Draft

Predator Control Program (Mainstem/Systemwide Province)

Program Summary

October 24, 2002

Prepared for the
Northwest Power Planning Council

Team Leader and Lead Writer
David L. Ward
Oregon Department of Fish and Wildlife

Contributors
Ken Collis
Real Time Research

James H. Petersen
U.S. Geological Survey

Daniel D. Roby
Oregon State University

Susan P. Barnes
Oregon Department of Fish and Wilflife

DRAFT: This document has not yet been reviewed or approved by the Northwest Power Planning Council

Predator Control Program Summary

Table of Contents

List of Tables

Mainstem Subbasin Program Description

Purpose of Program

The Northwest Power Planning Council (NWPPC) system-wide goal in the 1994 Columbia River Basin Fish and Wildlife Program is a healthy Columbia Basin: "one that supports both human settlement and the long-term sustainability of native fish and wildlife species in native habitats where possible, while recognizing that where impacts have irrevocably changed the ecosystem, we must protect and enhance the ecosystem that remains" (NWPPC 1994). The overall vision in the NWPPC's 2000 Columbia Basin Fish and Wildlife Program (NWPPC 2000) is "a Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife, mitigating across the basin for the adverse effects to fish and wildlife caused by the development and operation of the hydrosystem and providing the benefits from fish and wildlife valued by the people of the region." The Predator Control Program is one component of a larger comprehensive program seeking to protect and restore healthy populations of anadromous salmonids so that harvest opportunities for tribal and recreational fishers are sustained.

In general, mortality of juvenile salmonids away from dams is typically associated with predation. Predation losses include those to northern pikeminnow Ptychocheilus oregonensis or other resident fish, avian predators such as Caspian terns, *Sterna caspia*, and marine mammals. Some losses from predation are directly attributable to the hydropower system. Other losses should be minimized to prevent exacerbation of the problems caused by the hydropower system.

Northern Pikeminnow Predation

Development of the hydropower system in the Columbia River basin has resulted in increased losses of juvenile salmonids to resident fish predators. At dams, migrating juvenile salmonids are concentrated in forebays and tailraces, causing increased predation and salmonid loss (Poe et al. 1991; Vigg et al. 1991; Ward et al. 1995). Migration past dams also causes injury and physiological stress, which may increase the vulnerability of salmonids to predators (Mesa 1994). Impoundments enhance populations of resident predatory fish (Zimmerman and Parker 1995), and increase travel time for migrating juvenile salmonids, prolonging their exposure to predators (Raymond 1988; Poe et al. 1991).

Rieman et al. (1991) estimated a mean annual loss of 2.7 million juvenile salmonids to predation by northern pikeminnow, walleye Stizostedion vitreum, and smallmouth bass *Micropterus dolomieu* in John Day Reservoir from 1983-86. Northern pikeminnow were responsible for 78% of the loss, or 2.1 million juvenile salmonids annually. Petersen (1994) revised this estimate to approximately 1.4 million juvenile salmonids (7% of the run) based on spatial patterns of predation. Ward et al. (1995) developed an index of northern pikeminnow predation, and estimated that annual losses from 1990-93 relative to the estimate for John Day Reservoir were 808% downstream from Bonneville Dam, 275% in Bonneville plus The Dalles reservoirs, 50% in McNary Reservoir, 98% in Columbia River reservoirs upstream from the Snake River, and 37% in the four lower Snake River reservoirs. These index values would translate into 16.4 million juvenile salmonids consumed annually by northern pikeminnow, or 8% of the approximately 200 million hatchery and wild juvenile salmonid outmigrants in the Columbia River system (Beamesderfer et al. 1996).

Estimates of predation losses were relatively unbiased by consumption of juvenile salmonids killed by dam passage. Most salmonids consumed by northern pikeminnow were eaten alive, despite observed preferences for dead salmonids in laboratory and field tests (Gadomski and Hall-Griswold 1992; Petersen et al. 1994). Petersen et al. (1994) marked and released dead and live salmonids into a dam tailrace in a 10% dead proportion that simulated turbine mortality rate and observed that 22% of marked salmonids subsequently recovered from northern pikeminnow were dead before release. If dead fish constitute 22% of northern pikeminnow prey near a dam, dam effects extend 10 km upstream and downstream, and 69% of predation occurs in that zone (Petersen 1994), then 85% of the estimated predation would be on live fish (1 –(0.69 x 0.22)).

Unlike walleye and smallmouth bass, population dynamics and behavior of northern pikeminnow indicate that reductions in predation through a removal program are feasible. Northern pikeminnow are long-lived and slow-growing, and become increasingly piscivorous with age (Poe et al. 1991; Parker et al. 1995). Salmonids are generally an important diet component only for large, old individuals (Vigg et al. 1991), and consumption rates of juvenile salmonids by northern pikeminnow increase exponentially as size increases (Beamesderfer et al. 1996). Coincidentally, northern pikeminnow vulnerability to most fishing gears also increases with size (Friesen and Ward 1999). Rieman and Beamesderfer (1990) used simulation models to estimate that sustained annual exploitation of 10-20% of northern pikeminnow >250 mm fork length would reduce predation by northern pikeminnow by 50%. The primary control mechanism is the cumulative effect of exploitation, which systematically reduces the number of older piscivorous individuals through time. Based on changes in the population structure of northern pikeminnow, Friesen and Ward (1999) estimate that as a result of northern pikeminnow harvest since 1990, predation on juvenile salmonids by northern pikeminnow has been reduced by approximately 25% annually.

Rieman and Beamesderfer (1990) concluded that compensation by surviving northern pikeminnow was unlikely because (1) fecundity is much lower than fecundity of species considered resilient, (2) growth is slow and mortality low compared with other species, and (3) density-dependent growth was not obvious. Knutsen and Ward (1999) found no evidence to date of compensation by surviving northern pikeminnow, although there are still some outstanding questions about compensatory feeding by northern pikeminnow (Petersen 2001b). Friesen and Ward (2000) and Ward and Zimmerman (1999) found no evidence to date of compensation by walleye or smallmouth bass.

Marine Fish Predation

Ocean survival of salmonids is evidently determined very early during their ocean residency, with predation thought to be a major influence on salmonid ocean survival rates (Fisher and Pearcy 1988; Pearcy 1988; 1992). Supporting this conclusion was Pearcy's (1988) discovery that average ocean purse seine catches of coho salmon *Oncorhynchus kisutch* in June correlated closely with coho salmon jack counts (and thus adult run size) in the fall. This indicates that most ocean mortality occurs during early ocean entry (April and May). Matthews et al. (1992) also found early ocean survival for juvenile Columbia River spring/summer chinook salmon Oncorhynchus tshawytscha migrating in 1990 to be very poor, especially for hatchery fish.

While scientists have observed the declining ocean survival of Northwest salmonids, they have also noticed large numbers of marine fish predators, particularly Pacific hake*, Merluccius productus*, Pacific mackerel, *Scomber japonicus*, and jack mackerel *Trachurus symmetricus* becoming more abundant, arriving earlier, and staying longer in coastal waters. For example, in 1977, mackerel were rarely captured during NMFS's triennial trawl surveys off Oregon; by 1995, mackerel were abundant and commonly caught at many stations (raw data provided by Mark Wilkins, NMFS, Seattle, WA). During a six-year ocean purse seine study off the Northwest, Brodeur and Pearcy (1986) identified a shift in the June fish community, from a community dominated by forage fish and squid from 1979-1982, to one being dominated by predators (Pacific mackerel, jack mackerel, and dogfish shark) from 1983-1984. These piscivorous fishes may be a significant cause of juvenile salmon mortalities. For example, an investigation in British Columbia, found that Pacific mackerel consumed nearly all the salmon smolts released from a nearby hatchery (Brent Hargreaves, Canadian Fish and Oceans, Pacific Biological Station, Nanaimo, B.C. Canada V9R 5K6, Pers. commun., March 1996), resulting in few returns from that brood-year release.

Marine predatory fishes could simply impact juvenile salmon populations because of their large population size. The Pacific hake population presently represents the largest single species fishery on the West Coast. Over 5 billion Pacific hake were expected to migrate into Northwest waters during the spring/summer of 1997 (Dorn 1996). The biological demands of this population undoubtedly have a large impact on coastal marine food webs and biological communities in northwestern coastal waters (Ware and McFarlane 1995). If each hake consumed only one salmonid they would decimate Northwest salmonid runs. Research off British Columbia indicates that the recent increases in the numbers of Pacific hake and mackerel in these waters has increased predation rates and decreased abundance of Pacific herring (Ware and McFarlane 1995). Timing of movement, food habits, and abundance of the seasonal migrant fish marine predators into Oregon and Washington coastal waters may have significant effects on the biological community for which juvenile salmonid ocean survival is dependent. Furthermore, the distribution and abundance of the nearshore marine predator and forage fish community may affect the amount of predation on juvenile salmonids by marine predatory fish.

Avian Predation

The U. S. Geological Survey - Oregon Cooperative Fish and Wildlife Research Unit at Oregon State University and the Columbia River Inter-Tribal Fish Commission initiated a BPA funded study (Contract 97BI33475) in 1997 to assess the impacts of piscivorous waterbirds on the survival of juvenile salmonids in the lower Columbia River. These investigations indicated that Caspian terns nesting on Rice Island, a dredged material disposal island in the Columbia River estuary, are the most significant avian predator of juvenile salmonids on the lower Columbia River (Roby et al. 1998; Collis et al. 1999; Collis et al., in press). Rice Island supported an expanding population of about 16,000 nesting Caspian terns until 2000 (Roby et al. 1998; Collis et al. 1999; Roby et al. in press). This was the largest Caspian tern breeding colony in the world, and supported about 70% of all the Caspian terns nesting along the Pacific Coast of North America (Cuthbert and Wires 1999). Diet analysis indicated that Caspian terns nesting on Rice Island consumed more juvenile salmonids than any other prey type (73% of prey items in 1997-1998; Collis et al. in press). Using bioenergetics modeling, we estimated that in 1998 Caspian terns nesting on Rice Island consumed about 11.2 million juvenile salmonids (95% c.i. = 8.5 – 14.1 million), or approximately 11.8% (95% c.i. = 8.3% - 15.3%) of the estimated 96.6 million out-migrating smolts that reached the estuary during the 1998 migration year (Roby et al., in review). Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that steelhead smolts were more vulnerable to tern predation than other species of salmonids, and that more than 13.3% of all PIT-tagged steelhead smolts that reached the estuary were consumed by terns nesting on Rice Island in 1998 (Collis et al. 2001). Hatchery-raised yearling chinook salmon smolts were more vulnerable to tern predation than their wild counterparts. ESA-listed and unlisted salmonid smolts were consumed in proportion to their availability (Collis et al. 2001a).

