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YAKIMA RIVER SPECIES INTERACTING STUDIES

Annual Report 1999

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Annual Report 1999

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Executive Summary

Species interactions research and monitoring was initiated in 1989 to investigate ecological interactions among fish in response to proposed supplementation of salmon and steelhead in the upper Yakima River basin. This is the eighth of a series of progress reports that address species interactions research and pre-supplementation monitoring of fishes in the Yakima River basin. Data have been collected prior to supplementation to characterize the ecology and demographics of non-target taxa (NTT) and target taxon, and develop methods to monitor interactions and supplementation success. Major topics of this report are associated with implementing NTT monitoring prescriptions for detecting potential impacts of hatchery supplementation, hatchery fish interactions, and monitoring fish predation indices. This report is organized into four chapters, with a general introduction preceding the first chapter. This annual report summarizes data collected primarily by the Washington Department of Fish and Wildlife (WDFW) between January 1, 1998 and December 31, 1999 in the Yakima basin, however these data were compared to data from previous years to identify preliminary trends and patterns. Summaries of each of the chapters included in this report are described below.

- Monitoring prescriptions were developed to determine whether non-target taxa objectives were being achieved relative to salmon supplementation in the Yakima Basin. The implementation of the monitoring prescriptions revealed that all of the NTT were within the containment objectives after the first stocking of hatchery chinook and coho salmon smolts. Some declines occurred in the status of NTT but models account for most as the result of biotic or abiotic interactions unrelated to hatchery supplementation. However, our ability to statistically detect impacts is very limited until several years of data are available to evaluate impacts. If impacts did occur, it would be unlikely that they could be detected after 1 year. Monitoring prescriptions should continue to be implemented during 2000.

- We examined behavioral dominance and predator avoidance relationships of spring chinook salmon presmolts that were reared under optimal conventional hatchery conditions (OCT) or semi-natural hatchery conditions (SNT). Fish were transported from acclimation sites to the Cle Elum Hatchery and introduced into behavioral arenas for seven days. Most of the fish were within 6% of the body length of each other. Behavioral arenas had one location with highly favorable attributes (e.g., food, cover, optimal velocity). Dominance was assigned to the fish that acquired the most food, initiated the most agonistic interactions, and occupied the preferred position the most. After dominance observations were completed, a model bird predator was introduced over the top of the experimental arena, and behavioral responses of the fishes were recorded. Thirty replicate pairs of fish were observed. Seventy-seven percent of the trials were dominated by large fish, regardless of rearing history. Of the smaller fish that dominated larger fish, 71% (5 of 7) were OCT. Fish size and rearing history explained 93% of the variation in dominance that we observed. The initial behavioral responses of SNT and OCT fish to a model predator were similar. Approximately half of the fish showed little or no response to the model predator. Increased sample sizes and inclusion of wild fish will be pursued in the year 2000.

- We estimated the number of salmonids that smallmouth bass ate during the spring of 1999 in the Yakima River. Predator surveys were conducted weekly from March 25 through June 10 in two sections of the lower Yakima River and in small areas of hypothetically high predation, termed "hotspots". Abundance was estimated using a relationship between catch per unit effort and population estimates, which were calculated using maximum likelihood estimators of mark and recapture data. Diet was determined by lavaging smallmouth bass and identifying consumed fish in the lab by examining diagnostic bones. Daily consumption was calculated by estimating the average number of salmonids that a bass ate per day and extrapolating that number to the number of bass in the lower 68 kilometers of the Yakima River. Daily consumption estimates were then summed to yield total consumption during the spring. In addition, data from 1998 was reanalyzed using procedures used to analyze data collected in 1999. Abundance of bass >150 mm increased during the spring from a low of 8,066 on March 25 to a high of 35,378 on June 10. The increases in abundance were primarily due to immigration of fish from the Columbia River. Daily consumption of salmonids was relatively low until late April and peaked in late May. Consumption dramatically decreased in June, despite the facts that bass abundance and water temperatures were highest during this period. This decrease is likely to be due to bass shifting their behaviors from feeding to spawning. Smallmouth bass ate an estimated 171,031 salmonids during the spring. Only 3,795 of these were estimated to be spring chinook. The remainder were mostly fall chinook salmon. In contrast to 1998 salmonid consumption estimates, 1999 estimates were over 2.5 times lower (1998 estimates: 442,085 salmonids, 2,863 spring chinook salmon). Horn Rapids Dam (Wanawish) has the potential to be the area of highest predation in the Yakima River because of the large number of bass that congregate below the Dam. Other presumptive hotspots such as Roza Dam and the Chandler bypass pipe had very low densities of bass or northern pikeminnow during 1999. We suspect that predation on salmonids during 1998 and 1999 was low relative to other years that have warmer water temperatures and lower flows.

