canyon (not surveyed in 2000), 3) the river below the canyon and 4) the two hot spot locations. In addition, the 2000 survey included nine foot surveys along the Teanaway River. Estimates of biomass consumed were calculated for this area, however a lack of data on fish composition and size prevented calculations of the number of fish taken. The equations used to estimate bird abundance, and eventually calculate the number of smolts taken, 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. In addition, feeding rates and bird abundance data were collected at two "hotspots" on the river. Assumptions common to all strata were that all birds observed were correctly counted and identified to species, that observing the birds did not effect the behavior, and that the behavior and abundance of birds during the time of observation was representative of birds at all times. The assumption was also made that smolt predation only occurred between the hours of dawn and dusk. In addition there were several stratum specific assumptions which are discussed later in the text. The total number of smolts taken from the river during the outmigration season M , is estimated by summing the estimates across strata. An estimate of M ,

is given by,

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

Where,

$$\hat{M}$$

equals the total number of smolts consumed, and

$$\hat{M}_i$$

equals the estimated number of smolts consumed in the i^{th} stratum ($i = 1, \dots, 4$)

River Reaches

Surveys in Stratum 1 were conducted by river drifts at regular intervals throughout the survey period. Two reaches of the river (Easton and Cle Elum) were surveyed, each on a different day. The Cle Elum section was surveyed more than the Easton section for each survey period (spring and summer). The reach surveyed was assumed to be representative of the entire stratum. Smolt consumption is estimated by the following:

$$\hat{M}_1 = \sum_{j=1}^{B_1} \sum_{k=1}^{t_{1ks}} \frac{W_j P_j}{\left(\sum_{h=1}^H s_{1kh} p_{1kh} \right)^I} \left[\frac{T_1}{\sum_{s=1}^n t_{1ks}} \cdot \frac{Km_1}{\sum_{s=1}^n km_{1ks}} \cdot \sum_{s=1}^n b_{1jks} \right] \quad (2)$$

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 k^{th} 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} ($j = 1, 2, \dots, B$) bird species in terms of grams per day,
- P_j = the proportion of the j^{th} ($j = 1, 2, \dots, B$) bird species diet comprised of the h^{th} salmonid species ($h = 1, 2, \dots, H$),

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.

(2.c)

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

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

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:

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.

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 weighted average of salmonid smolt size can be calculated by:

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

$$\left(\sum_{h=1}^H s_{1kh} \cdot p_{1kh} \right)$$

(2.a)

(2.d)

and the spatial sampling fraction was,

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

(2.b)

Stratum 1 contained two reaches, Easton and Cle Elum, 29.3 and 28.3 km in length respectively. The Cle Elum reach was surveyed throughout the season, from April to August and the Easton reach was surveyed from May to August. 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.

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 were 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:

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

(2.e)

Bird abundance for each block was estimated by:

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

$$\frac{T_{1k}}{\sum_{s=1}^n t_{1ks}} \cdot \frac{Km_1}{\sum_{s=1}^n km_{1ks}} \cdot \sum_{s=1}^n b_{1jks}$$

The abundance of both spring chinook and coho can be calculated using the number of each species released from the hatcheries and rearing ponds dur-

ing 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,

$$\sum_{k=1}^{t_1} \frac{W_j P_j}{\left(\sum_{h=1}^H S_{1kh} P_{1kh} \right)^I} \left[\frac{T_1}{\sum_{s=1}^n t_{1ks}} \cdot \frac{Km_1}{\sum_{s=1}^n km_{1ks}} \cdot \sum_{s=1}^n b_{1jks} \right] \quad (2.f)$$

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 (Eq. 2) 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 preying 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 a 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.

The calculations for Stratum 3 are similar to Stratum

1. The Benton reach was floated with the Vangie (West Richland) reach, so these two reaches were treated as one. The Zillah reach was always floated alone and 1 week separated the Zillah and Benton/Vangie reach. Therefore, blocks were generally 1 week in length, centered on a survey of either the Zillah or Benton/Vangie reach. There was one 2-week block where only the Vangie reach was surveyed due to logistical constraints. As a result, it was treated as its own spatial and temporal expansion factor representing that one drift.

Because there were no surveys conducted in Stratum 2 by design, no estimations of consumption are presented. It is anticipated that this stratum will be surveyed in the 2001 season.

Hotspots

Horn Rapids Dam and the Chandler Canal Bypass Outfall were defined as hotspot locations due to high levels of avian predation. On-shore observers collected data on bird abundance and feeding rates. The consumption estimates were calculated for each juvenile salmonid species passing through the Chandler Juvenile Fish Processing Center. The estimate of the total number of smolts (or grams of fish) taken in this stratum is,

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

where

A_{jnmr} = the number of active birds feeding in the r^{th} 5 minute period ($r = 1, 2, \dots, 6$), of the n^{th} survey period ($n = 1, 2, \dots, P$), on the m^{th} day ($m = 1, 2, \dots, t$), for the j^{th} species ($i = 1, 2, \dots, B_i$),

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

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,

There were 24 5-minute periods in 2 hours, six of which were sampled for feeding rates, giving a sampling fraction of 6/24. The number of fish taken in the six 5-minute periods was expanded by the sampling fraction, hence the 24/6 term in the calculation. The number of fish consumed each day was multiplied by the proportion of each salmonid species present in the river on that day as defined by Chandler Dam passage.

North Fork Teanaway River Surveys

Bird abundance data were also collected during a foot survey along a reach of the North Fork Teanaway River including the Jack Creek Acclimation Site. The estimate of biomass consumption is for the length of the survey reach only (i.e., not extrapolated to the river length), for the time between two surveys. Biomass (M_5) was calculated by,

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

where

- T_5 = the length of the survey season in days for stratum five,
- t_5 = the number of survey days for stratum five
- $b_{5,jk}$ = 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} ($j = 1,2,\dots,B$) bird species in terms of grams per day,
- P_j = the proportion of the diet consisting of the j^{th} ($j = 1,2,\dots,B$) comprised of the h^{th} salmonid species ($h = 1,2,\dots,H$).

RESULTS

River Reach Surveys

Avian Piscivore Abundance--Spring

After combining gull species into a single group (gulls), 12 species of avian piscivores were identified, including the Bald Eagle, Black-crowned Night Heron, Belted Kingfisher, Common Merganser, Double-crested Cormorant, Great Blue Heron, Gulls, Hooded Merganser, Caspian Tern, Green Heron, Barrow's Goldeneye and Osprey. While Barrow's Goldeneye were occasionally sighted, few appear to breed within the areas surveyed. Sightings were most common within the early spring and males and females were in approximately equal ratios. For these reasons, it is believed that most individuals of this species were migrants moving further north to the Canadian Interior. These data and the availability of information supporting the hypothesis that goldeneyes do not consume significant amounts of fish will likely result in this species' removal from future analyses.

Inclusive of gulls, avian piscivore abundance during spring surveys ranged from 1.2 birds/km on the Cle Elum reach to 2.9 birds/km on the Vangie reach (Figure 2). The peak abundance of all piscivorous birds for any single survey day was 3.3 birds/km on 16-May within the Zillah reach. If gulls are excluded,

mean bird abundance ranged from 0.7 birds/km within the Benton reach to 2.2 birds/km on the Zillah reach. Because gulls were rarely sighted on the Zillah and Cle Elum drifts, abundance of avian piscivores does not decline when gulls are excluded. Of the 12 species encountered, only the Great-blue Heron occurred within all four reaches surveyed during the spring. The Common Merganser was identified within three of the four survey reaches, absent only in the Benton reach.

Common Mergansers, which are of particular importance due to their known utilization of salmon smolts as forage and their relative high abundance due to breeding activities within the upper reaches of the Yakima River, were encountered most frequently in the Cle Elum reach (0.70 birds/km; Figure 3). They represented 57.3% of all piscivorous birds within the Cle Elum reach during spring. In the lower sections, Common Mergansers were only seen in the Zillah and Vangie reaches and accounted for only 14.7% (0.3 birds/km) of all avian piscivores observed (gulls included) on these two reaches.