Of the other piscivorous waterbirds investigated in 1997-1998, double-crested cormorants *Phalacrocorax auritus* nesting on or near Rice Island consumed the next highest percentage of salmonids (45.7% of identified diet mass), followed by double-crested cormorants nesting on East Sand Island (15.9% of identified diet mass; Collis et al. in press). In 1998, total consumption of juvenile salmonids by double-crested cormorants nesting in the Columbia River estuary was estimated at 6.9 million (95% c.i. = 5.5 – 8.2 million; D.D. Roby, USGS - Oregon State University, unpublished data). The cormorant colonies in the estuary are large, growing rapidly, and cormorants have high food requirements compared to other piscivorous waterbirds. These factors taken together indicate that the magnitude of predation on juvenile salmonids by double-crested cormorants in the Columbia River estuary is sufficient to warrant monitoring by salmon managers.

At sites on the lower and mid-Columbia River, feeding aggregations of piscivorous waterbirds (i.e., gulls, cormorants, and terns) have been observed near dams (Steuber et al. 1993; Jones et al. 1996), at hatcheries (Schaeffer 1991; 1992), and barge release points (K. Collis, personal observations). Ruggerone (1986) estimated that 2% of the juvenile salmonids passing Wanapum Dam on the mid-Columbia River during the spring were eaten by gulls foraging in the tailrace below the powerhouse. Avian predation on radio-tagged chinook smolts has been documented in the tailraces below The Dalles and John Day dams, with 11.3 % and 5.7% of radio-tagged yearling and sub-yearling chinook salmon falling prey to gulls below The Dalles Dam, respectively (J. Snelling and C. Schreck, Oregon State University, personal communication). Increasing numbers of cormorants and terns have been observed foraging near dams on the mid-Columbia River in recent years (S. Bickford, personal communication), congruent with dramatic increases in the size of waterbird colonies on the lower Columbia River (Collis et al. in press). Recent research on the diet composition of birds nesting at these upriver colonies has indicated that Caspian terns nesting on two small colonies (i.e., Three Mile Canyon Island and Crescent Island) are heavily reliant on juvenile salmonids as a food source (ca. 70-85%; Collis et al. in press, Collis et al. 2000, Collis et al. 2001b). The diet of California gulls *Larus californicus* and ring-billed gulls *L. delawarensis* nesting in colonies above The Dalles Dam included few fish and very few juvenile salmonids. The sole exception was a small colony of California gulls near The Dalles Dam, where salmonids accounted for 15% of the diet by mass (Collis et al. in press). Gulls from other up-river colonies may occasionally prey on juvenile salmonids when available in shallow pools or near dams, but recent data suggest that at the level of the colony, juvenile salmonids were a minor component of the diet (Collis et al. in press). Current efforts to control avian predation on smolts at the lower Columbia River dams (Jones et al. 1996) and salmon hatcheries (Schaeffer 1991; 1992) have apparently been effective in reducing gull predation as a source of mortality to juvenile salmonids from levels that have previously been reported (Ruggerone 1986). Continued monitoring of these upriver bird colonies is warranted to assess their impacts to juvenile salmonids now and in the future.

Marine Mammal Predation

Sea lions *Zalophus californianus* in the tailrace of Bonneville Dam in the spring have been documented in fishway inspection reports since the early 1980's. There has even been one mention of a sea lion up in the tailrace of The Dalles Dam after apparently passing through the lock at Bonneville Dam. In 1994 the Oregon Department of Fish and Wildlife reported 74 (36.5%) of 203 steelhead sampled at Bonneville Dam had marine mammal injuries, and marine mammal bite marks have been recorded at Lower Granite Dam since 1990 (14%-19% 1990-1993). Many fish injured by marine mammals die before reaching this hydroproject. As noted by the Draft Recovery Plan for Snake River Salmon (NMFS 1995), pinniped numbers in the Columbia River have increased significantly over the past 20 years. These animals are regularly observed over 100 miles from the ocean up to Bonneville Dam and Willamette Falls. On many occasions, California sea lions have been observed feeding on adult salmon near the fishway entrances below Bonneville Dam.

Typically, there were never more than a couple of sea lions at any one time in the tailrace of Bonneville Dam. However, in 2001, when the largest run of spring chinook salmon to pass since Bonneville Dam began counting fish occurred, several observations of six sea lions at one time were reported. USACE personnel, Bonneville Project rangers, and the Oregon State Police (monitoring fishing) all began recording sea lion observations on an irregular basis beginning 11 April and continued through May, with the last sea lion being observed on 13 May. There were 48 total observation periods on 24 separate days with sea lions recorded. Thirteen males, 14 females, one pup, and 42 unspecified sea lion observations were documented. The most at one time was six. Of the behaviors observed for the 70 sea lion observations, 15 were feeding/eating, one was chasing a hook and line-caught salmon, 40 were swimming/searching, three were floating, and 10 behaviors were not recorded. Of the 70 observations, 42 were located in the second powerhouse tailrace, 12 in the spillway tailrace, three in the first powerhouse tailrace, six off the tip of Bradford Island, and seven near Tanner Creek.

Scope of Program

All species and races of juvenile salmonids migrating through the lower Columbia and Snake rivers are likely to benefit from this program. Predation by northern pikeminnow has been reduced in the Columbia Rivers downstream from Priest Rapids Dam, and in the Snake River downstream from the Hells Canyon Reach. Increased knowledge and effective management of predation by marine fish and marine mammals would also benefit numerous stocks of salmonids.

Avian predators nest at various locations on the lower Columbia River from the estuary to the head of McNary Pool. Some of the populations are having a significant impact on juvenile salmonids survival and as a consequence are being managed (e.g., Caspian terns nesting in the Columbia River Estuary). Other bird populations may be impacting juvenile salmonid survival, but more information is needed to fully evaluate these impacts; some of these data are being collected by studies funded by the Army Corps of Engineers. This study evaluates the impacts of both managed and unmanaged bird populations on juvenile salmonid survival in the lower Columbia River. The information gathered as part of this study will help (1) identify bird populations that are having a significant impact on juvenile salmonid survival, (2) develop management initiatives to reduce avian predation, and (3) monitor and evaluate the effectiveness of bird management plans.

Accomplishments/Results

Project Histories

Northern Pikeminnow Management Program

The Northern Pikeminnow Management Program (NPMP) began in 1990, based on findings from the earlier work conducted in John Day Reservoir (Poe et al. 1991; Vigg et al. 1991; Beamesderfer and Rieman 1991; Rieman et al. 1991), and on the potential for successful predation management (Rieman and Beamesderfer 1990). Overall objectives of the project were to (1) determine the significance of predation in Columbia River reservoirs through implementation of indexing of predator abundance and integration with consumption indices, (2) implement a predator control fishery development plan, beginning with a test fishery in John Day Reservoir in 1990, and (3) initiate an evaluation of the Predator Control Program.

Initial predation indexing was conducted from 1990-93 by the ODFW, the National Biological Service (NBS), and the WDFW. Indexing was conducted in lower Columbia River reservoirs (1990), lower Snake River reservoirs (1991), downstream from Bonneville Dam (1992), and in mid-Columbia River reservoirs (1993). Indexing was conducted prior to significant removals of northern pikeminnow in each area (Parker et al. 1995).

Test fisheries for northern pikeminnow initiated in John Day Reservoir in 1990 included a public sport-reward fishery, a tribal long-line fishery, and an agency-operated dam-angling fishery (John Day and McNary dams). The dam-angling fishery was also conducted at Bonneville, The Dalles, and Ice Harbor dams. The success of the sport-reward fishery led to implementation of the fishery throughout the lower Columbia and Snake rivers in 1991. Dam-angling was also successful in 1990, leading to implementation at the four lower Columbia River dams and the four lower Snake River dams in 1991. The long-line fishery was expanded to include Bonneville and The Dalles reservoirs in 1991.

The long-line fishery was discontinued after 1991 due to lack of participation. Other technologies for removal of northern pikeminnow were tested from 1990-93, including lure trolling, purse seining, electrofishing, trap-netting, and commercial long-lining; however, none proved effective. In 1994, a site-specific gillnet fishery to remove northern pikeminnow near hatchery release points and tributary mouths was implemented and considered successful. Implementation of new test fisheries was discontinued after 1994, leaving sport-reward, dam-angling, and site-specific fisheries as the methods of northern pikeminnow removal.

Since 1990, over 1.7 million northern pikeminnow have been removed from the lower Columbia and Snake rivers, with annual exploitation since 1991 averaging over 12% of fish >250 mm fork length (Table 1). Evaluation of the program consists of (1) monitoring the exploitation rate and size of northern pikeminnow harvested annually for each fishery, and (2) monitoring the effects of observed exploitation rates on predation. Monitoring the effects of exploitation includes (1) comparing predation indices before and after sustained implementation of the program, (2) describing the response of northern pikeminnow to sustained removals, and (3) describing the response of other predators (walleye and smallmouth bass) to sustained removals of northern pikeminnow.

Table 1. Catch and exploitation rate in the Northern pikeminnow Management Program. 1990-2001. Includes only fish >250 mm fork length (minimum size changed to approximately 200 mm fork length in 2000).

Year	Sport Reward		Dam Angling		Site Specific		Other	
1990	4,681	(--)	11,005	(--)	--	(--)	1,648	(--)
1991	153,508	(8.5%)	39,196	(2.2%)	--	(--)	7,366	(--)
1992	186,095	(9.3%)	27,442	(2.7%)	--	(--)	8,766	(--)
1993	104,536	(6.8%)	17,105	(1.3%)	--	(--)	3,460	(--)
1994	129,384	(10.9%)	15,938	(1.1%)	9,018	(1.2%)	--	(--)
1995	199,788	(13.4%)	5,397	(0.3%)	9,484	(1.9%)	--	(--)
1996	157,230	(12.1%)	5,381	(0.3%)	6,167	(0.5%)	--	(--)
1997	119,047	(8.8%)	3,517	(0.1%)	2,806	(0.5%)	--	(--)
1998	108,372	(11.1%)	3,175	(0.1%)	3,035	(0.3%)	--	(--)
1999	114,687	(12.5%)	3,559	(0.0%)	1,604	(0.1%)	--	(--)
2000	121,519	(11.9%)	423	(0.0%)	554	(0.0%)	--	(--)
2001	153,577	(16.0%)	2,751	(0.0%)	518	(0.0%)	--	(--)

As shown in the Table 1, annual exploitation rates since 1991 have averaged over 12% of northern pikeminnow >250 mm fork length, and the minimum goal of 10% exploitation has been met or exceeded in 9 of 11 years. All fisheries target large, piscivorous northern pikeminnow, with mean fork lengths of 346 mm in the sport-reward fishery, 401 mm in the dam-angling fishery, and 409 mm in the site-specific fishery (Friesen and Ward 1999).

Predation by northern pikeminnow was indexed throughout the lower Columbia and Snake rivers each year from 1990-96, and in 1999. Indices of predation were consistently lower from 1994-96 than from 1990-93 (Zimmerman and Ward 1999). Whether piscivory by surviving northern pikeminnow has changed since implementation of the program has not been fully resolved (Zimmerman 1999; Petersen 2001b).