- We conducted population estimates of northern pikeminnow *Ptychocheilus oregonensis* using mark recapture methodology during April, May and June in three sections of the Yakima River above Prosser Dam. Northern pikeminnow abundance (fish > 200 mm fork length/km) was highest directly below Sunnyside Dam in the vicinity of the fish bypass facility. The abundance of northern pikeminnow > 200 mm fork length/km in free flowing sections of the Yakima River ranged from 116.1 – 220.8 fish/km. Most recaptured northern pikeminnow (n = 111; 94.5%) were recaptured in the same section that they were originally tagged, suggesting limited northern pikeminnow movement during the period of this study. Salmonid consumption by northern pikeminnow was higher during the May and June sampling periods than the April period at all sites. Throughout the salmonid outmigration season (April 12 – June 21, 1999) 4.1% of the northern pikeminnow sampled contained salmonids. We classified all salmonids as yearling smolts (spring chinook *Oncorhynchus tshawytscha* or coho *Oncorhynchus kisutch*) based on predicted fork length from diagnostic bones. We were unable to confidently differentiate between spring chinook or coho or hatchery versus wild origin fish based on diagnostic bones or the presence or absence of tags. We estimated a total of 60,583 yearling salmonids were consumed by northern pikeminnow from Prosser Dam to Roza Dam from April 12 – June 21, 1999. Development of a northern pikeminnow predation index in future years should utilize weekly salmonid consumption estimates since this portion of the predation index is likely more variable throughout the outmigration period than predator abundance.

All findings in this report should be considered preliminary and subject to further revision unless they have been published in a peer-reviewed technical journal (i.e., see General Introduction).

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General Introduction

This report is intended to satisfy two concurrent needs: 1) provide a contract deliverable from the Washington Department of Fish and Wildlife (WDFW) to the Bonneville Power Administration (BPA), with emphasis on identification of salient results of value to ongoing Yakima/Klickitat Fisheries Project (YKFP) planning, and 2) summarize results of research that have broader scientific relevance. This is the eighth of a series of progress reports that address species interactions research and supplementation monitoring of fishes in response to supplementation of salmon and steelhead in the upper Yakima River basin (Hindman et al. 1991; McMichael et al. 1992; Pearsons et al. 1993; Pearsons et al. 1994; Pearsons et al. 1996; Pearsons et al. 1998, Pearsons et al. 1999). Journal articles and book chapters have also been published from our work (McMichael 1993; Martin et al. 1995; McMichael et al. 1997; McMichael and Pearsons 1998; McMichael et al. 1998; Pearsons and Fritts 1999; McMichael et al. 1999; McMichael et al. 1999; Pearsons and Hopley 1999; Ham and Pearsons 2000; Ham and Pearsons 2001; Amaral et al. in press; McMichael and Pearsons in press; Pearsons et al. in press). This progress report summarizes data collected between January 1, 1998 and December 31, 1999. These data were compared to findings from previous years to identify general trends and make preliminary comparisons. Interactions between fish produced as part of the YKFP, termed target species or stocks, and other species or stocks (non-target taxa) may alter the population status of non-target species or stocks. This may occur through a variety of mechanisms, such as competition, predation, and interbreeding (reviewed in Pearsons et al. 1994; Busack et al. 1997). Furthermore, the success of a supplementation program may be limited by strong ecological interactions such as predation or competition (Busack et al. 1997).

Our work has adapted to new information needs as the YKFP has evolved. Initially, our work focused on interactions between anadromous steelhead and resident rainbow trout (for explanation see Pearsons et al. 1993), then interactions between spring chinook salmon and rainbow trout, and recently interactions between spring chinook salmon and highly valued non-target taxa (NTT; e.g., bull trout); and interactions between strong interactor taxa (e.g., those that may strongly influence the abundance of spring chinook salmon; e.g., smallmouth bass) and spring chinook salmon. The change in emphasis to spring chinook salmon has largely been influenced by the shift in the target species planned for supplementation (Bonneville Power Administration et al. 1996; Fast and Craig 1997). Originally, steelhead and spring chinook salmon were proposed to be supplemented simultaneously (Clune and Dauble 1991). However, due in part to the uncertainties associated with interactions between steelhead and rainbow trout, spring chinook salmon were supplemented before steelhead. This redirection in the species to be supplemented has prompted us to prioritize interactions between spring chinook and rainbow trout, while beginning to investigate other ecological interactions of concern. Pre-facility monitoring of variables such as rainbow trout density, distribution, and size structure was continued and monitoring of other NTT was initiated in 1997.

This report is organized into four chapters which represent major topics associated with monitoring stewardship, utilization, and strong interactor taxa. Chapter 1 reports the results of non-target taxa monitoring after the first release of hatchery salmon smolts in the upper Yakima

Basin. Chapter 2 documents behavioral dominance and predator avoidance of juvenile spring chinook salmon that were reared under semi-natural and conventional hatchery conditions. Chapter 3 (smallmouth bass and channel catfish) and 4 (northern pikeminnow) describe predation on juvenile salmonids in the lower Yakima River.