Exclusive of gulls, Great-blue Herons were the most frequently encountered bird species across all four reaches (Figures 4 to 7), averaging 0.4 birds/km. Common Mergansers and Double-crested Cormorants were the second most frequently observed birds (0.4 birds/km for both species).

Figure 2. Spring abundance of all avian piscivores by reach—including gull sightings, 10 Apr to 30 Jun. Error bars represent standard deviation.

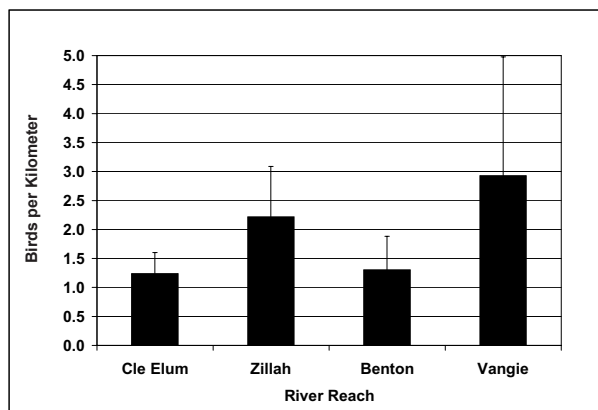


Figure 3. Spring abundance of Common Merganser by reach, 10 Apr to 30 Jun. Error bars represent standard deviation.

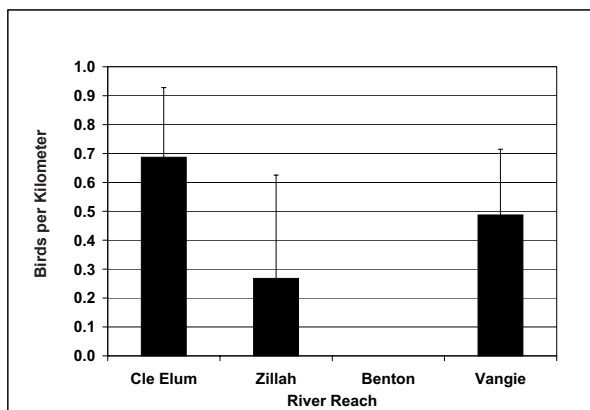


Figure 4. Average spring avian piscivore abundance per kilometer within the Cle Elum river reach, 10 Apr to 30 Jun. Error bars represent standard deviations. Bars without errors represent a single observation.

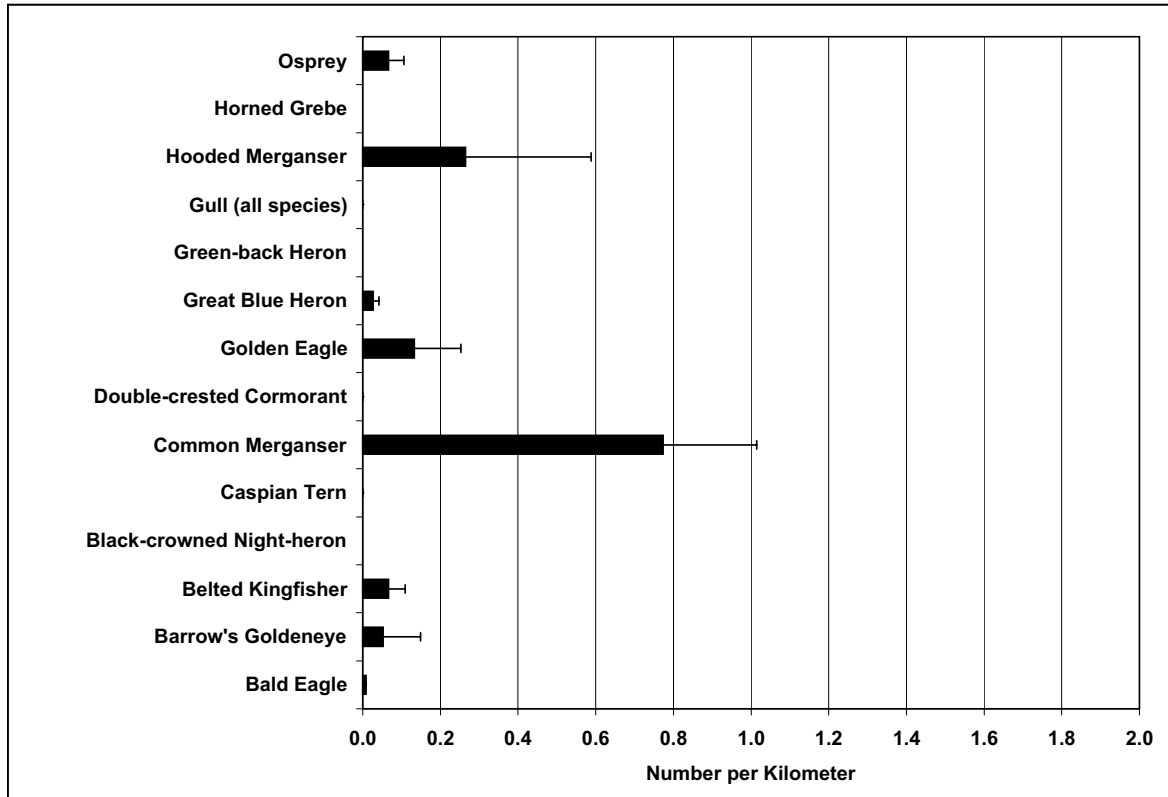


Figure 5. Average spring avian piscivore abundance per kilometer within the Zillah river reach, 10 Apr to 30 Jun. Error bars represent standard deviations. Bars without errors represent a single observation.

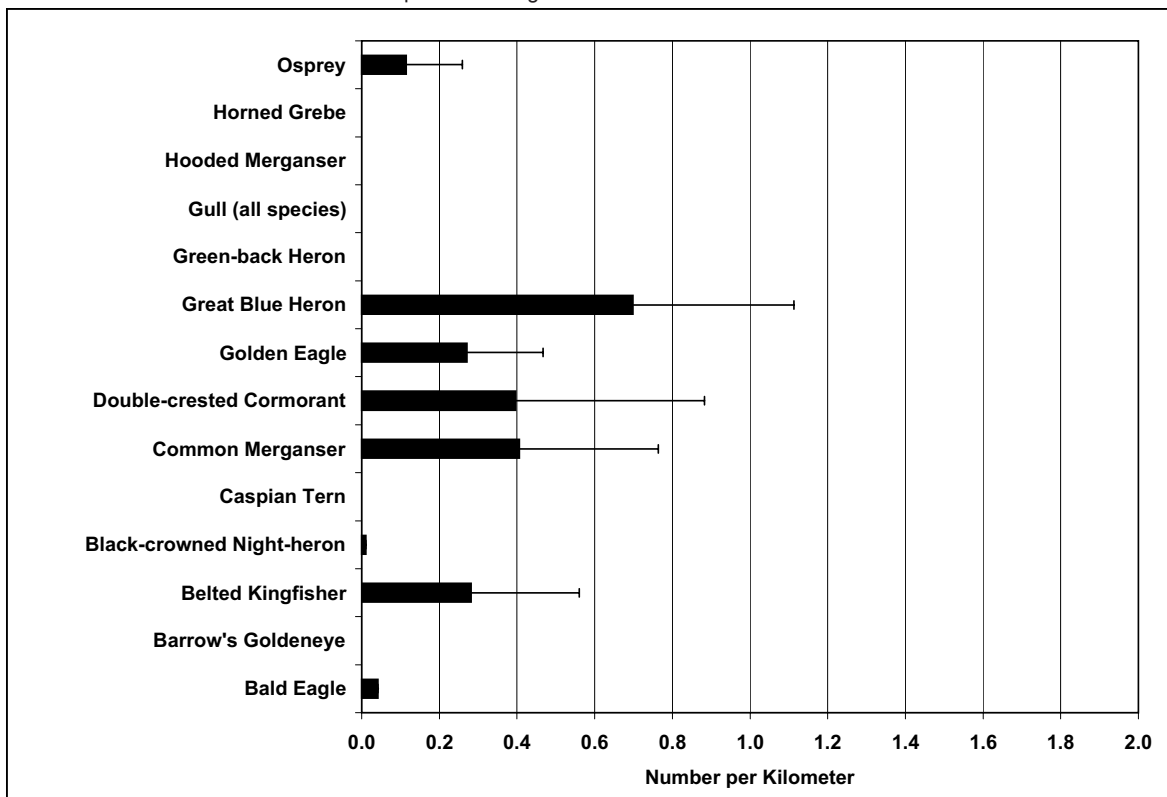


Figure 6. Average spring avian piscivore abundance per kilometer within the Benton river reach, 10 Apr to 30 Jun. Error bars represent standard deviations. Bars without errors represent a single observation.