Marine Fish Predation

Work on this project began in 1998. Initial sampling consisted of assessing the efficacy of various large commercial trawling gear with different configurations (doors, weights, etc.) and speeds. In late June use of a rope trawl and foam filled doors proved to be the most effective gear type for collecting large marine fishes near the surface. In 1998, a total of 9 cruises and 72 hauls were conducted off the Columbia River, ranging from Grays Harbor to the north to Cape Falcon to the south, finishing in late August. Over 34,000 fishes were

captured, from 27 different species, and included over 10,000 Pacific hake, 700 Pacific mackerel, and 300 jack mackerel. We collected approximately 2,000 stomachs during these surveys. Some juvenile salmon were observed in some of the stomach samples.
In 1999 an additional 10 trawl surveys were conducted off the mouth of the Columbia River from April through July, and a database was developed. Preliminary results indicate that baitfish numerically dominate the nearshore community. Important predators such as Pacific hake, jack mackerel, and Pacific mackerel are at times abundant. Initial food-habit studies have not identified direct predation on salmonids.

USACE Fish Predation Projects

Predation by resident fishes is known to be a substantial cause of juvenile salmonid mortality, especially in dam tailraces and at outfall locations. Predation studies are being conducted in some areas near dams, funded by the Army Corps of Engineers. For example, conditions in The Dalles Dam tailrace are unique compared to other projects on the Columbia or Snake rivers, having a complex basin with a series of downriver islands where predators are known to reside. Studies have been conducted to examine the behavior of predators in The Dalles Dam tailrace, estimate the relative densities of northern pikeminnow and smallmouth bass in The Dalles Dam tailrace, and apply habitat models for these predators (Martinelli and Shively 1997; Petersen et al. 2001).

Recent studies showed a relatively high number of smallmouth bass, compared to northern pikeminnow, occurred in The Dalles Dam tailrace (Petersen et al. 2001). Habitat models have been developed for northern pikeminnow, using water velocity, depth, distance to shore, and bottom substrate type as independent variables. Fitted equations were used in a geographic information system (GIS) to predict the relative quality of northern pikeminnow habitat throughout The Dalles Dam tailrace for three flow conditions (Petersen et al. 2001). Future work will attempt to improve the northern pikeminnow models by testing some assumptions and adding new data from radio-tagged predators. Habitat models will also be developed for juvenile salmonids and smallmouth bass in The Dalles Dam tailrace using recent, or planned, telemetry studies. These models will be linked to computational fluid dynamics (CFD) models of the tailrace, providing a flexible tool for management decisions. Future studies may also include work in the John Day Dam tailrace to examine predator and prey behavior in response to dam operation and to evaluate the juvenile salmonid bypass.

Avian Predation Project

In 1997, a study was initiated to investigate the impacts of piscivorous colonial waterbirds nesting on the lower Columbia River on the survival of juvenile salmonids (Roby et al. 1998). The study area included the Columbia River from the mouth (river km 0) to the head of the impoundment created by McNary Dam (river km 553). The species investigated were California gulls, ring-billed gulls, glaucous-winged/western gulls (*Larus glaucescens* X *L. occidentalis*), Caspian terns, and double-crested cormorants. This study revealed differences in diet composition among the different bird species and colony locations (Collis et al. in press). Caspian terns and double-crested cormorants were strictly piscivorous, whereas the three gull species consumed a diverse array of food types. Gulls nesting at up-river colonies consumed primarily anthropogenic food items (e.g., cherries, potatoes, human refuse). In contrast, glaucous-winged/western gulls nesting in the Columbia River estuary consumed primarily fish. In general, gulls nesting on Rice Island (river km 34) ate primarily riverine fishes, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. This same dietary difference was evident in the diets of double-crested cormorants nesting on Rice and East Sand islands (Collis et al. in press).

In general, piscivorous waterbirds nesting in the Columbia River estuary ate more juvenile salmonids than those nesting up-river. In 1997 and 1998, Caspian terns nesting on Rice Island consumed the highest percentage of juvenile salmonids (73%) of those species of piscivorous colonial waterbirds nesting in the estuary (Collis et al. in press). Rice Island, a dredged material disposal site at river km 34, supported an expanding colony of about 16,000 nesting terns in 1998 (Collis et al. in press). This colony was the largest known Caspian tern breeding colony in the world, and supported about two-thirds of all the Caspian terns nesting along the Pacific Coast of North America (Cuthbert and Wires 1999). Using bioenergetics modeling, it was estimated that in 1998 this tern colony consumed about 11.2 million juvenile salmonids (95% c.i. = 8.3 – 14.2 million; Roby et al. in review), or approximately 12% (95% c.i. = 9% - 15%) of the estimated 95 million out-migrating smolts that reached the estuary during the 1998 migration year. Analysis of over 36,000 smolt PIT tags recovered from the Caspian tern breeding colony on Rice Island revealed that over 13.5% of all PIT-tagged steelhead smolts that reached the estuary were consumed by terns in 1998 (Collis et al. 2001a).

The magnitude of predation on juvenile salmonids by Rice Island terns led to management action in 1999 (Roby et al. in press). A pilot study was conducted to determine whether the Rice Island tern colony could be relocated 16 miles closer to the ocean on East Sand Island (river km 8), where it was hoped terns would consume fewer salmonids. Habitat restoration, social attraction (decoys and audio playback systems), and selective gull removal were used to encourage terns to nest on East Sand Island. About 1,400 pairs of Caspian terns nested at the new colony site in 1999, where nesting success was considerably higher than on Rice Island (Roby et al. in press). In 2000, about 9,100 pairs of Caspian terns nested on East Sand Island, or 94% of all terns nesting in the estuary, and nesting success was again much higher than at Rice Island (Roby et al. in press).

During 1999 and 2000, the terns nesting on East Sand Island foraged more in marine and brackish water habitats than did the terns nesting on Rice Island. The diet of East Sand Island terns consisted of 46% and 47% salmonids in 1999 and 2000, respectively, compared to the diet of Rice Island terns, which consisted of 77% and 90% salmonids, respectively (Roby et al. in press). The relocation of nearly all the nesting terns from Rice Island to East Sand Island in 2000 resulted in a sharp drop in consumption of juvenile salmonids by terns nesting in the Columbia River estuary; total consumption was estimated at 7.3 million smolts (95% c.i. = 6.1 – 8.6 million smolts), a reduction in smolt consumption of about 4.4 million (38%) compared to 1999 (Collis et al. 2000).

In 2001, all Caspian terns nesting in the Columbia River estuary used 3.9 acres of the restored habitat on East Sand Island. The estimated size of the East Sand Island colony (9,100 pairs) was not significantly different from 2000, suggesting that the tern breeding population is no longer increasing (Roby et al. in press). Tern nesting success at the East Sand Island colony in 2001 (1.3 young raised per nesting pair) was the highest ever recorded for Caspian terns nesting in the Columbia River estuary, apparently a reflection of high forage fish availability (Roby et al. in press). The proportion of juvenile salmonids in the diet (33%) was the lowest ever recorded for terns nesting in the estuary (Roby et al. in press). This resulted in another decline in consumption of juvenile salmonids by terns in the Columbia River estuary;

consumption in 2001 was estimated at 5.9 million smolts (95% c.i. = 4.8 – 7.0 million smolts). This represents a reduction in smolt consumption by terns of about 5.9 million (50%) compared to the 1999 consumption estimate (Collis et al. 2001b). These results indicate that relocating the Caspian tern colony was an effective management action for reducing predation on juvenile salmonids without harm to the population of breeding terns, at least in the short-term.

USACE Marine Mammal Predation Project

This project will begin in spring 2002, and therefore has no history yet. The goal is to determine the impact California sea lions in the tailrace area of Bonneville Dam have on salmonid populations as they migrate past the project. Objectives are (1) determine seasonal timing and numbers of sea lions present at Bonneville Dam, review available data and supplement if necessary, (2) estimate sea lion consumption of adult salmonids in the Bonneville Dam tailrace, (3) identify methods to mark and identify individual sea lions at Bonneville Dam and determine whether they return in subsequent years, and (4) If sea lion activity in the tailrace of Bonneville Dam is determined to be excessively detrimental to salmonid populations, identify potential control measures that could be implemented.

Adaptive Management Implications

Northern Pikeminnow Management Program

Development of northern pikeminnow fisheries was based on adaptive management. Numerous techniques to harvest northern pikeminnow were tested from 1990-93, but only the most successful were continued. Lure trolling, purse seining, electrofishing, trap-netting, and tribal and commercial long-line fisheries were all discontinued because they were not able to harvest significant numbers of northern pikeminnow.

Success of the continuing fisheries has also relied on adaptive management. The sport-reward fishery was relatively unsuccessful in 1990 until the reward was raised from $1 to $3 per northern pikeminnow. Implementation of a tiered reward system in 1995, based on total number of fish caught, resulted in increased participation in the fishery. Number and locations of registration stations for the sport-reward fishery have also changed over the years, depending on trends in effort and catch. Current locations of the stations maximize the efficiency of the fishery.

The dam-angling and site-specific fisheries have utilized adaptive management to maximize catches while decreasing costs. Dam angling is concentrated in tailraces of the dams where catch per effort is highest. The site-specific fishery is also concentrated in areas where catch per effort is highest. Lessons learned through the NPMP could potentially be used for understanding, and limiting, predation mortality caused by other species of predators.

Avian Predation Project

As participants in the Caspian Tern Working Group, OSU/CRITFC/RTR researchers provide technical assistance to managers in developing and refining management initiatives to reduce avian predation on juvenile salmonids in the lower Columbia River. Project researchers provide information to regional resource managers within the Working Group to help them evaluate the efficacy of on-going management initiatives and thereby provide the opportunity for adaptive management both in-season and in out-years. Information is also provided on unmanaged bird populations to help determine the need for further management action. This information is provided at regular Working Group meetings, on a web page developed to disseminate in-season project results (www.columbiabirdresearch.org), and in annual reports and peer-reviewed journal publications.

Benefits to Fish and Wildlife

The Predator Control Program will contribute to the Northwest Power Planning Council's (NWPPC) Fish and Wildlife Program (FWP) vision of a Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife, mitigating across the basin for the adverse effects to fish and wildlife caused by the development and operation of the hydrosystem and providing the benefits from fish and wildlife valued by the people of the region. More specifically, the Predator Control Program addresses FWP objectives for biological performance related to anadromous fish losses: (1) Halt declining trends in salmon and steelhead populations above Bonneville Dam by 2005, (2) Restore the widest possible set of healthy naturally reproducing populations of salmon and steelhead in each relevant province by 2012, and (3) Increase total adult salmon and steelhead runs above Bonneville Dam by 2025 to an average of 5 million annually in a manner that supports tribal and non-tribal harvest.

The FWP also calls for the continuation of existing measures until subbasin plans are adopted, the measure has been specifically repealed, or three years have elapsed, whichever comes first. Therefore, measures from the 1994 FWP addressing predator control are still in effect.

Northern Pikeminnow Management Program

Reduction in predation by northern pikeminnow is specifically called for under Measures 5.7A and 5.7B of the FWP. Implementation of northern pikeminnow fisheries is directly related to FWP measures 5.7A.1 (reduce pikeminnow population by more than 20% in the Snake and Columbia rivers), and 5.7B.1 (continue implementation of the current pikeminnow project). Objective 3, evaluation of the project, is directly related to FWP measures 5.7B.2 (document population dynamics, life history, and behavior of pikeminnow to monitor responses of populations to control measures), 5.7B.3 (monitor program effectiveness, monitor exploitation rates, age structures, etc.), and 5.7B.4 (assess effects of pikeminnow control on other salmon predators).