The chapters in this report are in various stages of development and should be considered preliminary unless they have been published in a peer-reviewed journal. Three pieces of work were published in peer-reviewed journals during the contract period (Ham and Pearsons 2000; Ham and Pearsons 2001; McMichael and Pearsons 2001). These papers are not reprinted in this report. Additional field work and/or analysis is in progress for topics covered in this report. Throughout this report, a premium was placed on presenting data in tables so that other interested parties could have access to the data. Readers are cautioned that any preliminary conclusions are subject to future revision as more data and analytical results become available.

Except where otherwise noted, the methods and general site descriptions are the same as described in previous reports (Hindman et al. 1991; McMichael et al. 1992; Pearsons et al. 1993; Pearsons et al. 1994; Pearsons et al. 1996; Pearsons et al. 1998; Pearsons et al. 1999).

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References

Amaral, S. V., F. C. Winchell, and T. N. Pearsons. In press. Reaction of chinook salmon smolts and predators to behavioral guidance stimuli. Symposium on fish guidance technologies. American Fisheries Society Press.

Bonneville Power Administration, Washington Department of Fish and Wildlife and Yakama Indian Nation. 1996. Yakima Fisheries Project - Final Environmental Impact Statement. Bonneville Power Administration, Portland, Oregon. DOE/BP-2784.

Busack, C., B. Watson, T. Pearsons, C. Knudsen, S. Phelps, and M. Johnston. 1997. Yakima Fisheries Project Spring Chinook Supplementation Monitoring Plan. Bonneville Power Administration, Portland, Oregon. DOE/BP-64878-1.

Clune, T., and D. Dauble. 1991. The Yakima/Klickitat fisheries project: a strategy for supplementation of anadromous salmonids. Fisheries 16(5):28-34.

Fast, D. E., and C. Craig. 1997. Innovative hatchery project working to rebuild wild salmon populations. Hydro Review XVI:30-33.

Ham, K. D., and T. N. Pearsons. 2000. Can reduced salmonid population abundance be detected in time to limit management impacts? Canadian Journal of Fisheries and Aquatic Sciences 57:1-8.

Ham, K. D., and T. N. Pearsons. 2001. A practical approach for containing ecological risks associated with fish stocking programs. Fisheries 26(4):15-23.

Hindman, J. N., G. A. McMichael, J. P. Olson, and S. A. Leider. 1991. Yakima River Species Interactions Studies. Annual Report FY 1990 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-01483-1. 75 pp.

Martin, S. W., J. A. Long, and T. N. Pearsons. 1995. Comparison of survival, gonad development, and growth between rainbow trout with and without surgically implanted dummy radio transmitters. North American Journal of Fisheries Management 15:494-498.

McMichael, G. A., J. P. Olson, E. L. Bartrand, M. Fischer, J. N. Hindman, and S. A. Leider. 1992. Yakima River Species Interactions Studies. Annual Report FY 1991 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-01483-2. 177 pp.

McMichael, G. A. 1993. Examination of electrofishing injury and short-term mortality in hatchery rainbow trout. North American Journal of Fisheries Management 13:229-233.

McMichael, G. A., C. S. Sharpe, and T. N. Pearsons. 1997. Effects of residual hatchery-reared steelhead on growth of wild rainbow trout and spring chinook salmon. Transactions of the American Fisheries Society 126:230-239.

McMichael, G. A., and T. N. Pearsons. 1998. Effects of wild juvenile spring chinook salmon on growth and abundance of wild rainbow trout. Transactions of the American Fisheries Society 127:261-274.

McMichael, G. A., A. L. Fritts, and T. N. Pearsons. 1998. Electrofishing injury to stream salmonids; injury assessment at the sample, reach, and stream scales. North American Journal of Fisheries Management 18:894-904.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 1999. Minimizing ecological impacts of hatchery-reared juvenile steelhead on wild salmonids in a Yakima basin tributary. Pages 365-380 in Eric Knudson et al. editors. Sustainable fisheries management: Pacific salmon. CRC Press, Boca Raton, FL.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 1999. Behavioral interactions among hatchery-reared steelhead smolts and wild *Oncorhynchus mykiss* in natural streams. North American Journal of Fisheries Management 19:948-956.

McMichael, G. A. and T. N. Pearsons. 2001. Upstream movement of residual hatchery steelhead trout into areas containing bull trout. North American Journal of Fisheries Management.

Pearsons, T. N., G. A. McMichael, E. L. Bartrand, M. Fischer, J. T. Monahan, and S. A. Leider. 1993. Yakima Species Interactions Study. Annual Report FY 1992 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-01483-3. 98 pp.