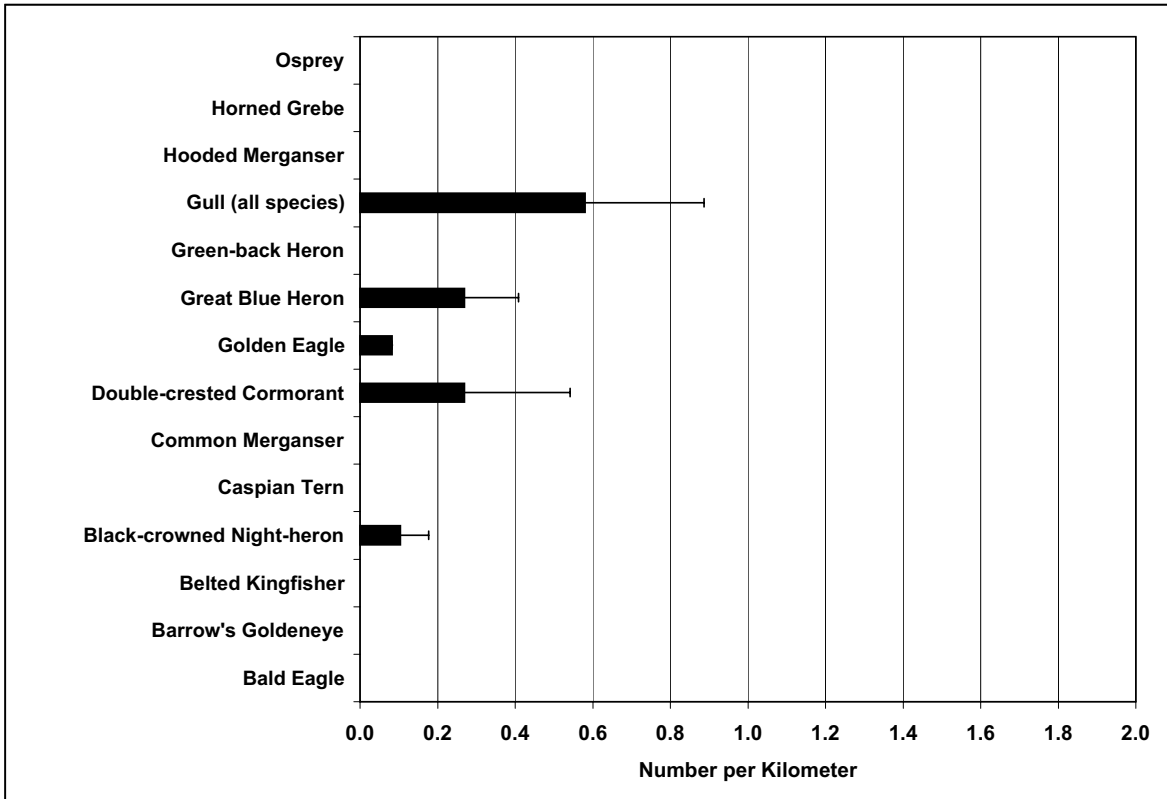
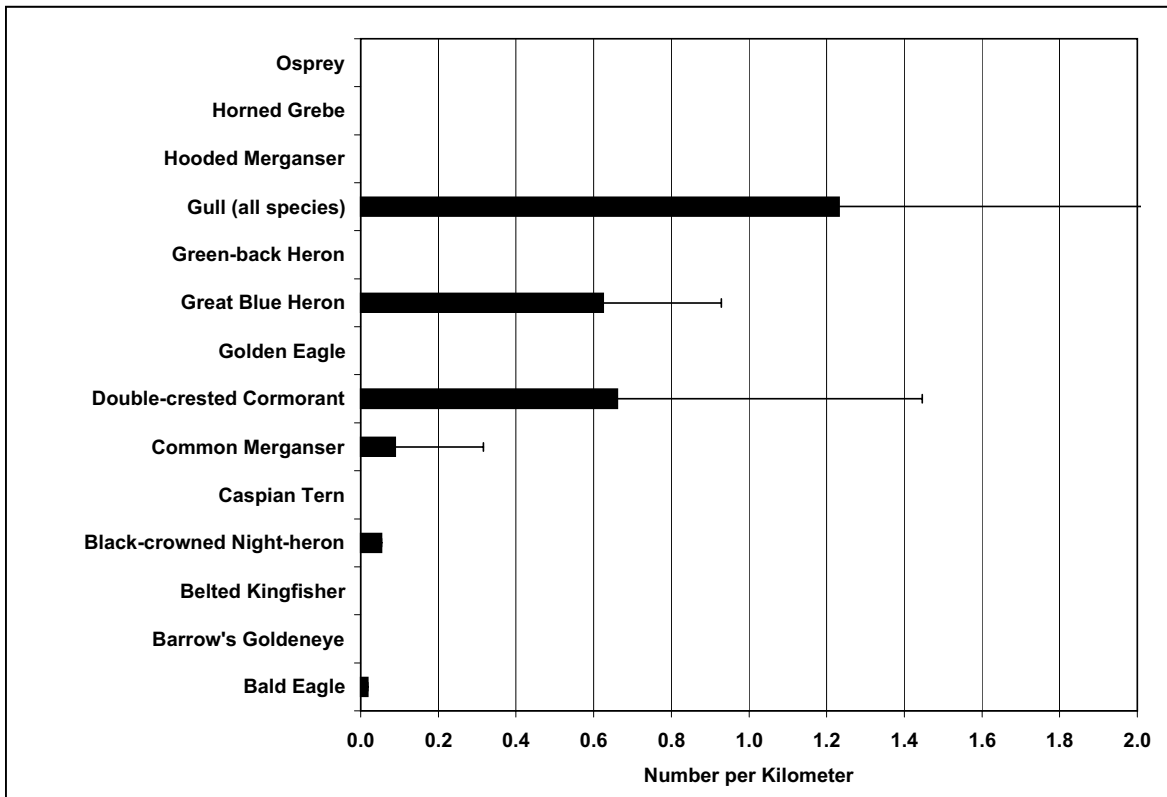


Figure 7. Average spring avian piscivore abundance per kilometer within the Vangie river reach, 10 Apr to 30 Jun. Error bars represent standard deviations. Bars without errors represent a single observation.



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 and Cle Elum reaches. After combining gull species into a single group (gulls), seven species of avian piscivores were identified across both reaches. These included: Caspian Tern, Belted Kingfisher, Common Merganser, Double-crested Cormorant, Great Blue Heron, Gulls, and Osprey (Figures 8 and 9). Inclusive of gulls, avian piscivore abundance during the summer surveys was 0.9 birds/km on the Cle Elum reach and 2.2 birds/km on the Easton reach. (Figure 10). The peak abundance of all piscivorous birds for any single survey day was 3.3 birds/km on 28 Jul within the Easton reach. Because gulls were extremely rare on these two reaches of the upper Yakima (0.04 birds/km on Cle Elum only), excluding them from the counts

creates negligible differences in mean or peak numbers of birds observed. Of the seven species encountered, all but Double-crested Cormorants and gulls were observed on both reaches.