In addition to the Fish and Wildlife Program, recently completed subbasin summaries have recognized the need for continuation of the Northern Pikeminnow Management Program. The list of fish and wildlife needs in the Columbia Plateau subbasin summary included (1) continue implementation and evaluation of the Northern Pikeminnow Management Program, (2) continue evaluation of intensive removal of predaceous northern pikeminnow. Implement evaluation of control programs for other predators including seagulls, bass, and walleyes, (3) determine losses of juvenile fall chinook salmon in the Hanford Reach and Wanapum Dam tailrace from predation by smallmouth bass and channel catfish, and (4) evaluate relationships between exotic fish predator (smallmouth bass, walleye, and channel catfish) abundance and operation of the hydropower system. Assess feasibility of reducing predation on juvenile salmonids through changes in operations or by other means.

Avian Predation Project

The Avian Predation Project addresses measures 5.7A.6, 5.7B.20, 5.7B.21, 5.7B.22, 5.7B.23 in the 1994 Fish and Wildlife Program. As part of the FWP, Bonneville Power Administration and other agencies have been charged with monitoring and assessing bird predation on juvenile salmonids in lower Columbia and Snake river reservoirs (5.7B.20) and in the Columbia River estuary (5.7B.21), and identifying non-lethal methods for control of piscivorous waterbird populations posing a problem to salmon survival (5.7B.22).

Program Funding to Date

Funding for the NPMP from 1990-2001 totaled $45,789,754. Costs per year have been:

1990: $1,421,813; 1991: $5,259,629; 1992: $6,846,410; 1993: $4,253,600; 1994: $3,670,707; 1995: $4,311,186; 1996: $3,846,248; 1997: $3,730,347; 1998: $3,259,230; 1999: $3,306,000; 2000: $3,104,592; 2001:$2,779,992.

Funding for the Avian Predation Project totaled $2,781,766 from 1997-2002.

Funding for the Marine Fish Predation Project totaled approximately $790,000 from 1998-2001.

Reports and Technical Papers

Northern Pikeminnow Management Program – Reports

Friesen, T. A., and D. L. Ward. 2000. Biological characteristics of Columbia River walleye in relation to northern pikeminnow management. Oregon Department of Fish and Wildlife, Information Report 2000-05. Clackamas, Oregon.

Nigro, A. A. 1990. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. DE-B179-90BP07084, Portland, Oregon.

Petersen, J. H. 2001. Compensatory feeding after a predator removal program: detection and mechanisms. DRAFT report submitted to the Bonneville Power Administration, Portland, Oregon.

Petersen, J. H., M. G. Mesa, J. Hall-Griswold, W. C. Schrader, G. W. Short, and T. P. Poe. 1990. Magnitude and dynamics of predation on juvenile salmonids in Columbia and Snake River reservoirs. Bonneville Power Administration, Portland, Oregon.

Petersen, J. H., and T. P. Poe (eds.). 1993. System-wide significance of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report for 1992. Bonneville Power Administration, Portland, Oregon.

Porter, R. 1999. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. 94BI24514, Portland, Oregon.

Porter R. 2000. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. 94BI24514, Portland, Oregon.

Ward, D. L. 1998. Evaluation of the northern squawfish management program, final report of research, 1990-96. Final Report to Bonneville Power Administration, Contract Nos. DE-B179-90BP07084 and 94BI24514, Portland, Oregon.

Willis, C. F., and A. A. Nigro. 1993. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. DE-B179-90BP07084, Portland, Oregon.

Willis, C. F., D. L. Ward, and A. A. Nigro. 1994. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. DE-B179-90BP07084, Portland, Oregon.

Willis, C. F., and D. L. Ward. 1995. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. DE-B179-90BP07084, Portland, Oregon.

Willis, C. F., and F. R. Young. 1995. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. 94BI24514, Portland, Oregon.

Young, F. R. 1997. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. 94BI24514, Portland, Oregon.

Young, F. R. 1998. Development of a system-wide predator control program: stepwise implementation of a predation index, predator control fisheries, and evaluation plan in the Columbia River basin. Annual Report to Bonneville Power Administration, Contract No. 94BI24514, Portland, Oregon.

Northern Pikeminnow Management Program – Peer Review Articles

Beamesderfer, C.P., D.L. Ward, and A.A. Nigro. 1996. Evaluation of the biological basis for a predator control program on northern squawfish (*Ptychocheilus oregonensis*) in the Columbia and Snake rivers. Canadian Journal of Fisheries and Aquatic Sciences 53:2898-2908.

Barfoot, C. A., D. M. Gadomski, and R. H. Wertheimer. 1999. Growth and mortality of age-0 northern squawfish, *Ptychocheilus oregonensis*, rearing in shoreline habitats of a Columbia River reservoir. Environmental Biology of Fishes 54: 107-115.

Cech, J. J. Jr., D. T. Castleberry, T. E. Hopkins, and J. H. Petersen. 1994. Northern squawfish, *Ptychochelius oregonensis*, O2 consumption rate: effect of temperature and body size. Canadian Journal of Fisheries and Aquatic Sciences 51: 8-12.

Cech, J. J. Jr., D. T. Castleberry, and T. E. Hopkins. 1994. Temperature and CO2 effects on blood O2 equilibria in northern squawfish, *Ptychochelius oregonensis*. Canadian Journal of Fisheries and Aquatic Sciences 51: 13-19.

Collis, K., R.E. Beaty, and B.R. Crain. 1995. Changes in catch rate and diet of northern squawfish associated with the release of hatchery-reared juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 15:346-357. Friesen, T. A., and D. L. Ward. 1999.

DeAngelis, D. L., and J. H. Petersen. 2001. Importance of the predator's ecological neighborhood in modeling predation by migrating prey. Oikos 94:315-325.

Friesen, T.A., and D.L. Ward. 1999. Management of northern pikeminnow and implications for juvenile salmonid survival in the lower Columbia and Snake rivers. North American Journal of Fisheries Management 19:406-420.

Gadomski, D. M., and J. A. Hall-Griswold. 1992. Predation by northern squawfish on live and dead juvenile chinook salmon. Transactions of the American Fisheries Society. 121: 680-685.

Gadomski, D. M., M. G. Mesa, and T. M. Olson. 1994. Vulnerability to predation and physiological stress responses of experimentally descaled juvenile chinook salmon, *Oncorhynchus tshawytscha*. Environmental Biology of Fishes. 39: 191-199.

Gadomski, D. M., and C. A. Barfoot. 1998. Diel and distributional abundance patterns of fish embryos and larvae in the lower Columbia and Deschutes rivers. Environmental Biology of Fishes 51:353-368.

Gadomski, D. M., C. A. Barfoot, J. M. Bayer, and T. P. Poe. 2001. Early life history of the northern pikeminnow in the lower Columbia River Basin. Transactions of the American Fisheries Society 130: 250-262

Knutsen, C.J., and D.L. Ward. 1999. Biological characteristics of northern pikeminnow in the lower Columbia and Snake rivers before and after sustained exploitation. Transactions of the American Fisheries Society 128:1008-1019.

Martinelli, T. L., and R. S. Shively. 1997. Seasonal distribution, movements and habitat associations of northern squawfish in two lower Columbia River reservoirs. Regulated rivers: research & management 13:543-556.

Mesa, M. G., and T. M. Olson. 1993. Prolonged swimming performance of northern squawfish. Transactions of the American Fisheries Society 122:1104-1110.

Mesa, M. G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. Transactions of the American Fisheries Society 123:786-793.

Mesa, M. G., T. P. Poe, D. M. Gadomski, and J. H. Petersen. 1994. Are all prey created equal? A review and synthesis of differential predation on prey in substandard condition. Journal of Fish Biology 45:81-96.

Mesa, M. G. and J. J. Warren. 1997. Predator avoidance ability of juvenile chinook salmon subjected to sublethal exposures to gas supersaturated water. Canadian Journal of Fisheries and Aquatic Sciences 54:757-764.

Mesa, M. G., T. P. Poe, A. G. Maule, and C. B. Schreck. 1998. Vulnerability to predation and physiological stress responses in juvenile chinook salmon experimentally infected with Renibacterium salmoninarum. Canadian Journal of Fisheries and Aquatic Sciences 55:1599-1606.

Parker, R.M., M.P. Zimmerman, and D.L. Ward. 1995. Variability in biological characteristics of northern squawfish in the Lower Columbia and Snake rivers. Transactions of the American Fisheries Society 124:335-346.

Petersen, J. H. 1994. Importance of spatial pattern in estimating predation on juvenile salmonids in the Columbia River. Transactions of the American Fisheries Society 123:924-930.

Petersen, J. H. 2001. Density, aggregation, and body size of northern pikeminnow preying on juvenile salmonids in a large river. Journal of Fish Biology 58:1137-1148.

Petersen, J. H., and D. L. DeAngelis. 1992. Functional response and capture timing in an individual-based model: predation by northern squawfish (*Ptychocheilus oregonensis*) on juvenile salmonids in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 49:2551-2565.

Petersen, J. H., and D. L. DeAngelis. 2000. Dynamics of prey moving through a predator field: a model of migrating juvenile salmon. Mathematical Biosciences 165:97-114.

Petersen, J. H., and D. M. Gadomski. 1994. Light-mediated predation by northern squawfish on juvenile chinook salmon. Journal of Fish Biology 45A:227-242.

Petersen, J. H., D. M. Gadomski, and T. P. Poe. 1994. Differential predation by northern squawfish (*Ptychocheilus oregonensis*) on live and dead juvenile salmonids in the Bonneville Dam tailrace (Columbia River). Canadian Journal of Fisheries and Aquatic Sciences 51:1197-1204.

Petersen, J. H. and T. P. Poe. 1992. Approaches to estimating predation losses in a large river system: predation upon juvenile salmonids in the Columbia River. In C. D. Levings and G. A. Hunter (eds.), An account of the workshop on research approaches to predation/competition questions in river fish communities. Canadian Manuscript Report of Fisheries and Aquatic Science 2150:13-18.

Petersen, J. H., and D. L. Ward. 1999. Development and corroboration of a bioenergetics model for northern pikeminnow feeding on juvenile salmonids in the Columbia River. Transactions of the American Fisheries Society 128:784-801.

Petersen, J. H., and J. F. Kitchell. 2001. Climate regimes and water temperature changes in the Columbia River: bioenergetic implications for predators of juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences 58:1831-1841.Poe, T. P., R. S. Shively, and R. A. Tabor. 1994. Ecological consequences of introduced piscivorous fishes in the lower Columbia and Snake rivers. In Theory and application in fish feeding ecology. Edited by D. J. Stouder, K. L. Fresh, and R. J. Feller, University of South Carolina Press, Columbia, S. C. pp. 347-360.

Shively, R. S., T. P. Poe, and S. T. Sauter. 1996. Feeding response by northern squawfish to a hatchery release of juvenile salmonids in the Clearwater River, Idaho. Transactions of the American Fisheries Society 125:230-236.