Pearsons, T. N., G. A. McMichael, S. W. Martin, E. L. Bartrand, M. Fischer, and S. A. Leider. 1994. Yakima River Species Interactions Studies. Annual Report FY 1993 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-99852-2. 247 pp.

Pearsons, T. N., G. A. McMichael, S. W. Martin, E. L. Bartrand, J. A. Long, and S. A. Leider. 1996. Yakima River Species Interactions Studies. Annual Report FY 1994 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-99852-3. 150 pp.

Pearsons, T. N., G. A. McMichael, K. D. Ham, E. L. Bartrand, A. L. Fritts, and C. W. Hopley. 1998. Yakima River Species Interactions Studies. Progress Report FY 1995-1997 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-64878-6.

Pearsons, T. N., K. D. Ham, G. A. McMichael, E. L. Bartrand, A. L. Fritts, and C. W. Hopley. 1999. Yakima River Species Interactions Studies. Annual Report FY 1998 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-64878-5.

Pearsons, T. N., and A. L. Fritts. 1999. Maximum size of chinook salmon consumed by juvenile coho salmon. North American Journal of Fisheries Management 19:165-170.

Pearsons, T. N., and C. W. Hopley. 1999. A practical approach for assessing ecological risks associated with fish stocking programs. Fisheries 24(9):16-23.

Pearsons, T. N., S. R. Phelps, S. W. Martin, E. L. Bartrand, and G. A. McMichael. In press. Gene flow between resident rainbow trout and steelhead in the Yakima basin: ecological and genetic evidence. In P. Howell and D. Buchannan editors, proceedings of the inland rainbow trout workshop. Malheur Field Station, Oregon.

Chapter 1

Results of non-target taxa monitoring after the first release of hatchery salmon smolts in the upper Yakima Basin

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Abstract

Monitoring prescriptions were developed to determine whether non-target taxa objectives were being achieved relative to salmon supplementation in the Yakima Basin. The implementation of the monitoring prescriptions revealed that all of the NTT were within the containment objectives after the first stocking of hatchery chinook and coho salmon smolts. Some declines occurred in the status of NTT but models account for most as the result of biotic or abiotic interactions unrelated to hatchery supplementation. However, our ability to statistically detect impacts is very limited until several years of data are available to evaluate impacts. If impacts did occur, it would be unlikely that they could be detected after 1 year. Monitoring prescriptions should continue to be implemented during 2000.

Introduction

Concerns about the possibility of hatchery fish having negative impacts on valued non-target taxa (NTT) in the Yakima Basin prompted the development and implementation of a risk containment monitoring program. This report presents the results of risk containment monitoring for NTT during the first year of hatchery supplementation releases. Spring chinook and coho salmon were released in the upper Yakima Basin during spring 1999 as part of the Yakima/Klickitat Fisheries Project (YKFP). The goal for both of these species is to increase natural production using artificial propagation (supplementation). Approximately 410,000 spring chinook and 500,000 coho salmon smolts were released into the upper Yakima Basin. Spring chinook salmon were volitionally released into the Yakima River from sites near the cities of Easton and Thorp. Coho salmon were volitionally released into the Yakima River from sites near the city of Cle Elum (hatchery slough) and near Jack Creek on the North Fork of the Teanaway River.

Monitoring prescriptions were developed to determine whether non-target taxa objectives were being achieved (Ham and Pearsons 1999). These prescriptions were updated based on new analyses, and the modified prescriptions are presented in Table 1. We found that impacts to baseline status were rarely detectable below 20%. This finding prompted the development of monitoring methods that were more sensitive. The statistical power of the modified monitoring prescriptions has also been determined and they are considerably better than status monitoring alone (Ham and Pearsons 1999, Ham and Pearsons in press). Monitoring prescriptions are the best combination of status and interactions measures to facilitate early detection of impacts without unnecessary false alarms. Finally, a risk containment framework was developed that includes impact detection and containment plan components (Ham and Pearsons 1999, Ham and Pearsons 2001). The aforementioned research contributes to our ability to adaptively manage hatchery and wild resources in the Yakima Basin.

Depending upon the type of ecological interactions, NTT may benefit or suffer during the initiation of a supplementation program. The interactions that occur between hatchery fish and wild fish have been referred to as Type I interactions (Pearsons et al. 1993). Ecological interactions may also occur between naturally produced offspring of hatchery fish and wild fish, but these interactions will not occur in the upper Yakima Basin until 2002. Because the hatchery removes a proportion of salmon that would have ordinarily spawned in the wild, NTT may benefit from interacting with lower numbers of naturally produced juvenile chinook salmon. This scenario could result in ecological release of NTT. In contrast, production of large numbers of hatchery residuals may offset any ecological release produced by reduced numbers of wild juveniles.