Mergansers were the predominant species, averaging 1.7 and 0.7 birds per kilometer on the Easton and Cle Elum reaches, respectively (Figure 11). This represented 76% and 72% of all piscivorous birds counted, respectively. Mergansers breed extensively in the upper Yakima and many of the birds recorded were young of the year. The only other avian piscivores occurring consistently across drifts were Belted Kingfishers and Osprey. On both reaches these two species averaged 0.21 and 0.12 birds/km, respectively.

Avian Piscivore Consumption--Spring

Consumption of fish by Bald Eagles and Osprey was estimated at 4,501 kg across all survey periods

Figure 8. Average abundance of all avian piscivores per river kilometer by drift along the Easton river reach. Error bars represent standard deviations. Bars without errors represent a single observation. Standard deviation for Common Merganser is 0.7.

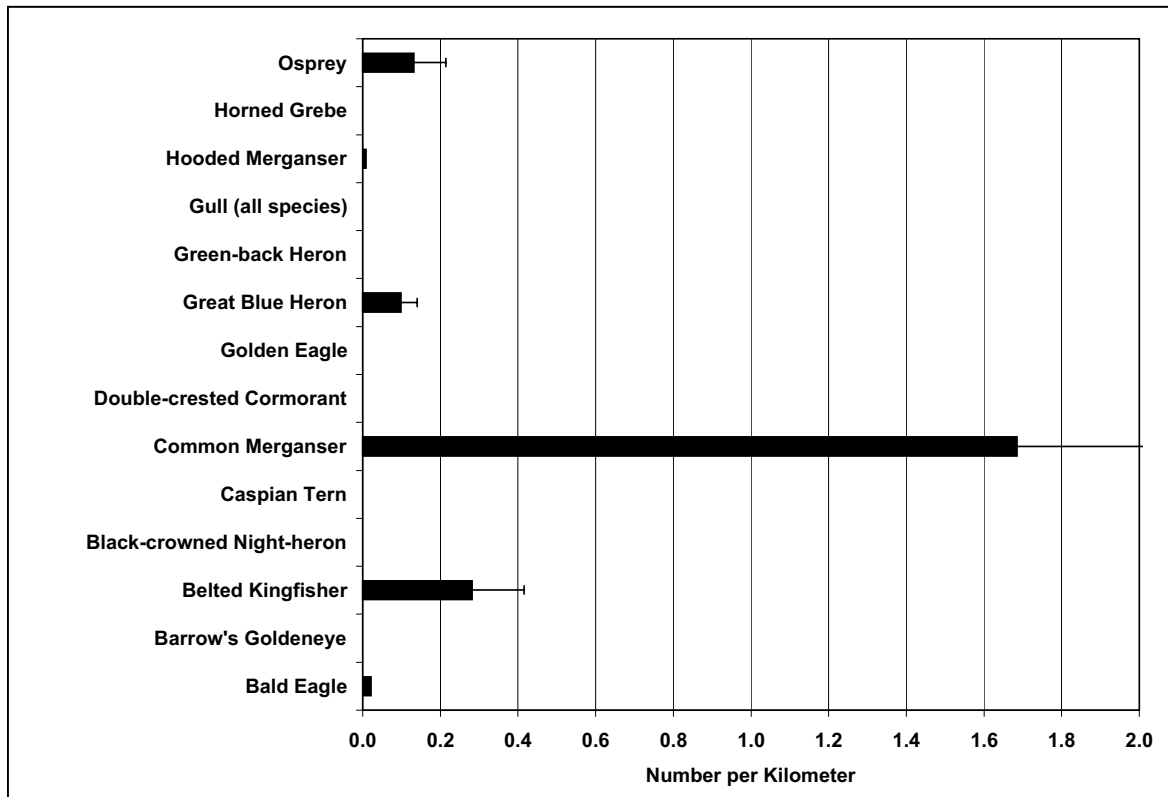


Figure 9. Average abundance of all avian piscivores per river kilometer by drift along the Cle Elum river reach. Error bars represent standard deviations. Bars without errors represent a single observation.

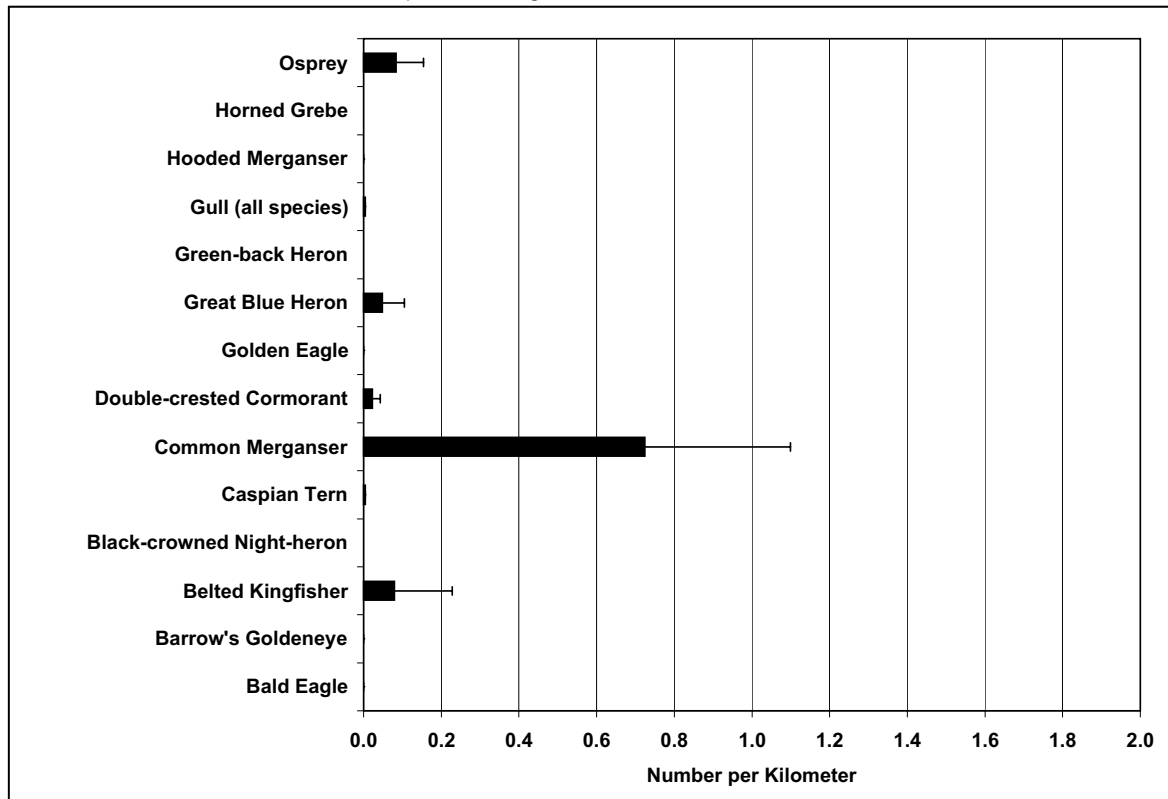


Figure 10. Average summer avian piscivore abundance within the Easton and Cle Elum reaches, 1 July to 30 Aug. Error bars represent standard deviation.