Shively, R. S., T. P. Poe, M. B. Sheer, and R. Peters. 1996. Criteria for reducing predation by northern squawfish near juvenile salmonid bypass outfalls at Columbia River dams. Regulated rivers: research & management 12:483-500.

Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation of juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13: 831-838.

Ward, D.L., J.H. Petersen, and J.Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River, and in the Lower Snake River. Transactions of the American Fisheries Society 124:321-334.

Ward, D.L., and M. P. Zimmerman. 1999. Response of smallmouth bass to sustained removals of northern pikeminnow in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society 128:1020-1035.

Zimmerman, M. P. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the lower Columbia River Basin during outmigration of juvenile anadromous salmonids. Transactions of the American Fisheries Society 128:1036-1054.

Zimmerman, M.P., and D.L. Ward. 1999. Index of predation on juvenile salmonids by northern pikeminnow in the lower Columbia River basin from 1994-96. Transactions of the American Fisheries Society 128:995-1007.

Zimmerman, M.P., and R.M. Parker. 1995. Relative density and distribution of smallmouth bass, channel catfish, and walleye in the lower Columbia and Snake rivers. Northwest Sci. 69:19-28.

Marine Fish Predation – Report

Emmett, R. L., P. J. Bentley, and G. K. Krutzikowsky. 2001. Ecology of marine predatory and prey fishes off the Columbia River, 1998 and 1999. U. S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-51.

Avian Predation – Reports

Collis, K., S. L. Adamany, D. D. Roby, D. P. Craig, and D. E. Lyons. 1999. Avian predation on juvenile salmonids in the lower Columbia River. 1998 Annual Report of the Oregon Cooperative Fish and Wildlife Unit at Oregon State University to Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

Collis, K., D. D. Roby, D. E. Lyons, and D. P. Craig. 2000. 2000 Draft Season Summary: Columbia Bird Research Update. (Available at the website: www.columbiabirdresearch.org).

Collis, K., D. D. Roby, D. E. Lyons, and R.M. Suryan. 2001. 2001 Draft Season Summary: Columbia Bird Research Update. (Available at the website: www.columbiabirdresearch.org).

Roby, D. D., D. P. Craig, K. Collis, and S. L. Adamany. 1998. Avian predation on juvenile salmonids in the lower Columbia River. 1997 Annual Report of the Oregon Cooperative Fish and Wildlife Research Unit at Oregon State University to Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

Roby, D. D., K. Collis, D. P. Craig and D. E. Lyons. 1999. 1999 Interim Report: Columbia Bird Research Update. (Available at the website: www.columbiabirdresearch.org).

United States Army Corps of Engineers (USACE). 2001. Caspian Tern Relocation FY 2001-2002 Management Plan and Pile Dike Modification to Discourage Cormorant Use, Lower Columbia River, Oregon and Washington. Environmental Assessment and Finding of No Significant Impact. Portland, Oregon.

Avian Predation – Peer Review Articles

Collis, K., D. D. Roby, D. P. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with Passive Integrated Transponders in the Columbia River Estuary: Vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Adkins, and D. E. Lyons. *In press*. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids. Transactions of the American Fisheries Society 00:000-000.

Collis, K., D. D. Roby, C. W. Thompson, D. E. Lyons, and M. Tirhi. *In review*. Barges as temporary nesting colonies for Caspian terns: Assessing suitability of potential colony restoration sites. Biological Conservation.

Cuthbert, F. J., and L. Wires. 1999. Caspian tern (*Sterna caspia*). *in* A. Poole and F. Gill, editors. The Birds of North America, no. 403. The Birds of North America, Inc., Philadelphia, Pennsylvania.

Roby, D. D., K. Collis, D. E. Lyons, D. P. Craig, J. Y. Adkins, A. M. Myers, and R. M. Suryan. In press. Effects of colony relocation on diet and productivity of Caspian terns. Journal of Wildlife Management 66:000-000.

Roby, D. D., K. Collis, D. E. Lyons, M. Antolos, and D. P. Craig. *In press*. Caspian Tern (*Sterna caspia*). Species account submitted to Birds of Oregon: A General Reference (D. Marshall, M. Hunter, and A. Contreras, eds.), Oregon State Univ. Press, Corvallis.

Roby, D. D., D. E. Lyons, D. P. Craig, K. Collis, and H. Visser. *In review*. Caspian tern predation on juvenile salmonids in the Columbia River Estuary: A bioenergetics approach. Canadian Journal of Fisheries and Aquatic Sciences.

Ryan, B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River basin. North American Journal of Fisheries Management 21:417-421.

Thompson, C. W., E. R. Donelan, M. M. Lance, and A. E. Edwards. *In press*. Diet of caspina terns in Commencement Bay, Washington. Waterbirds.

USACE Projects - Reports

Petersen, J. H., C. A. Barfoot, S. T. Sauter, D. M. Gadomski, P. J. Connolly, and T. P. Poe. 1999. Predicting the effects of dam breaching in the lower Snake River on predators of juvenile salmon. Report submitted to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Petersen, J., C. Barfoot, and M. Sheer. 2001. Predation by northern pikeminnow on juvenile salmonids in The Dalles Dam tailrace: field, laboratory, and habitat modeling studies (FY2000). Report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Relationship To Regional Programs

The Predator Control Program addresses goals and priorities specified in the Action Agencies (BPA, USACE, USBR) Five-year Implementation Plan for anadromous and resident fish. Goal 1 of the Implementation Plan is to “avoid jeopardy and assist in meeting recovery standards for Columbia Basin salmon, steelhead, bull trout, sturgeon, and other aquatic species that are affected by the FCRPS.” Furthermore, the Implementation Plan states that, “our goal is to achieve the greatest gains in survival, as quickly as possible while acknowledging that unlimited resources are not available to the Action Agencies. For example, actions that can be quickly implemented, can be accomplished with available resources, and provide a significant and measurable survival benefit would be implemented first.”

The Predator Control Program addresses at least two of the “hydrosystem priority” criteria from the Implementation Plan. Criterion 2 states that, “ultimately, we are seeking overall improved survival of juvenile and adult fish through the hydro corridor. Consequently, attention is given to those actions that have the highest estimated or potential improvement to the most fish and to the most ESU's within the hydro corridor.” Criterion 4 states that “priority would be given to actions that target reservoirs determined to have the lowest rates of juvenile survival. For example, data consistently shows the lowest reservoir survival rates occur in the pool between McNary and John Day dams. John Day reservoir survival improvement actions (e.g. predator control) are relatively high in priority.”

The Predator Control Program may also address an immediate habitat priority of the Implementation Plan. One immediate habitat priority is “the Action Agencies will conduct some experimental projects to see if mainstem habitat conditions can be improved.” This could include changes to habitat conditions that result in a decrease in predation on juvenile salmonids.

The NPMP is also a component of *Wy-Kan-Ush-Mi Wa-Kish-Wit*, the anadromous fish restoration plan of the Nez Perce, Umatilla, Warm Springs, and Yakama tribes. *Wy-Kan-Ush-Mi Wa-Kish-Wit* recommends continued evaluation of intensive removal of northern pikeminnow.

The Marine Fish Predation project is related to many other projects because incorporating measures of ocean survival (as indicated by increased or decreased adult salmon returns) may enhance appropriate evaluations of freshwater restoration projects. For example, evaluations of restoration projects that do not appear to be functioning (e.g. no increase in salmonid returns) may actually be influenced by poor ocean survival, which overshadowed project benefits. Finally, only effective ocean studies will verify if poor ocean conditions (in the broadest sense) are actually contributing to the continued decline, or non-increase, in regional salmonid abundances.

Juvenile salmonid survival benefits associated with the management of Caspian terns in the Columbia River estuary have been demonstrated (see above). These reductions in avian predation address many of the goals outlined in the Action Agencies (BPA, USACE, USBR) Five-year Implementation Plan. Furthermore, Regional plans for Snake River salmon recovery have recommended that avian predation be thoroughly investigated, and managed if necessary (NPPC 1994, NMFS 1995, CRITFC 1995).

Relationship Of Program To NMFS Biological Opinion

A "Predator Control Strategy is outlined in the "Measures to Avoid Jeopardy" section of the NMFS Biological Opinion. NMFS believes that some degree of predator control is necessary and that the certain measures will help achieve the survival performance goals of the biological opinion, particularly related to the 10% reduction in reservoir mortality estimates. Specific reasonable and prudent alternatives (RPA's) that from the biological opinion that are pertinent to the Predator Control Program are:

RPA Action 49: The Corps shall evaluate strategies to enhance post-release survival of transported fish; examples of such strategies include timing releases so that fish arrival at the estuary corresponds to minimal interactions with predators and maximum availability of forage and locating releases so as to decrease passage time through areas of high predation.
RPA Action 100: The Action Agencies shall continue to implement and study methods to reduce loss of juvenile salmonids to predacious fishes in the lower Columbia and lower Snake rivers. This effort will include continuation and improvement of the ongoing Northern Pikeminnow Management Program and evaluation of methods to control predation by non-indigenous predacious fishes, including smallmouth bass, walleye, and channel catfish.

RPA Action 101: The Corps, in coordination with the NMFS Regional Forum process, shall implement and maintain effective means of discouraging avian predation (e.g., water spray, avian predator lines) at all forebay, tailrace, and bypass outfall locations where avian predator activity has been observed at FCRPS dams. These controls shall remain in effect from April through August, unless otherwise coordinated through the Regional Forum process. This effort shall also include removal of old net frames attached to the two submerged outfall bypasses at Bonneville Dam. The Corps shall work with NMFS, FPOM, USDA Wildlife Services, and USFWS on recommendations for any additional measures and implementation schedules and report progress in the annual facility operating reports to NMFS. Following consultation with NMFS, corrective measures shall be implemented as soon as possible.

RPA Action 102: The Action Agencies, in coordination with the Caspian Tern Working Group, shall continue to conduct studies (including migrational behavior) to evaluate avian predation on juvenile salmonids in the FCRPS reservoirs above Bonneville Dam. If warranted and after consultation with NMFS and USFWS, the Action Agencies shall develop and implement methods of control that may include reducing the populations of these predators.

RPA Action 103: The Action Agencies shall quantify the extent of predation by white pelicans on juvenile salmon in the McNary pool and tailrace. A study plan shall be submitted to NMFS by September 30, 2001, detailing the study objectives, methods, and schedule.

Based on study findings, and in consultation with USFWS and NMFS, the Action Agencies shall develop recommendations and, if appropriate, and implementation plan.

RPA Action 104: The Action Agencies shall recover PIT-tag information from predacious bird colonies and evaluate trends, including hatchery-to-hatchery and hatchery-to-wild depredation reatios.

RPA Action 105: The Action Agencies shall develop a pilot study to assess the feasibility of enhancing the function of ecological communities to reduce predation losses and increase survival in reservoirs and the estuary.

RPA Action 106: The Action Agencies, in coordination with NMFS, shall investigate marine mammal predation in the tailrace of Bonneville Dam. A study plan shall be submitted to NMFS by June 30, 2001, detailing the study objectives, methods, and schedule.