Methods

Field monitoring methods were the same as described previously for baseline (pre-supplementation) surveys (Ham and Pearsons 1999, Ham and Pearsons 2000). The primary impact detection strategy in the monitoring prescription for each NTT will be briefly explained. Results for secondary and additional impact detection strategies will not be presented unless they are NTT status parameters. The primary impact detection strategies for bull and cutthroat trout are spatial overlap with spring chinook salmon in tributary index sites. Snorkeling in the North Fork Teanaway is used to determine overlap for bull trout and backpack electrofishing is used in many upper basin tributaries for cutthroat trout. Age 1+ rainbow trout in the upper Yakima River mainstem are used as analogs for steelhead and they are sampled during driftboat electrofishing surveys. Visual estimates of all suckers during electrofishing surveys are used as analogs for mountain sucker. Fall chinook salmon, leopard dace, and sand roller are monitored as part of data collection for a predation index (Chapter 3). Fall chinook predation index results are used as an analog for Pacific lamprey. The remaining NTT are monitored by examining their status, in terms of the abundance, distribution, and size structure of the population of interest. Status is determined during backpack electrofishing surveys in the tributaries or during mainstem driftboat electrofishing surveys. Temporal variation unrelated to stocking is accounted for, to the extent possible, by models relating changes in impact indicators to changes in easily measured environmental parameters. Models are not used for bull trout, Pacific lamprey, and rainbow trout in tributaries.

The data is presented in two ways: changes in NTT during 1999 relative to 1) NTT baseline status (without the use of models to explain non-supplementation sources of variation), and 2) monitoring prescriptions. Results are expressed as percent changes from baseline conditions. The numerical values of NTT status during 1999 are also presented to facilitate interpretation of percent changes to status and to provide updated information from our annual monitoring program. Values derived for monitoring prescriptions often differ from simple NTT status because of the use of models, analogs, and interaction indicators that improve our ability to detect change.

Results

All of the NTT met their containment objectives relative to monitoring prescriptions (Table 2). Many NTT would not have met their containment objectives if simple status variables alone were the chosen indicator of impact (Table 3). Bull trout, cutthroat trout, Pacific lamprey, steelhead, fall chinook, mountain sucker, and mountain whitefish exceeded the containment objective for at least one of the simple status descriptors (e.g., abundance, size, distribution). There was no overlap of spring chinook or coho salmon with bull trout or cutthroat trout in our index sites, so the declines in status for these NTT were probably unrelated to salmon supplementation. The lack of overlap is reflected in our monitoring prescription. Steelhead smolt abundance declined by 39%, but the likelihood that this decrease was caused by salmon supplementation is unlikely because steelhead smolts generally migrated before most of the hatchery salmon, steelhead smolts had a very small temporal overlap with salmon, and impacts to growth should have been detected in the rainbow trout size if they occurred. The small decline in Pacific lamprey (e.g., -1%) was well within the natural variation observed for the species and would not be statistically significant. In contrast to the small status decline, the analog for Pacific lamprey and fall chinook, exhibited an increase, and no effect of supplementation is indicated. Fall chinook salmon were within the containment objective for size, but not for abundance. Indirect predation is the only interactions mechanism that could account for the large decrease, but the predation index for smallmouth bass and northern pikeminnow was lower than occurred in 1998. So, indirect predation is unlikely to be responsible unless other predators responded differently (Chapter 3, 4). Also, the consumption of salmonids by birds was relatively low during 1999 (James Grassley, University of Washington, personal communication). Mountain sucker and mountain whitefish were within the containment objective for abundance but not for size. It is possible that residualized spring chinook could have impacted their growth, but environmental models suggest that temperature and flow were more likely responsible for the decrease.

Table 1. Impact detection plans for salmonid NTT in the Yakima basin.

	Impact detection strategies		
NTT	Primary	Secondary	Additional
Bull trout	Spring chinook salmon spatial overlap	Status	Status: redd surveys; Incidental monitoring
Cutthroat trout	Spring chinook salmon spatial overlap	Status	Incidental monitoring
Pacific Lamprey	Predation index (fall chinook salmon as analog)	Status: juvenile counts	Status: adult counts
Steelhead	Status: (small rainbow trout as analogs)	Status: smolt counts	Status: redd surveys; Predation index; Pied-piper index
Fall chinook salmon	Predation index	Status	Status: redd surveys
Leopard dace	Predation index with all dace as analogs		Status: longnose dace as analogs
Mountain sucker	Status: all suckers as analogs	Predation index with all suckers as analogs	Incidental monitoring
Sand roller	Predation index (sand roller or chiselmouth <100 mm analogs)		Incidental monitoring
Rainbow trout-mainstem	Status		
Spring chinook salmon	Status	Predation index, treatment-reference comparison of smolts-per-spawner	Status: stock specific redd surveys
Mountain whitefish	Status		
Rainbow trout – tributaries	Status		
Longnose dace	Status		Predation index
Speckled dace	Status		Predation index
Sculpins	Status		Predation index
Suckers	Status		Predation index
Other native species			Incidental monitoring

Table 2. Change in 1999 NTT monitoring variable value relative to baseline period.