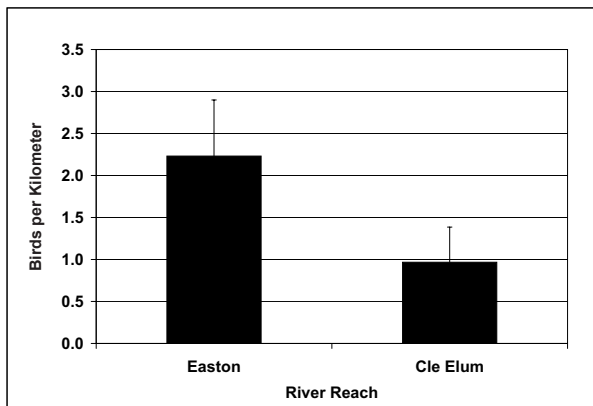
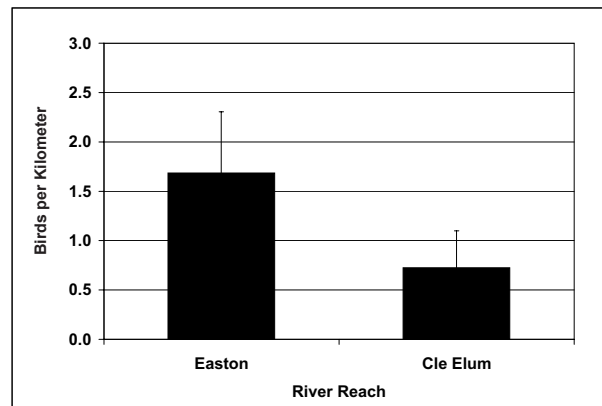


Figure 11. Average summer Common Merganser abundance within the Easton and Cle Elum reaches, 1 July to 30 Aug. Error bars represent standard deviation.



in Strata 1 and 3. Current efforts are being made to better understand the dietary preferences of these species. It is probable that their impact on smolt or parr sized salmonids is much less than that calculated. If this were true, decreasing the consumption estimate of these three bird species would lower the overall biomass estimates for each stratum and proportionately raise the estimated

impacts of other species such as Common Mergansers, Great-blue Herons and Belted Kingfishers. Current biomass estimates do include consumption estimates for Bald Eagles and Osprey. Decisions on the removal of these and other candidate species will be left for the 2001 report.

Mean total biomass consumption for the spring sur-

vey season was greater within Stratum 3 (72.8 kg/km) than within Stratum 1 (41.5 kg/km). The primary consumer within Stratum 1 was the Common Merganser, accounting for 66.9% of total biomass consumed. The next species of significance within Stratum 1 during spring was the Great-blue Heron which accounted for only 2.0 % of the total biomass consumed.

Stratum 3 had a greater diversity of avian piscivores consuming a significant biomass. These included: Double-crested Cormorants, Great-blue Herons, and Common Mergansers. Of this group, Great-blue Herons were estimated to have consumed the largest percentage of fish biomass (27.5%), while Double-crested Cormorants and Common Mergansers consumed 26.3 and 13.4 %, respectively. Though present in substantial numbers in both Stratum 1 and 3 during the spring, Belted Kingfishers consumed less than 1% of the total biomass taken in either stratum.

Avian Piscivore Consumption--Summer

Because water temperatures in the lower river were too high for salmon smolts to survive, summer surveys were conducted only within Stratum 1 (upper reaches of the Yakima). During this time of year, salmonids are represented by residualized hatchery and wild spring chinook, rainbow trout and summer parr in the upper river and are still vulnerable to avian predation. Mean total biomass consumed within Stratum 1 in summer was 40.0 kg/km. This represented approximately half (49%) of all the estimated biomass consumed within Stratum 1 for the entire season. Common Mergansers accounted for the greatest proportion of the take (87% of total consumed) during this time period. During this time period, Common Mergansers are in their highest numbers because large broods have moved onto the river to feed. Though Great-blue Herons are not known to breed within the upper reaches, they were much more frequent during this survey within Stratum 1 than during the spring. Their estimated consumption was approximately 5% of total estimated biomass consumed (second to that of Common Mergansers) . Belted Kingfishers nearly tripled in abundance from the

spring survey period, yet still accounted for just less than 1% of the total estimated take.

Hotspot Surveys

Avian Piscivore Abundance

In 2000, hotspot surveys were conducted on 30 days at both Chandler Canal Bypass (Chandler) and Horn Rapids Dam (Horn Rapids). Surveys occurred between 10 Apr and 30 Jun. Although other piscivorous birds were identified, gulls were by far the most numerous. Mean gull abundance was low (< 5 per day) in April and didn't begin to climb significantly until mid-May. Peak numbers occurred during the last week in May through the first week of June and then began to drop again until the end of the surveys.

Species identified at the Chandler hotspot included Black-crowned Night-heron, Great Blue Heron, Gulls (California, and Ring-bill), Common Merganser, and Double-crested Cormorant. Gulls were the most frequently observed species at Chandler and Horn Rapids. Other species identified at Horn Rapids included Double-crested Cormorant, California and Ring-bill Gulls, Caspian Tern, Great Blue Heron, and Osprey. Within the time period surveyed, the maximum number of gulls at Chandler occurred on 17 May with an average of 39.5 (Figure 12) and at Horn Rapids the maximum occurred on 26 May with 132.9 (Figure 13). This represented an increase from 1999 of approximately 265% and 268%, respectively.

When gull numbers reached their peak levels (100 and above), accurate counts became problematic due to the difficulty in separating counted from uncounted gulls. At Horn Rapids in particular, where survey personnel were often at considerable distance from feeding gulls (upwards of 50 meters), gulls would often fly in and out of dense groups, making counting difficult. Although gull numbers rarely reached such high numbers, when they did occur, surveyors estimated the total number of gulls present. Diurnal patterns of gull abundance were

Figure 12. Average gull abundance at Chandler Canal Bypass Pipe 10 Apr to 30 Jun. Error bars represent standard error

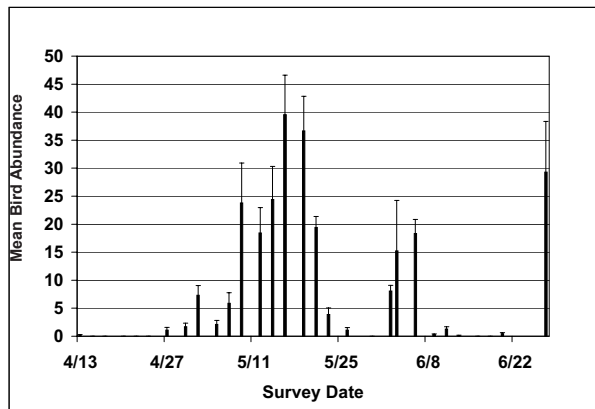
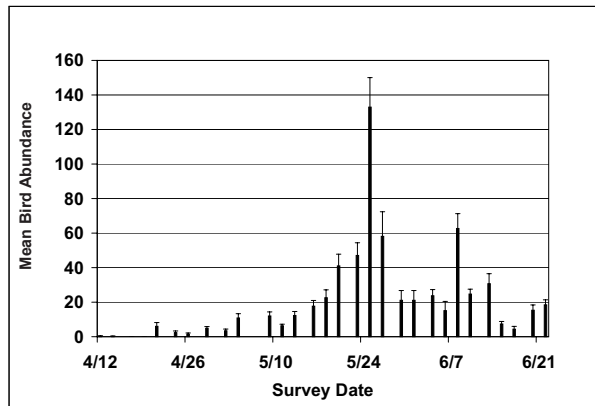


Figure 13. Average gull abundance at Horn Rapids Dam 10 Apr to 30 Jun. Error bars represent standard error.



difficult to discern when gull numbers were low, as occurred the first 6 weeks of the survey period. As gull numbers increased in mid May, patterns of diurnal abundance became more apparent. To resolve these patterns, survey periods which were numbered sequentially 1 to 8 (each 2 hours long with seven or eight occurring per day depending upon survey start time and day length) were averaged across the survey season—10 Apr to 30 June. All survey Period 1 gull observations (first and second hour after sunrise) were averaged across all days, all survey Period 2 gull observations (third and fourth hour after sunrise) and so on for all survey periods.

Mean daily abundance patterns at Chandler show a quickly building gull presence from sunrise to a mean daily peak abundance in Period 3 (12.4 gulls). This is approximately the 5th or 6th hour after sunrise.

The pattern of gull abundance after the peak is not consistent, although it does show a general decline. By Period 8, the last of the surveys, gull numbers dropped to below four and observations after sunset were not possible. It is assumed that there was insufficient light for effective foraging after this point.

A similar analysis at Horn Rapids shows a pattern slightly different from that at Chandler. While gull numbers did increase quickly to a peak during the third period, they remained near this level the remainder of the day. By the last period (8), mean gull abundance had only decreased by two birds (25.56 during Period 3 to 23.63 in Period 8).

Consistent with survey results from 1999, both sites did show a daily peak in the 3rd period. However, neither site surveyed in 2000 showed a consistent pattern of decline from the 3rd period to the end of the day as seen in 1999. This brings into question the ability of utilizing the daily peak as an index for mean daily gull abundance as was suggested in our 1999 annual report. Data from 2001 may help clarify this issue.