RPA Action 195: The Action Agencies shall investigate and partition the causes of mortality below Bonneville Dam after juvenile salmonid passage through the FCRPS.

Future Needs

Project Recommendations

Northern Pikeminnow Management Program

Considerable effort and resources have been expended in initiating and implementing the NPMP. Unlike many predator control programs, the NPMP is based on sound science and in-depth knowledge of the situation: (1) development of the Columbia River basin hydrosystem has increased predation on out-migrating juvenile salmonids, (2) northern pikeminnow are responsible for the overwhelming majority of the predation, (3) population dynamics and behavior of northern pikeminnow facilitate relatively large reductions in predation from relatively low exploitation, and (4) compensation by surviving northern pikeminnow or other predators is unlikely. The current estimate of an approximate 25% reduction in annual losses to predation by northern pikeminnow equates to saving more than 5 million juvenile salmonids annually. If the project is not continued, predation will increase each year until levels observed prior to implementation are reached. The potential consequence of stopping the project is therefore the loss of 5 million juvenile salmonids annually, a significant portion of the total run. This includes stocks listed as threatened or endangered; therefore, this consequence is unacceptable.

Marine Fish Predation Project

Although freshwater survival for salmonids in the Columbia River Basin may have increased as a result of regional programs, ocean survival of salmonids is often very poor. Given the recent increased number of mackerel (two species) and hake residing off Oregon and Washington, predation by these species (and possibly others) may seriously impact ocean survival. Furthermore, the once abundant northern anchovy *Engraulis mordax* appears to have decreased significantly in recent years (Emmett et al. 1997) exacerbating predation by not providing an alternative prey for these marine predatory fishes.

If large pisciverous marine fishes are significant salmonid predators, fishery managers will be able to incorporate these findings into their management plans, and hopefully increase ocean survival of many salmonid stocks. For example, hake and mackerel are migratory species; hatchery salmonids could be released before and after the period hake and mackerel reside off the Columbia River. Alternatively, these fishes could be targeted for harvest by either sport or commercial fisheries. Other possible management options available include releasing hatchery fishes when other alternative prey are abundant (i.e., when pisciverous fishes are foraging on prey different than salmonids).

Avian Predation Project

Despite progress toward developing and implementing a management plan for Caspian terns that reduces predation on juvenile salmonids in the Columbia River estuary, there remain several impediments to implementation. Several bird conservation groups have sued to block efforts to manage terns in the Columbia River estuary until an Environmental Impact Statement is completed. A recent U.S. District Court ruling concurred with the plaintiffs claim that current scientific knowledge does not prove that tern colony relocation will aid salmon recovery efforts in the Columbia River Basin, nor does it prove that colony relocation will not harm terns in the long term. Research is needed to determine if reductions in Caspian tern predation on juvenile salmonids in the Columbia River estuary result in increased adult escapement, and if colony relocation results in poor productivity and population declines in Caspian terns.

The short-term advantages to both juvenile salmonids and Caspian terns associated with the relocation of nesting terns from Rice Island to East Sand Island are evident. There may be risks, however, associated with the continued concentration of such a large number of breeding Caspian terns at a single colony site (currently East Sand Island). Large proportions of the Pacific Coast population (ca. 70%), the continent-wide metapopulation (ca. 25%), and the worldwide numbers of Caspian terns (ca. 10%) continue to nest at one location in the Columbia River estuary (Cuthbert and Wires 1999, Craig et al., in prep.). Under current conditions, the risks from disease, storms, predators, human disturbance, oil spills, or other local events are substantially greater than if the population was more widely distributed at a number of smaller breeding colonies. Coupled with a potential return to poor ocean conditions and reduced availability of marine forage fish, this could lead to an increase in the reliance of terns on juvenile salmonids as a food source. Close monitoring is needed to assess the long-term effects of the relocation of the Caspian tern colony on survival of juvenile salmonids, as well as the productivity and demography of Caspian terns in the Columbia River estuary.

To minimize risks to Columbia Basin salmonids and Caspian terns, long-term management could include attracting a portion of the Caspian tern colony on East Sand Island to nest at several new and/or restored colony sites outside the Columbia River estuary. The East Sand Island colony is currently the only Caspian tern breeding site anywhere along the coast of the Pacific Northwest. Caspian terns formerly nested in large colonies (> 1,000 pairs) on islands in Willapa Bay and Grays Harbor, estuaries that no longer support nesting Caspian terns. Caspian tern colonies were also located along the coast of Puget Sound near Everett and Tacoma, Washington, but these colonies have been intentionally destroyed. The welfare of other listed or beleaguered salmonid stocks has been a primary concern in areas considered for restoration of Caspian tern colonies, yet for most former colony sites there is little or no evidence that juvenile salmonids were a significant component of tern diets. Restoration of permanent colony sites for Caspian terns along the coast of the Pacific Northwest appears unlikely without empirical evidence that local salmonid stocks will not be at risk. Toward that end, a study was recently conducted to test the feasibility of using small barges as temporary colony sites for Caspian terns as a means to assess diet composition of terns at potential colony restoration sites outside the Columbia River estuary (Collis et al., in review). The success of the pilot study suggests that this approach holds promise for providing resource managers with the information needed for a science-based long-term management plan.

Further investigations of unmanaged piscivorous waterbirds (e.g., double-crested cormorants, glaucous-winged/western gulls) are necessary in order to determine their impacts on juvenile salmonids from the Columbia River basin. These birds may pose an increasing threat to salmon survival because (1) the species' geographic range, abundance, and colony size has been increasing throughout the Pacific Northwest in recent years, and (2) current management to reduce tern predation on Columbia Basin salmonids may lead to increased availability of smolts to other avian predators.

Needed Future Actions

Reducing Predation Through Hydropower System Operation

Work is needed to address the effects of specific hydropower system operations on predation by resident fish on juvenile salmonids. RPA Action 105 calls for a pilot study (see above for RPA text) that "should include a combination of hydrosystem operations, enhancement of mainstem and estuarine habitat, and directed fishery management options. Information for the near-term studies would serve as the basis for a longer-term effort to enhance habitat and community function within the mainstem corridor. Issues to evaluate include natural and manmade habitat alterations, reservoir level fluctuations during predator spawning seasons, sport fish management options, and sediment and nutrient transport." Such a pilot study would also address RPA Action 155: BPA, working with BOR, the Corps, EPA, and USGS, shall develop a program to 1) identify mainstem habitat sampling reaches, survey conditions, describe cause-and-effect relationships, and identify research needs; 2) develop improvement plans for all mainstem reaches; and 3) initiate improvements in three mainstem reaches.

One goal of the pilot study would be to assess the feasibility of reducing predation on juvenile salmonids in the Columbia River through operation of the hydropower system. Objectives would include (1) assess the feasibility of determining the effects of hydropower operations on populations of predatory resident fish, and (2) if feasible, evaluate the effect of reservoir level fluctuations on populations of predatory resident fish. This project would include a review and summary of existing data on hydropower system operations and year-class strength of northern pikeminnow, smallmouth bass, and walleye in Lower Columbia River reservoirs and the free-flowing Hanford Reach. Data to be examined would include reservoir and river fluctuations during predator spawning seasons, incubation period, and other times critical to the setting of year-class strengths. If determined feasible new information would be collected on hydropower operations and predator populations by sampling for young of the year northern pikeminnow, smallmouth bass, and walleye during late summer and fall. Sampling for a number of years would probably be necessary to ensure a wide variation in hydropower operations.

Compensatory Feeding by Predators

The NPMP has been evaluated for its effects on the number and size structure of northern pikeminnow in the system, effects of removal on other predators such as smallmouth bass and walleye, and survival of juvenile salmon in the system (Beamesderfer et al. 1996; Friesen and Ward 1999; Knutsen and Ward 1999; Zimmerman 1999; Zimmerman and Ward 1999; Hankin and Richards 2000). Friesen and Ward (1999) estimated a reduction in predation on juvenile salmonids of about 25% (median estimate) through the NPMP, equivalent to saving about 2% of the total downstream migration (3.8 million salmon saved of ~200 million migrants). Hankin and Richards (2000) reviewed the biological and economic performance of the NPMP.

An important assumption behind this management program is that predation rate on salmonids by northern pikeminnow and other predators that remain in the rivers will not increase following removal (compensatory feeding; Beamesderfer et al. 1990), and thus reduce the expected benefits of removal. Of the possible compensatory processes (feeding rate, growth rate, reproduction, etc.) that might be occurring following predator removal, compensatory feeding may be especially important since it is a rapid behavioral response with sufficient scope to potentially diminish or negate the expected program benefits. Predation rates by northern pikeminnow on juvenile salmonids, especially in large midreservoir areas where many predators occur, averages roughly 10% of their maximum feeding rate (Vigg et al. 1991; Petersen 1994, 2001), so increased predation rates are feasible. Predators are not growing near their maximum rate (Petersen 2001a) and there is considerable evidence that northern pikeminnow and other predators switch to juvenile salmonids from other prey types when salmonid density increases (Thompson and Tufts 1967; Petersen and DeAngelis 1992; Tabor et al. 1993; Collis et al. 1995; Shively et al. 1996).

Conclusions about the occurrence and potential importance of compensatory feeding have, however, been mixed, and there is not a general consensus. General food habits of northern pikeminnow, smallmouth bass, and walleye in the lower Columbia and Snake rivers have not shown dramatic shifts since the early 1990's that could be ascribed to implementation of the NPMP (Zimmerman 1999; Zimmerman and Ward 1999). On the other hand, Petersen (2001a; 2001b) concluded changing predator density, predator size distribution, and prey density, consequences of the NPMP, were likely causing compensatory feeding in northern pikeminnow that remained in the system, but direct measurement of an increase in the feeding rate of northern pikeminnow would be difficult to detect because of high natural variability. Beamesderfer et al. (1996) concluded that exploitation goals were being met and that continued evaluation through indirect methods (predator population structure, consumption indexing, models, etc.) was necessary since a direct demonstration of a change in the rate of salmonid survival was not feasible. The studies above differed in how they pooled data, whether they included data collected before implementation of the NPMP, and in other techniques. The NPMP is implemented throughout the Columbia and lower Snake rivers, so all of the analyses suffer from the lack of a true control site, thus powerful statistical models cannot be used to test the compensatory feeding hypothesis (Hurlbert 1984; Underwood 1994).

Resolution of the compensatory feeding hypothesis would appear to be a high priority for continuing or modifying the NPMP, which costs about $3.1 million per year (Friesen and Ward 1999). Field, laboratory, or model studies might be conducted to test the null hypothesis directly, or specific assumptions implicit in different mechanisms might be tested. Specific objectives might be added to the ongoing NPMP.

Salmonid Mortality in the Lower Columbia River

Data collected during recent years suggest that survival of juvenile salmonids may be particularly poor in lower reservoirs of the Columbia River and below Bonneville Dam, likely due to predation. Studies or experiments will likely be necessary to obtain a better understanding of the mechanisms causing these high mortalities and might suggest management alternatives.