		Percent Change		
NTT	CO	Abundance	Size	Distribution
Bull trout	0	0	0	0
Cutthroat trout	0	0	0	0
Pacific lamprey	0	62		
Steelhead	0	0	1	
Fall chinook	-5	62	1	
Leopard dace	-5	75		
Mtn. Sucker	-5	0	65	
Sand roller	-5	96		
Rainbow – main	-10	0	1	0
Spring chinook	-10	6	1	
Mtn. Whitefish	-40	6	17	0
Rainbow – tribs	-40	1	0	0
Longnose dace	-65	13	14	-8
Speckled dace	-85	-25	32	-3
Sculpins	-90	-19	16	-13
Suckers	-90	0	65	1

Table 3. Change in 1999 NTT status relative to baseline period.

		Percent Change		
NTT	CO	Abundance	Size	Distribution
Bull trout	0	-9	-11	-7
Cutthroat trout	0	-86	-52	13
Pacific lamprey	0	-1		
Steelhead	0	-39	33	
Fall chinook	-5	-58	5	
Leopard dace	-5			
Mtn. Sucker	-5	-1	-43	
Sand roller	-5			
Rainbow – main	-10	9	4	0
Spring chinook	-10	72	5	
Mtn. Whitefish	-40	48	-50	0
Rainbow – tribs	-40	0	1	-3
Longnose dace	-65	-5	30	-30
Speckled dace	-85	-74	44	-14
Sculpins	-90	-57	31	-44
Suckers	-90	-1	-43	5

Table 4. Numerical values for 1999 NTT status.

NTT	Abundance	Size	Distribution
Bull trout	20	267 mm	56%
Cutthroat trout	20/km	115 mm	74%
Pacific lamprey	196 migrants		
Steelhead	38,266 smolts	209 mm	
Fall chinook	45,702 smolts	88 mm	
Leopard dace			
Mtn. Sucker			
Sand roller			
Rainbow – main	160 age 1/km	256 mm	100%
Spring chinook	245,019 smolts	131 mm	
Mtn. Whitefish	365 subadults/km	14% adults	100%
Rainbow – tribs	288/km	212 mm	97%
Longnose dace	536/km	9.8g	55%
Speckled dace	270/km	4.9g	77%
Sculpins	270/km	7.6g	51%
Suckers	189/km	26% adults	73%

Discussion

The implementation of the monitoring prescriptions revealed that all of the NTT were within the containment objectives after the first stocking of hatchery salmon. Some declines occurred in the status of NTT but the monitoring prescriptions results suggest that the declines were not caused by activities related to the stocking of hatchery salmon. It is likely that the declines that we observed for some NTT were caused by biotic or abiotic factors unrelated to hatchery supplementation. This discussion should be tempered by a realistic view of the natural variability of most indicators of impact. That variability limits the ability to detect impacts, even after 5 years of stocking (Ham and Pearsons 2000). The lack of impacts is, at this stage, insufficient evidence to draw conclusions about what interactions are or are not important. Monitoring prescriptions described in Table 1 appear to be working as they were designed and should continue to be implemented during 2000. They appear, thus far, to be relatively insensitive to impacts that were caused by factors other than supplementation.

Other lines of evidence suggest that we should continue to carefully monitor for impacts of supplementation. The large number of spring chinook salmon that did not migrate to the ocean after release (residuals) is cause for concern. Large numbers of residuals were observed below the Clark Flats acclimation site and some were observed below the Easton acclimation site. Residuals were larger than wild conspecifics and modal sized rainbow trout which can confer dominance status (Chapter 2). They also ate similar prey items, and food appeared to be limiting growth to rainbow trout and wild conspecifics (Pearsons and James, in progress). Previously, we found that residual hatchery spring chinook salmon impacted the growth of wild spring chinook salmon in small enclosures in the Teanaway Basin (WDFW unpublished data). Containment objectives for steelhead, mountain sucker, and rainbow trout in the mainstem are at the greatest risk if large numbers of salmon residualize. This is likely because these NTT have containment objectives that accept low impacts and because they overlap with residual spring chinook, which may contribute to increased probability of competition. In addition, impacts to the wild component of the target population are possible. Implementation of strategies to limit the number of precocially mature salmon entering the natural environment would decrease the risk of failing to meet containment objectives. As supplementation progresses, new impacts may appear. Only persistent impacts are likely to be of great importance, but that persistence also increases the probability that they will be detected.

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Literature Cited

Ham, K. D., and T. N. Pearsons. 1999. Can native fishes be monitored well enough to support adaptive management of ecological impacts? Chapter 2 in Pearsons, T. N. and others Yakima River Species Interactions Studies. Annual Report submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-64878-5.

Ham, K. D., and T. N. Pearsons. 2000. Can reduced salmonid population abundance be detected in time to limit management impacts? Canadian Journal of Fisheries and Aquatic Sciences 57:17-24.