Consumption by Gulls

Modeled average rates of successful fish capture by gulls at both hotspots resulted in consumption estimates for these sites of 28,120 fish at Chandler and 123,840 fish at Horn Rapids. If the release of 2.001 million fall chinook smolts from below Chandler Dam are taken into account (148,000 smolts on 10 Apr and 1,853,037 smolts on 25 May), then our combined consumption estimate of 151,960 fish represents 5.6% of all smolts estimated passing or being released from the Chandler Dam area during the 2000 smolt migration season. These figures do not include consumption by gulls at hotspots before surveys began (10 Apr) or after surveys ended (30 June) and assume that all fish taken were smolts.

North Fork Teanaway River Surveys

Surveys along the North Fork Teanaway resulted in only a small fraction of estimated bird abundance and consumption in 2000. Only Belted Kingfishers

and Great-blue Herons were observed. Total estimated consumption for this survey across the season was only 22.1 kg or 0.1% of all estimated fish consumption by birds along the Yakima for the season.

Acclimation Site Surveys

Completed surveys do not suggest that abnormally large numbers of piscivorous birds congregate within or near the Easton, Jack Creek and Clark Flats spring chinook acclimation facilities. Piscivorous birds observed included Great-blue Heron, Belted Kingfisher, Red-breasted Merganser, Osprey and Common Merganser. Of the three acclimation sites, Clark Flats had the greatest occurrence of birds, but numbers never exceeded a total of 11 birds and this occurred on only 2 days. Most days totalled 2 birds or less. Further detail regarding the results of these surveys will be provided in our 2001 report.

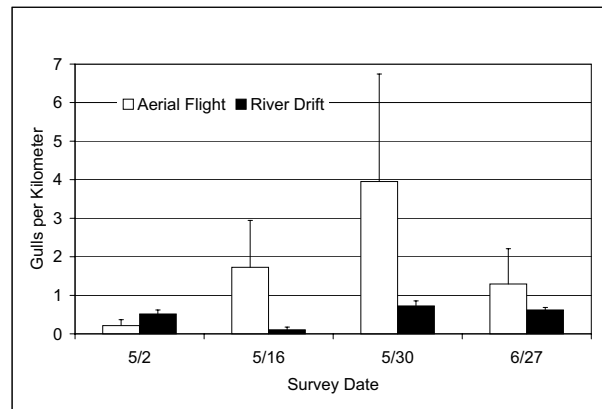
Aerial Surveys

Five aerial surveys were conducted by the YN between 2 May and 27 Jun. Aerial flights coincided (same day) with four river drifts along a single reach (Benton), the fifth flight being separated by 2 days from the river drift. This provided some limited paired data by which to make comparisons within Stratum 3. Due to difficult flying conditions, coverage by aerial surveys was incomplete for some portions of the river. Those reaches for which flights were incomplete represented everything upriver from the south end of the Yakima Canyon (Table 5).

Twelve species were enumerated through river drifting and seven were detected through aerial flight surveys. Two of the species detected by the aerial flights (American White Pelican and Great Egret) were not observed on any of the river drifts, while nine species detected through river drifts went undetected the by aerial surveys. A paired t-test analysis of the four concurrent drift-aerial flights for gull abundances found no significant difference between the two survey methods ($p=0.18$, 4 d.f.) at the 95% confidence limit. Gulls were the only

species counted consistently by both methods (Figure 14). Even with this species, however, the graphical evidence suggests that the t-test results are due to a lack of statistical power and not a similarity in the results of the two survey methods.

Figure 14 Average gull abundance comparisons of the Benton river reach from aerial flight and river drift surveys.



Miscellaneous Surveys

One 45-minute survey consistent with the hotspot methodology (Table 2) was done during 5 days each at the Cle Elum hatchery slough and the Easton ponds. Common Mergansers were the most abundant bird at each site, averaging between 4 and 5 birds/day across the five surveys at both sites (Figs 15 and 16). The maximum abundance on any survey day for an individual species was for Common Mergansers at both sites. There were 20 mergansers on 1-Jun at the Cle Elum slough and 12 mergansers on 4-May at the Easton ponds.

Figure 15. Average avian piscivore abundance per day from 5 surveys at the Cle Elum hatchery slough, 10 Apr to 30 Jun. Error bars represent standard deviation. Bars without error represent a single observation

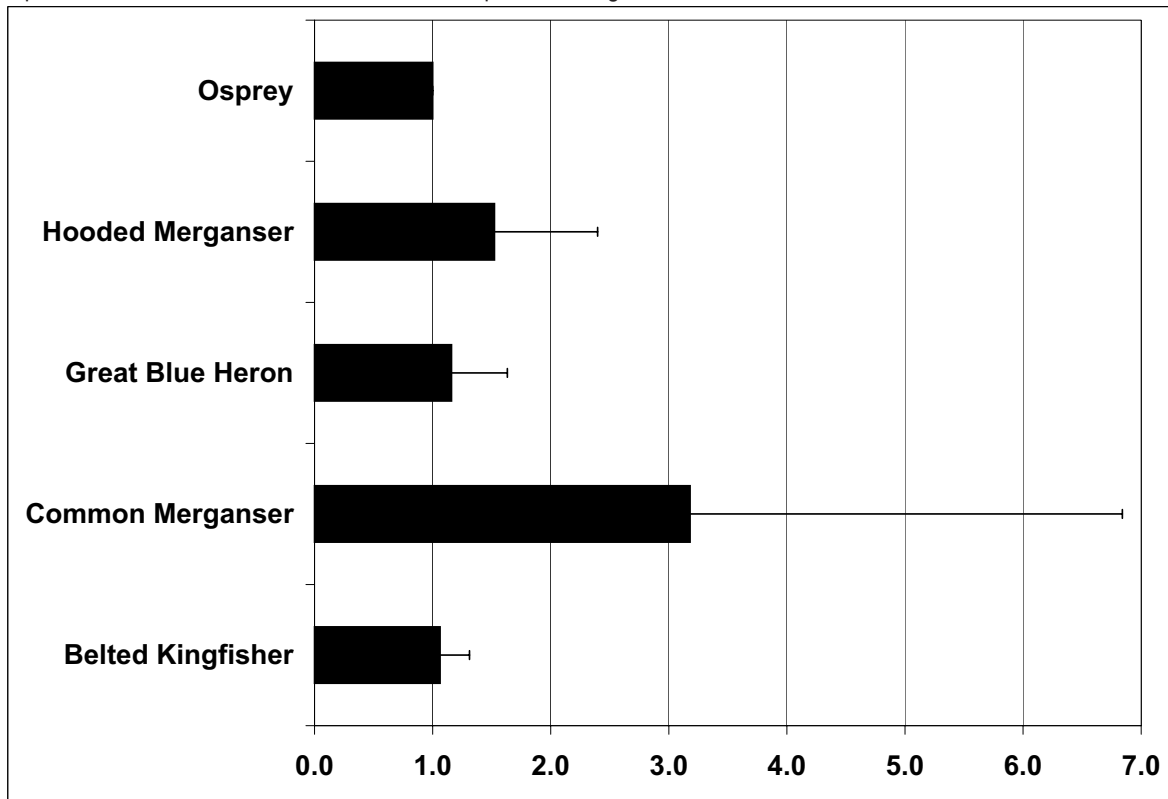
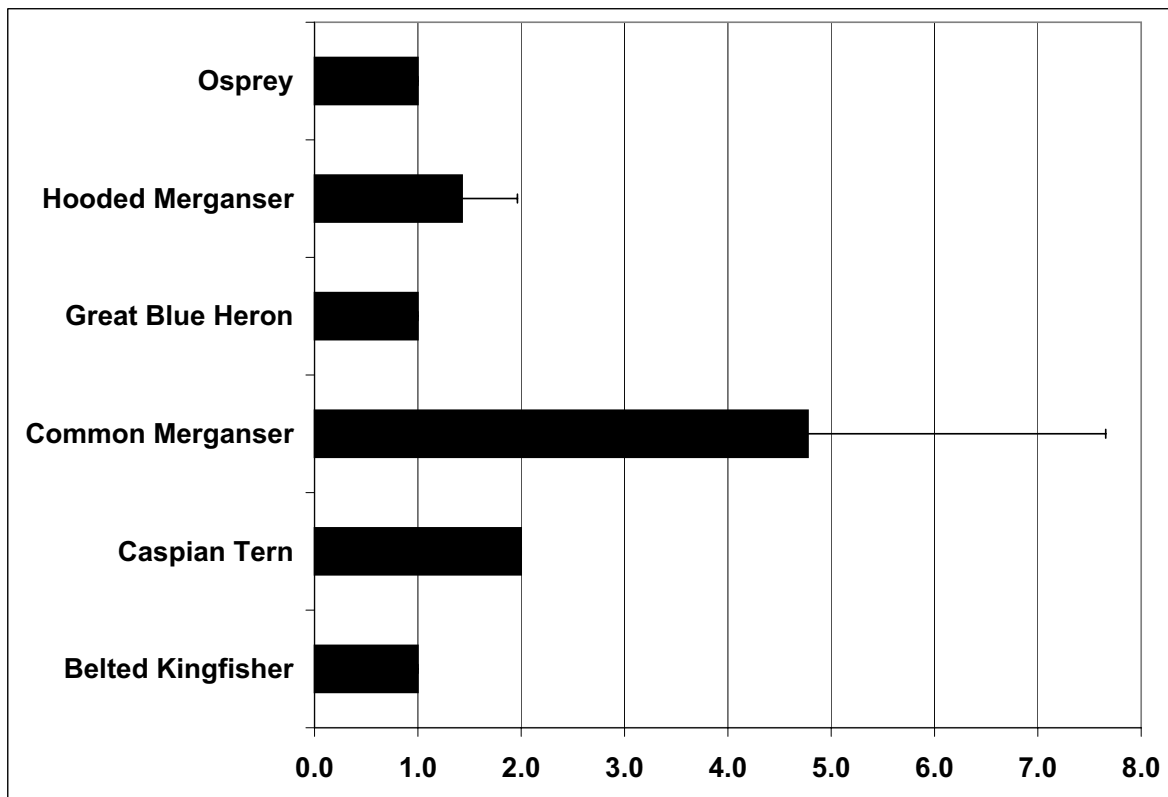