Studies funded by the USACE during the last several years have been using radio-tagged juvenile salmonids to estimate survival rates at dams, but can also be used to estimate rates of survival through pools away from dams (Counihan et al. 2001). Using these types of data, survival can be estimated in The Dalles and Bonneville reservoirs, and in the Columbia River below Bonneville Dam (Counihan et al. 2001; USGS, unpublished analyses). In 2000 and 2001, about 5% of yearling chinook salmon did not survive passage through The Dalles pool, while 10-14% of this stock died in Bonneville Reservoir. Below Bonneville dam, the rate of survival per km was similar to rates in the two lower reservoirs, however, expansion of these rates across roughly 200 km in the lower river suggests that over 30% of yearling chinook might die in this reach. The expanded loss assumes that the rate of mortality is constant through the lower river, which has not been examined. For subyearling chinook salmon, fewer data are available but estimated losses are higher than for yearling chinook or steelhead. Mortality through The Dalles and Bonneville reservoirs ranged from 16-38% during 2000 and 2001, while the expanded loss below Bonneville dam in 2001 was 55% (assumes a 200-km reach from Bonneville Dam to the upper estuary). Steelhead estimates were available for The Dalles reservoir only and survival was high, ranging from 96 to 98% (Counihan et al. 2001; USGS, unpublished analyses).

The cause(s) of mortality in these lower river reaches could be disease, predation, starvation, and perhaps other factors, but predation seems to be the most likely mechanism. The abundance of northern pikeminnow is relatively high in these reaches, compared to some other reservoirs and reaches further upriver (Ward et al. 1995). Predation rates by northern pikeminnow on juvenile salmonids tend to be higher in the lower river than in the lower Snake River or in mid-Columbia reservoirs. Finally, the density of juvenile salmonids is likely higher in the lower Columbia River since all juveniles must pass through this section of river, with only the Willamette River as a major source of water. This “funnel” effect may increase the density of juvenile salmonids. Northern pikeminnow and other predators often respond with non-linear increases in predation rates as prey density increases (Petersen and DeAngelis 1992; Collis et al. 1995; Shively et al. 1996; and others). A better documentation and understanding of this spatial pattern of juvenile salmonid mortality might be used to adaptively manage predation in the river system.

Exotic Species and Their Effects on Predation

The recent occurrence of several exotic species in the lower Columbia River (and perhaps elsewhere), and their influence on predator populations, may explain some of the high measured losses. Invasive plants have become common or abundant in several reservoirs, and their influence on the community is largely unknown. Backwater studies conducted in the John Day Reservoir during the 1970s and early 1980s) did not note the presence of water milfoil *Myriophyllum* spp., although it is now well established in many shallow-water areas of the Columbia River. Barfoot et al. (In press) observed a significant shift in the composition of the nearshore fish community over a 10-year period (1984-1995) in John Day Reservoir, possibly related to reservoir aging and increased abundance of milfoil. A recent survey (2001) of milfoil in Bonneville reservoir showed high densities along both the Oregon and Washington shores (T. Counihan, USGS, unpublished data). Aquatic plants such as milfoil often provide a protective habitat for the early life history stages of predators such as smallmouth bass or yellow perch *Perca flavescens*. Little is known of the fish that currently inhabit the extensive milfoil patches in the lower Columbia River.

American shad *Alosa sappidisima* have also become very abundant in the lower Columbia River during the last 60 years, with 2-3 million adults passing Bonneville Dam per year during the last decade. Adult shad migrate into the Columbia River during May through July and adults spawn soon after migration. A large proportion of adults appear to enter John Day and McNary reservoirs for spawning. Incubation of eggs is 3-8 days and juvenile shad rear in the mainstem Columbia and Snake rivers during July through late fall, when they migrate to the ocean. In John Day Reservoir, American shad are the predominant species in larval fish surveys during July (Gadomski and Barfoot 1998), and juvenile shad dominate seine hauls and hydroacoustic surveys in late summer (Petersen et al. In review*;* USGS unpublished data).

Juvenile American shad may be supplementing the diet and increasing the growth rates of predators in the system, thus having an indirect effect on juvenile salmonids. Past and ongoing studies indicate that over 80% of the diet of northern pikeminnow in late summer and fall may be juvenile American shad (Petersen et al. 1994; J. H. Petersen, unpublished data). Juvenile shad were not present in great numbers prior to the construction of dams, and shad are likely replacing crayfish and sculpins in the diet during fall. Bioenergetic simulations of northern pikeminnow growth rates suggest that replacing even 20% of the diet in the fall period with juvenile American shad may be causing quite substantial increases in fall growth rates and predator size going into the winter period (J.H. Petersen, USGS, unpublished analyses). Water temperatures during late summer and fall are optimal for northern pikeminnow growth and the predators may be doing much of their growth during this period (Petersen and Ward 1999). Enhanced growth in the fall, stimulated by optimum temperature and shad in the diet, may cause the predators to be larger and contain higher stores of lipids as they enter the winter period. These larger predators would likely have a higher overwinter survival rate and be in a better condition the following spring. Results of a BPA-funded study on American shad as a supplement to northern pikeminnow will be complete in 2002.

Avian Predation

Continued monitoring of managed bird populations (i.e., Caspian terns nesting in the Columbia River estuary) is necessary to assess the effectiveness of current management initiatives implemented to reduce the impacts of terns on juvenile salmonids from the Columbia River basin. Tern population size, productivity, diet composition, and consumption must be measured to determine if management objectives are being met. Future studies should compare what is in the diet of piscivorous waterbirds with what is available in river to determine the relative vulnerability of different salmonid stocks to avian predators. The reasons for differences in vulnerability (e.g., fish health, origin [hatchery vs. wild]) should also be investigated. Finally, to fully evaluate the extent of predation losses to birds in the estuary and elsewhere, it is necessary to have estimates of the number of juvenile salmonids available to avian predators. In 2002, we plan to conduct a pilot study to determine the feasibility of estimating annual survival of juvenile salmonids to the Columbia River Estuary. With this information accurate predation rates can be generated for terns and other predators in the estuary. If successful, we will propose this work as part of a new research program for separate BPA funding in 2003 and beyond.

In addition, further investigations of unmanaged piscivorous waterbirds (e.g., double-crested cormorants, glaucous-winged/western gulls) are necessary in order to determine their impacts on juvenile salmonids from the Columbia River basin. These birds may pose an increasing threat to salmon survival because (1) the species' geographic range, abundance, and colony size has been increasing throughout the Pacific Northwest in recent years, and (2) current management to reduce tern predation on Columbia Basin salmonids may lead to increased availability of smolts to other avian predators.

Marine Mammal Predation

Reasonable and Prudent Alternative Action 106 (Page 9-109) in the NMFS 2000 BiOp calls for an investigation of marine mammal predation in the tailrace of Bonneville Dam. The study plan is to be submitted to NMFS by June 30, 2001, detailing the study objectives, methods, and schedule. Oregon agrees that this study is necessary, however, Oregon strongly believes that there is a need to adequately understand the current relationships between predation (as a source of mortality) and the viability of fish stocks in the entire Columbia River system below Bonneville Dam – an area that includes near-ocean, the Columbia River estuary, and the mainstem Columbia River up to Bonneville Dam. Once such an understanding is achieved, an evaluation of the effects of predation on fish stocks of special concern can be made. Included in this study effort should be determination of pinniped abundance and distribution, movements in the Columbia River system, predation levels, and the vulnerability of various salmonid runs to such mortality. Evaluation of this predator activity should also include development of remedial methods such as relocation or lethal removal. Efforts should be coordinated with on-going marine mammal research and control activities in the Columbia River, estuary and near-ocean.

Project objectives should include:

1. Determine current abundance, population structure, and distribution patterns of harbor seals and California sea lions in the near-ocean, estuary, and Columbia River up to Bonneville Dam.
2. Determine areas and times of pinniped predation and identify physical/environmental factors that may contribute to predation success.
3. Determine annual prey and food requirements of pinnipeds occurring in the Columbia River.
4. Determine predation vulnerability of various salmonid runs and levels of mortality caused by pinniped predation.
5. Estimate direct and indirect mortality of salmon by pinnipeds in the Columbia River.
6. Identify and evaluate methods to reduce salmon mortality caused by pinnipeds in-river and in the Columbia River estuary.

REFERENCES

Barfoot, C. B, D. M. Gadomski, and J. H. Petersen. *In press*. Resident fish assemblages in shallow shorelines of a Columbia River impoundment: Northwest Science 76

Beamesderfer, R. C., and B. E. Rieman. 1991. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:439-447.

Beamesderfer, R. C., B. E. Rieman, L. J. Bledsoe, and S. Vigg. 1990. Management implications of a model of predation by a resident fish on juvenile salmonids migrating through a Columbia river reservoir. North American journal of Fisheries Management 10:290-304.

Beamesderfer, R. C. P., D. L. Ward, and A. A. Nigro. 1996. Evaluation of the biological basis for a predator control program on northern squawfish (*Ptychocheilus oregonensis*) in the Columbia and Snake rivers. Canadian Journal of Fisheries and Aquatic Sciences 53:2898-2908.

Brodeur, R. D., and W. G. Pearcy. 1986. Distribution and relative abundance of pelagic nonsalmonid nekton off Oregon and Washington, 1979-84. NOAA Tech. Rept. NMFS 46, 85 p.

Collis, K., R.E. Beaty, and B.R. Crain. 1995. Changes in catch rate and diet of northern squawfish associated with the release of hatchery-reared juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 15:346-357. Friesen, T. A., and D. L. Ward. 1999.

Collis, K., S. L. Adamany, D. D. Roby, D. P. Craig, and D. E. Lyons. 1999. Avian predation on juvenile salmonids in the lower Columbia River. 1998 Annual Report of the Oregon Cooperative Fish and Wildlife Unit at Oregon State University to Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

Collis, K., D. D. Roby, D. E. Lyons, and D. P. Craig. 2000. 2000 Draft Season Summary: Columbia Bird Research Update. (Available at the website: www.columbiabirdresearch.org).

Collis, K., D. D. Roby, D. P. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001a. Colonial waterbird predation on juvenile salmonids tagged with Passive Integrated Transponders in the Columbia River Estuary: Vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

Collis, K., D. D. Roby, D. E. Lyons, and R.M. Suryan. 2001b. 2001 Draft Season Summary: Columbia Bird Research Update. (Available at the website: www.columbiabirdresearch.org).

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Adkins, and D. E. Lyons. *In press*. Colony size and diet composition of piscivorous waterbirds on the lower Columbia

River: Implications for losses of juvenile salmonids. Transactions of the American Fisheries Society.

Collis, K., D. D. Roby, C. Thompson, D. E. Lyons, and M. Tirhi. In review. Barges as temporary nesting colonies for Caspian terns: Assessing suitability of potential colony restoration sites. Biological Conservation.

Counihan, T. D., K. J. Huskey, and J. H. Petersen. 2001. Survival estimates of migrant juvenile salmonids in the Columbia River from John Day Dam through Bonneville Dam using radio-telemetry. Annual Report. U.S. Army Corps of Engineers, Portland District.