Ham, K. D., and T. N. Pearsons. Submitted. What level of ecological impact can be detected in salmonid populations? Canadian Journal of Fisheries and Aquatic Sciences.

Ham, K. D., and T. N. Pearsons. 2001. A practical approach for containing ecological risks associated with fish stocking programs. Fisheries 26(4):15-23.

Pearsons, T. N., G. A. McMichael, E. L. Bartrand, M. Fischer, J. T. Monahan, and S. A. Leider. 1993. Yakima Species Interactions Study. Annual Report FY 1992 submitted to Bonneville Power Administration, Portland, Oregon. DOE/BP-01483-3. 98 pp.

Chapter 2

Behavioral dominance and predator avoidance in juvenile spring chinook salmon reared under different hatchery conditions

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Abstract

We examined behavioral dominance and predator avoidance relationships of spring chinook salmon presmolts that were reared under optimal conventional hatchery conditions (OCT) or semi-natural hatchery conditions (SNT). Fish were transported from acclimation sites to the Cle Elum Hatchery and introduced into behavioral arenas for seven days. Most of the fish were within 6% of the body length of each other. Behavioral arenas had one location with highly favorable attributes (e.g., food, cover, optimal velocity). Dominance was assigned to the fish that acquired the most food, initiated the most agonistic interactions, and occupied the preferred position the most. After dominance observations were completed, a model bird predator was introduced over the top of the experimental arena, and behavioral responses of the fishes were recorded. Thirty replicate pairs of fish were observed. Seventy-seven percent of the trials were dominated by large fish, regardless of rearing history. Of the smaller fish that dominated larger fish, 71% (5 of 7) were OCT. Fish size and rearing history explained 93% of the variation in dominance that we observed. The initial behavioral responses of SNT and OCT fish to a model predator were similar. Approximately half of the fish showed little or no response to the model predator. Increased sample sizes and inclusion of wild fish will be pursued in the year 2000.

Introduction

Hatchery supplementation attempts to produce fish that have some similar attributes to wild fish so that they have high survival when they are released and subsequently contribute to increased natural production. This strategy may also produce ecological benefits such as reduced intra- and inter specific impacts to wild fish. Conventionally reared hatchery fish have been shown to exhibit mal-adaptive behaviors, such as hyper-aggressiveness, which can result in reduced hatchery fish survival and increased impacts to wild fish (Ruzzante 1994, White et al. 1995, McMichael et al. 1999). Fish reared in more natural conditions may exhibit more natural behaviors such as natural levels of aggression (Maynard et al. 1995). In an untested supplementation program designed to increase natural production, it makes sense to minimize impacts to wild fish that are known to be successful at natural production. This has obvious implications for supplementing fish in areas with listed species such as occurs throughout the Pacific Northwest.

Dominance among salmonids has been demonstrated to be most consistently associated with fish size (Abbott et al. 1995, Berejikian et al. 1996, McMichael et al. 1999), but prior residence, prior winning experience, genetics, and hatchery rearing also influence dominance (Huntingford et al. 1990, Berejikian et al. 1996, Rhodes and Quinn 1998). Rhodes and Quinn (1998) found that greater size and rearing experience of hatchery-produced coho salmon were sufficient to overcome a wild salmon's advantage of prior residence. Hatchery-reared coho salmon dominated size-matched coho salmon from the same parental population reared in a stream and also dominated wild salmon with prior residence (Rhodes and Quinn 1998). Hatchery steelhead trout dominated wild *O. mykiss* in streams in 68% of behavioral contests and this dominance was largely attributed to larger relative size of hatchery fish (McMichael et al. 1999). Hatchery steelhead also used more behavioral interactions involving physical contacts (e.g., nips and butts) than wild fish (McMichael et al. 1999). Hatchery reared chinook salmon dominated smaller wild chinook salmon and altered wild fish behavior (Peery and Bjornn 1996).

Our objectives were to determine if the dominance and aggressiveness of stream type chinook salmon reared using semi-natural and conventional hatchery conditions were different. We tested this by pairing fish of similar and dissimilar sizes in laboratory behavioral arenas and observing food acquisition, habitat use, and behavioral interactions. Different sized fish were used in experiments because fish engaged in behavioral interactions in streams are rarely the same size. Presmolts-smolts were used in the experiments. It is currently recognized that smolts do not swim downstream constantly, but rather swim during certain periods and feed during other periods. It is during the feeding periods, when fish defend profitable feeding locations, that our results are most applicable.