Figure 16. Average avian piscivore abundance per day from 5 surveys at the Easton ponds, 10 Apr to 30 Jun. Error bars represent standard deviation. Bars without error represent a single observation



DISCUSSION

Hotspot Survey

Avian Piscivore Abundance

In 2000, hotspot surveys were conducted on 30 days at both Chandler Canal Bypass (Chandler) and Horn Rapids Dam (Horn Rapids). Although this intensity of observation was necessary to collect sufficiently detailed data required for consumption modeling and basic understanding of fish/bird interactions, it is not practical for long term monitoring efforts. We anticipate the continuation of this higher intensity of observation again in 2001. It is anticipated that by building long-term trend data with this level of monitoring, it will be possible to sub-sample the data for information crucial in designing a less intensive survey effort. Substantial trend data also allow for more extensive analyses of possible correlations between bird abundance, diurnal patterns in abundance, water flow and fish passage.

In 2000, hotspot surveys began on 10 Apr and ended on 30 Jun. Historically, steelhead smolts are the earliest migrants to pass Chandler Dam (Prosser, WA), followed closely by wild spring chinook, both beginning in early April. We would not anticipate increased gull abundance until sometime after the onset of smolt passage and this was the case in 2000. Fall chinook and wild coho are historically the last smolt populations to pass Chandler Dam, extending to as late as the third and fourth week of June. For these reasons, hotspot surveys in 2000 began earlier and continued longer than in 1999.

Daily abundance patterns at Chandler and Horn Rapids both indicated a daily peak in gull abundance during the third, 2-hour survey period—approximately 10:00 or 11:00—followed by an inconsistent pattern of abundance throughout the remainder of the day. Preliminary linear regression modeling done for this event in 1999 suggested a correlation between the daily peak abundance (survey period 3 abundance) and the average number of gulls/day. The patterns of gull abundance produced from 2000

data, however, showed no consistent pattern and also a very different pattern from 1999. Depending on the results of the 2001 monitoring effort, there may still be the possibility of utilizing a relationship between daily peak abundance and total abundance in designing future monitoring protocols, thereby significantly reducing survey efforts at hotspots.

In 1999, gull abundance data derived for Horn Rapids on 25 May was hypothesized to be the result of the release of 1.69 million fall chinook just below Chandler Dam on 24 May. This year's monitoring showed an identical pattern, with the peak day of gull abundance at Horn Rapids occurring on 26 May, 1 day after the release of 1.9 million fall chinook. The Chandler Hot spot did not show this response and it would not be expected at Chandler because of the close proximity of the hotspot to the release site. Smolts, if released in early morning or late evening, would quickly pass the hotspot before gulls could respond to them. Also, because nearly all the foraging at Chandler is concentrated at the outfall pipe, it is assumed that released smolts are not impacted by foraging gulls within the defined observational boundaries of the hotspot.

Consumption of Juvenile Salmonids by Gulls

Bird response to hatchery inputs is evidenced by the peak in gull abundance observed at Horn Rapids on 26 May, one day after the release of 1.9 million fall chinook (25 May). We believe this release stimulated the observed response in gull abundance (Figure 3). Gull abundance at Chandler and Horn Rapids on 27 May—2 days after the release of fall chinook—does not appear disproportionately elevated. These events suggest that smolt travel time between Chandler Dam and Horn Rapids Dam can, at least for some fraction of the fish released, be as little as 24 hours (total distance traveled = 46 kilometers). Similar increases in gull abundance were not observed at Chandler Dam Canal Bypass Pipe on 26 May (approximately 50 meters below the fall chinook release site), implying that these smolts quickly departed the initial release area.

While it remains unknown what fraction of fall chinook smolts released on 25 May reached Horn Rapids Dam by the afternoon of 26 May, the resulting single day spike in gull abundance followed by normal (or even low) numbers of gulls on 27 May suggests that these smolts are passing as one large cohort rather than spreading out within the river and passing over multiple days or even weeks. Also, having observed this quick response 2 years in a row suggests that a high percentage of gull consumption at Horn Rapids Dam on this day consists of juvenile salmonids. It is possible that similar events occurring under extremely low flow conditions may impact fish passage phenology between Chandler and Horn Rapids and change the pattern of this response by birds to fish release. We anticipate the opportunity to investigate these events further in 2001.

River Reach Survey—Spring and Summer

Avian Piscivore Abundance

Breeding activity of Belted Kingfishers (adults carrying fish) was observed within most river reaches and within the Easton and Cle Elum reaches for Common Mergansers (presence of juveniles) and Osprey (nesting activity). Great Blue Herons are not believed to breed in the upper reaches, but are known to have a large rookery along the banks within Stratum 3. No signs of breeding within any river reach were observed for the other avian piscivores of concern (Bald Eagles, gulls or Double-crested Cormorants).

Peak numbers of Common Mergansers were observed within the Cle Elum reach in early to late July and in August within the Easton reach. These numbers were comprised almost entirely of females with broods. By mid to late summer, males had departed the river and juveniles began accompanying adult females on the river. By middle to late August, first-year birds attain approximately 80 to 90 percent of adult female size, at which point identification between adult females and mature young of the year becomes difficult. As juvenile birds mature, females become less attentive and appeared to decline in

number throughout both river reaches. At this time, large groups of juveniles form along the river, sometimes reaching as many as 20-25 individuals. By late August, Common Merganser abundance had decreased dramatically compared to spring and early summer. It does not appear that there was a significant increase in overall merganser numbers between 1999 and 2000. This would suggest, at least preliminarily, that increased fish supplementation efforts are not resulting in a numerical bird response. However, more years of abundance data are needed to identify long term changes in predator populations.