CRITFC (Columbia River Inter-tribal Fish Commission). 1995. Wy-Kan-Ush-Mi Wa-Kish-Wit, Spirit of the Salmon. The Columbia River anadromous fish restoration plan of the Nez Perce, Umatilla, Warm Springs, and Yakama tribes. Vol. 1, Final draft. Portland, Oregon.

Craig, D.P., D.D. Roby, D.E. Lyons, K. Collis, T. Zimmerman, N.D. Chelgren, W.D. Shuford *In prep*. Status of Caspian terns in the Pacific Coast Population of North America. Condor.

Cuthbert, F. J., and L. Wires. 1999. Caspian tern (*Sterna caspia*). *in* A. Poole and F. Gill, editors. The Birds of North America, no. 403. The Birds of North America, Inc., Philadelphia, Pennsylvania.

Dorn, M. W. 1996. Status of the coastal Pacific whiting resource in 1996. In Appendix Volume I to the Status of the Pacific Coast Groundfish Fishery Through 1996 and Recommended Acceptable Biological Catches for 1997. Available from Pacific Fishery Marine Council.

Emmett, R. L., P. J. Bentley, and M. H. Schiewe. 1997. Abundance and distribution of northern anchovy eggs and larvae (*Engraulis mordax*) off the Oregon coast, Mid-1970s and 1994 and 1995. P. 505-508, In Forage Fishes in Marine Ecosystems, Proceedings.

Fisher, J. P., and W. G. Pearcy. 1988. Growth of juvenile coho salmon (*Oncorhynchus kisutch*) in the ocean off Oregon and Washington, USA, in years of differing coastal upwelling. Canadian Journal of Fisheries and Aquatic Sciences 45:1036-1044.

Friesen, T. A., and D. L. Ward. 1999. Management of northern pikeminnow and implications for juvenile salmonid survival in the lower Columbia and Snake rivers. North American Journal of Fisheries Management 19:406-420.

Friesen, T. A., and D. L. Ward. 2000. Biological characteristics of Columbia River walleye in relation to northern pikeminnow management. Oregon Department of Fish and Wildlife, Information Report 2000-05. Clackamas, Oregon.

Gadomski, D. M., and J. A. Hall-Griswold. 1992. Predation by northern squawfish on live and dead juvenile chinook salmon. Transactions of the American Fisheries Society. 121: 680-685.

Gadomski, D. M., and C. A. Barfoot. 1998. Diel and distributional abundance patterns of fish embryos and larvae in the lower Columbia and Deschutes rivers. Environmental Biology of Fishes 51:353-368.

Hankin, D. G., and J. Richards. 2000. The northern pikeminnow management program: An independent review of program justification, performance, and cost-effectiveness. Final Report to the Northwest Power Planning Council.

Hurlbert, S. J. 1984. Pseudoreplication and design of ecological field experiments. Ecological Monographs. 54:187-211.

Jones, S. T., G. M. Starke, and R. J. Stansell. 1996. Predation by birds and effectiveness of predation control measures at Bonneville, The Dalles, and John Day dams in 1995. U.S. Army Corps of Engineers, Portland District, Operations Division, CENPP-CO-SRF. 10 pp.Knutsen, C.J., and D.L. Ward. 1999. Biological characteristics of northern pikeminnow in the lower Columbia and Snake rivers before and after sustained exploitation. Transactions of the American Fisheries Society 128:1008-1019.

Knutsen, C. J., and D. L. Ward. 1999. Biological characteristics of northern pikeminnow in the lower Columbia and Snake rivers before and after sustained exploitation. Transactions of the American Fisheries Society 128:1008-1019.

Martinelli, T. L., and R. S. Shively. 1997. Seasonal distribution, movements and habitat associations of northern squawfish in two lower Columbia River reservoirs. Regulated rivers: research & management 13:543-556.

Matthews, G. M., S. Achord, J. R. Harmon, O. W. Johnson, D. M. Marsh, B. P. Sandford, N. N. Paasch, K. W. McIntryre, and K. L. Thomas. 1992. Evaluation of transportation of juvenile salmonids and related research on the Columbia and Snake Rivers, 1990.

Mesa, M. G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. Transactions of the American Fisheries Society 123:786-793.

National Marine Fisheries Service (NMFS). 1995. Proposed Recovery Plan for Snake River Salmon. United States Department of Commerce. National Oceanic and Atmospheric Administration. Washington, D. C.

Northwest Power Planning Council (NWPPC)). 1994. Columbia River Basin Fish and Wildlife Program. Portland, OR.

Northwest Power Planning Council (NWPPC). 2000. Columbia Basin Fish and Wildlife Program. Portland, OR.

Parker, R. M., M. P. Zimmerman, and D. L. Ward. 1995. Variability in biological characteristics of northern squawfish in the Lower Columbia and Snake rivers. Transactions of the American Fisheries Society 124:335-346.

Pearcy, W. G. 1988. Factors affecting survival of coho salmon off Oregon and Washington. Pages 67-73, In W. J. McNeal (editor), Salmon Production, Management, and Allocation. Oregon State University Press, Corvallis, OR.

Pearcy, W. G. 1992. Ocean ecology of North Pacific salmonids. Washington Sea Grant, University of Washington Press, Seattle.

Petersen, J. H. 1994. Importance of spatial pattern in estimating predation on juvenile salmonids in the Columbia River. Transactions of the American Fisheries Society 123:924-930.

Petersen, J. H. 2001a. Density, aggregation, and body size of northern pikeminnow preying on juvenile salmonids in a large river. Journal of Fish Biology 58:1137-1148.

Petersen, J. H. 2001b. Compensatory feeding following a predator removal program: detection and mechanisms. Report submitted to Bonneville Power Administration.

Petersen, J., C. Barfoot, and M. Sheer. 2001. Predation by northern pikeminnow on juvenile salmonids in The Dalles Dam tailrace: field, laboratory, and habitat modeling studies (FY2000). Report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Petersen, J. H., and D. L. DeAngelis. 1992. Functional response and capture timing in an individual-based model: predation by northern squawfish (*Ptychocheilus oregonensis)* on juvenile salmonids in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 49:2551-2565.

Petersen, J. H., D. M. Gadomski, and T. P. Poe. 1994. Differential predation by northern squawfish (*Ptychocheilus oregonensis*) on live and dead juvenile salmonids in the Bonneville Dam tailrace (Columbia River). Canadian Journal of Fisheries and Aquatic Sciences 51:1197-1204.

Petersen, J. H., and D. L. Ward. 1999. Development and corroboration of a bioenergetics model for northern pikeminnow feeding on juvenile salmonids in the Columbia River. Transactions of the American Fisheries Society 128:784-801.

Petersen, J. H., R. A. Hinrichsen, D. M. Gadomski, D. H. Feil, and D. W. Rondorf. *In review.* American shad in the Columbia River. American Fisheries Society.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:405-420.

Raymond, H. L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer chinook salmon and steelhead in the Columbia River basin. North American Journal of Fisheries Management 8:1-24.

Rieman, B. E., and R. C. Beamesderfer. 1990. Dynamics of a northern squawfish population and the potential to reduce predation on juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 10:228-241.

Rieman, B. E., R. C. Beamesderfer, S. Vigg, and T. P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:448-458.

Roby, D. D., D. P. Craig, K. Collis, and S. L. Adamany. 1998. Avian predation on juvenile salmonids in the lower Columbia River. 1997 Annual Report of the Oregon

Cooperative Fish and Wildlife Research Unit at Oregon State University to Bonneville Power Administration and U.S. Army Corps of Engineers, Portland, Oregon.

Roby, D. D., K. Collis, D. E. Lyons, D. P. Craig, J. Y. Adkins, A. M. Myers, and R. M. Suryan. *In press*. Effects of colony relocation on diet and productivity of Caspian terns. Journal of Wildlife Management 66:000-000.

Roby, D. D., K. Collis, D. E. Lyons, M. Antolos, and D. P. Craig. *In press*. Caspian Tern (*Sterna caspia*). Species account submitted to Birds of Oregon: A General Reference (D. Marshall, M. Hunter, and A. Contreras, eds.), Oregon State Univ. Press, Corvallis.

Roby, D. D., D. E. Lyons, D. P. Craig, K. Collis, and H. Visser. *In review*. Caspian tern predation on juvenile salmonids in the Columbia River Estuary: A bioenergetics approach. Canadian Journal of Fisheries and Aquatic Sciences.

Ruggerone, G. T. 1986. Consumption of migrating juvenile salmonids by gulls foraging below a Columbia River dam. Transactions of the American Fisheries Society 115:736-742.

Schaeffer, L. 1991. Predation study: Salmon hatchery smolts and survival. Oregon Department of Fish and Wildlife, Technical Report. 33 pp.

Schaeffer, L. 1992. Avian predators at ODFW hatcheries: Their identification and control. Oregon Department of Fish and Wildlife, Technical Report 92-1. 19 pp.

Shively, R. S., T. P. Poe, and S. T. Sauter. 1996. Feeding response by northern squawfish to a hatchery release of juvenile salmonids in the Clearwater River, Idaho. Transactions of the American Fisheries Society 125:230-236.

Steuber, J. E., M. E. Pitzler, and J. G. Oldenburg. 1993. Protecting juvenile salmonids from gull predation using wire exclusion below hydroelectric dams. United States Army Corps of Engineers. United States Department of Agriculture, Animal Damage Control.

Tabor, R. A., R. S. Shively, and T. P. Poe. 1993. Predation of juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13: 831-838.

Thompson, R. B., and D. F. Tufts. 1967. Predation by Dolly Varden and northern squawfish on hatchery-reared sockeye salmon in Lake Wenatchee, Washington. Transactions of the American Fisheries Society 96:424-427.

Underwood, A. J, 1994. On beyond BACI: Sampling designs that might reliably detect environmental disturbances. Ecological Monographs 4:3-15.

Vigg, S., T. P. Poe, L. A. Prendergast, and H. C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Ward, D. L., J. H. Petersen, and J. Loch. 1995. Index of predation on juvenile salmonids by northern squawfish in the lower and middle Columbia River, and in the Lower Snake River. Transactions of the American Fisheries Society 124:321-334.

Ward, D. L., and M. P. Zimmerman. 1999. Response of smallmouth bass to sustained removals of northern pikeminnow in the lower Columbia and Snake rivers. Transactions of the American Fisheries Society 128:1020-1035.

Ware, D. M., and G. A. McFarlane. 1995. Climate-induced changes in Pacific hake (*Merluccius productus*) abundance and pelagic community interactions in the Vancouver Island upwelling system.

Zimmerman, M. P. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the lower Columbia River Basin during outmigration of juvenile anadromous salmonids. Transactions of the American Fisheries Society 128:1036-1054.

Zimmerman, M. P., and R. M. Parker. 1995. Relative density and distribution of smallmouth bass, channel catfish, and walleye in the lower Columbia and Snake rivers. Northwest Sci. 69:19-28.

Zimmerman, M. P., and D. L. Ward. 1999. Index of predation on juvenile salmonids by northern pikeminnow in the lower Columbia River basin from 1994-96. Transactions of the American Fisheries Society 128:995-1007.

W:\cbfwa\files\province\systemwide\subsum\021024Predation.doc