Double Counting Birds-River Drifts

The aspect of river reach surveys which produced the greatest uncertainty was the potential to count the same bird more than once. This problem (over-counting) may occur under two specific scenarios. The first scenario occurs when a bird encountered on a river drift is pushed down river out of sight of observers, creating uncertainty as to whether the next bird identified of the same species/age/sex is the same bird or a new bird. This behavior is referred to as “running”. The second scenario occurs when a bird from up river (from behind the survey boat), flies down into view of the survey personnel, creating confusion as to whether the bird was already counted. This behavior is referred to as “tailing”.

Running was by far the most frequent and simplest to remedy. When birds run, the initial encounter is recorded. If a bird of the same species/sex/age is passed by the survey boat within the next 1,000 meters of river, it was not recorded (i.e., assumed to be the same bird). If a bird of the same species/age/sex as that which was running was not again identified within 1,000 meters of the initial sighting, it was assumed to have departed the river or passed unnoticed by survey personnel, the observation was retained, and the next bird of the same species/sex/age was recorded as a new bird. Some latitude on the 1,000 meters was given to Osprey which can cover great distances in a short time.

This method can result in a double count of the same

bird if the running bird avoids a second detection within the next 1,000 meters, and is then again encountered and enumerated a second time somewhere further downriver. While the frequency of such events is ultimately unknown, we believe the occurrence of such events is very low. The great majority of encounters resulting in running by the identified bird were reconciled within several hundred meters of river. Navigation of the survey boat to the opposite side of the river away from encountered birds minimized running by birds.

This method also has the advantage of not being biased due to the differential escape methods (escape from the survey boat) utilized by different species of birds. Common Mergansers, which rarely depart the river when running, will eventually be passed even if the point of passage is 1,000 meters beyond the initial encounter. In contrast, other birds—such as Great Blue Herons, Belted Kingfishers, Green Herons, Black-crowned Night Herons—escape into tree cover adjacent to the river, creating a higher probability that the bird will not be observed a second time within the 1,000 meter limit. Because enumeration occurs at the point of initial sighting, both the Common Merganser and the Great Blue Heron (each with different escape behaviors) were recorded.

The alternative to this method is to enumerate a bird only upon passage by the survey boat. While this method addresses over-counting, it introduces the alternate probability of under-counting. Such under-counting would occur when a bird runs, and then departs the viewable area of the river once out of sight of the survey personnel, resulting in no record of the initial sighting. Given the different escape methods utilized by bird species, this method would be biased towards birds which remained on the river, and against those birds which escaped from view.

The potential to under count during a run also exists if the running bird, once it has left the view of the survey personnel, departs the river, and by coincidence there exists another bird of the same species/sex/age around the corner. Under such circum-

stances the running bird's departure from the river would go undetected, and the identical bird will be assumed to be the running bird. No method has been developed to prevent this event, and it is believed to be exceedingly rare.

The second event which can result in double counting occurs when a bird flies from up river, is noticed by the survey crew, then moves out of sight again in either an up river or down river direction. Under such conditions it is unknown whether the bird was previously counted. In order to minimize overestimation of bird abundance due to double counting, we assumed that the bird had been previously counted.

Consumption

In 2000, avian consumption modeling was conducted for hotspots and for the two survey periods along reference river reaches. Currently, only biomass estimates are being produced as adequate fish community composition data to partition bird take across individual species and/or size classes are lacking. Also being investigated is the rationale for eliminating certain piscivorous birds from the modeling effort due to published information indicating that they are not likely to be impacting salmonids in the smolt or parr size class. Such examples might include Bald Eagles and Ospreys. Great-blue Herons are also being assessed as to the possibility that they may not feed in those habitats most frequented by salmon smolts.

Published estimates of the daily food requirement (DFR) of Common Mergansers range from 370 (Wood and Hand 1985) to 501 (Feltham 1995b) grams per day. These estimates have been derived from a variety of methods, including assessments of stomach contents, observation of feeding behaviors, consumption by captive adults, energy demand modeling, and doubly-labelled water analysis (DLW). The latter, DLW analysis, has been argued to be the most accurate method of DFR estimation due to the avoidance of specific methodological problems inherent in the former methods, which usually result in an under estimation of true consumption (Feltham and

Davies 1996). For the purposes of this research, DFR values used for Common Mergansers (501 grams per day were derived by DLW studies (Feltham 1995b).

Aerial Surveys

Even with the conduct of four paired aerial/drift surveys in 2000, it is apparent that more paired surveys would be needed to provide sufficient statistical power to adequately compare the two methods. Certain species of avian piscivores are differentially detected by the two survey methods. Based upon results of the surveys conducted in 1999 and 2000, aerial surveys appear biased against small birds, dark colored birds, and cover loving birds (eg. kingfishers, night herons, etc.), and biased towards large birds, white birds, and birds which prefer open habitats (gulls, pelicans, cormorants, etc). Common Mergansers were identified sporadically by the aerial flights, especially in the upper portions of the river. This is probably because they are easily visible when in the open, but spend much of their time closer to shore or under cover (especially true of females tending broods), and because of the difficulties in flying these sections of the river. For these reasons, aerial flights would be unsuitable for keeping track of any breeding populations of mergansers, but may prove useful for early season counts of mergansers within the lower, more open sections of the river. Gulls on the other hand were readily picked up by aerial surveys and those utilizing near-shore habitat not seen by river drifts were occasionally enumerated by aerial flights making comparisons between the two methods even more problematic. Lastly, other species of possible concern as avian piscivores occurring throughout the river system such as Great-blue Herons, Black-crowned Night Herons and Belted Kingfishers were not detected by the aerial surveys.

Although the substitution of river drifts by aerial flights may not ultimately be feasible, the latter are still valuable. To accurately assess avian predation of salmon smolts within the Yakima River, hotspot surveys should be conducted where and when large concentrations of avian piscivores occur. Although informa-

tion regarding the occurrence of consistently intense feeding activity within areas not formally under observation by survey personnel is derived by communication with other YKFP participants and other informal observations, aerial flights help to ensure that newly developing hotspots do not go undetected.

In summation, it is not evident that aerial flights provide a more accurate survey method than river drifts and likely underestimate the abundance of avian piscivores. Aerial flights can be a valuable tool in identifying large concentrations of conspicuous birds such as gulls, and pelicans and early season groups of mergansers on the lower river sections. However, it is unlikely that aerial surveys could replace river drifts in an effort to accurately enumerate all piscivorous bird species utilizing the river.

North Fork Teanaway River Surveys

These surveys recorded very little in the way of avian piscivore abundance. Observations consisted of infrequent encounters of only two species (Belted Kingfisher and Great-blue Heron). Thus, there is no apparent bird response to date associated with the initiation of operations at the Jack Creek acclimation and release site. It is hypothesized that there is an inadequate food supply over the entire season in this waterway to support a breeding population of birds and it is therefore unlikely there will be any increase in bird response to smolt releases in subsequent years. It is possible, however, that birds might respond to large, simultaneous movements of smolts from the Teanaway into the Yakima by congregating at the mouth of the Teanaway where it empties into the Yakima. Future monitoring efforts within the Cle Elum reach should include this possibility.

Miscellaneous Surveys

Surveys done at the Easton ponds and the Cle Elum hatchery slough detected piscivorous bird activity, though the daily averages were low (less than 5 mergansers per day--the most abundant species). It is unknown, however, whether the birds seen remain throughout the day or are replaced by others

and what fraction of their diet is derived from smolts at these sites. Because these sites represent highly efficient foraging situations (high densities of smolts), bird abundance will be directly tied to hatchery rearing and acclimation schedules. At times when smolts are not present at these sites it would be expected that all resident birds would utilize the river. This makes it problematic to accurately determine how birds seen at these sites impact the river system. If it is assumed that some birds forage preferentially at these sites, only moving onto the river after smolts have been released, then impacts to smolts from these birds is likely being underestimated. To quantify impacts at these sites from piscivorous bird predation and establish a relationship with bird activity on the river would require more intensive monitoring of these sites in conjunction with the ongoing river surveys.

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