Methods

Fish used in this experiment were offspring of wild spring chinook salmon that were collected at Roza Dam during 1997. Fish were spawned, eggs incubated, and juveniles reared in one of two types of raceways under similar densities (e.g., approximately 40,000 fish/raceway). The two types of rearing environments differed in their degree of "naturalness". The "optimal conventional treatment" (OCT) is a combination of the conventional factors that have been demonstrated to produce good results from other hatcheries. This includes low rearing density, optimal flow conditions, and desirable food distributions. The second of the two treatments, "semi-natural treatment" (SNT), uses the same strategies as the OCT but adds some factors that are present in natural streams. These factors include overhead cover (floating mats), instream cover (christmas trees), natural coloration (painted raceways), and underwater feeding.

Fish were collected from hatchery raceways located at two sites, Clark Flats and Easton. Fish were dip-netted from raceways and transported to the Cle Elum Supplementation research facility. In some cases, fish were size matched. Both fish were introduced into an observation chamber within 15 minutes of each other to prevent any prior residence advantage.

Experiments were conducted in 5.2 m long, 0.5 m wide fiberglass vessels at the Cle Elum Hatchery. Four of these vessels were fitted with large viewing windows. Each of the four vessels was partitioned into three equally sized behavioral arenas for a total of 12 arenas. The arenas were configured to provide one highly preferred location that was close to an underwater food source, provided cover, and had desirable water velocities. A blind was constructed of black plastic to prevent fish from seeing the observer. One OCT and SNT spring chinook salmon were placed in each chamber. One of the hatchery fish was marked with a small upper caudal clip to identify it's origin and fish were acclimated for at least seven days in each of the arenas. This time length was previously determined by comparing behavioral responses and dominance from pairs of fish that were held for different lengths of time. After seven days, the behavioral responses and dominance did not generally change. After acclimation, food acquisition, agonistic interactions, and habitat location were observed. Five food items (pellets) were introduced through a tube with running water. The number of food items acquired by each fish was recorded. After five food items have been acquired, agonistic interactions were recorded for five minutes. We recorded which fish initiated an interaction and whether they dominated. Dominance was assigned to the fish that defended a position or removed another fish from the preferred position. Following behavioral observations, the location of each fish was recorded once every minute for five minutes. The location was expressed as the distance from the source of food and flow, the vertical position in the water column, and whether the fish was in the middle or the side of the tank. Fish that occupied the zone that was considered to be the preferred area were classified as the dominant. The preferred area had access to cover, was close to the food source and provided optimal velocity. This was generally in the middle of the tank, from 1-10 inches off the bottom, and from the end of the pipe to 36 inches behind the pipe. If both fish were in this zone, then the fish closest to the pipe was considered dominant. Four sets of food observations, agonistic observations, and habitat locations were measured for each group of fish. Total observation time for each arena was one hour (i.e., four x fifteen minute sets). Dominance was attributed to the fish that acquired the most food, won the most behavioral contests, and occupied the preferred location the most. Fish size and rearing history were examined to determine how they influenced dominance.

After dominance experiments were completed, an imitation bird was introduced to determine the behavioral responses of fish. An imitation bird was waved over the top of the fish for approximately 2-5 seconds and the initial response to the imitation was recorded. Behaviors were categorized as erratic flight, motionless, swim to cover, swim toward predator, stay in cover, and drop to bottom. These behaviors are defined below:

Erratic flight – zig-zag or haphazard swimming away from predator
Motionless – body motionless but fins become erect
Swim to cover – swim toward an area that provides overhead cover
Swim toward predator – swim toward the predator
Stay in cover – stay in an area that has overhead cover
Drop to bottom – drops, as opposed to swims, towards the bottom

Behaviors were further categorized as being strong, weak, or non-existent. Behaviors were categorized as strong if they occurred quickly and strongly, weak if they occurred slowly and without force, and non-existent if they did not respond. The bird model was constructed out of polyvinyl chloride pipe and cardboard and looked like a merganser silhouette. The length and weight of each fish was measured at the termination of the experiment.

Results

OCT and SNT fish dominated an equal percentage (50%) of trials. Seventy-three percent (22/30) of the paired fish were within 6% of the size of the subdominant fish which is typically the threshold size difference that confers dominance (Abbott et al. 1995, Rhodes and Quinn 1998). However, 77% of the trials were dominated by the larger fish, irrespective of rearing history. Of the smaller fish that dominated, 71% (5/7) were OCT. One of the 7 trials where a smaller SNT fish dominated was questionable. The total variance in dominance that was explained by size and rearing history was 93%.

The presence of the upper caudal clip did not appear to influence the results. Seventeen of the 30 dominants were clipped.

Table 1. Length and weight of fish used in experiments. Raceways are represented by location (E=Easton, T=Thorp) and raceway number.

Date	Cell #	OCT Raceway	Length (FL mm)	Weight (g)	SNT Raceway	Length (FL mm)	Weight (g)
April 13	1	E4	120	18	E1	125	19
April 13	2	E4	133	24	E1	139	29
April 13	3	E4	120	20	E1	140	31
April 23	1	E2	132	27	E3	135	29
April 23	2	E2	134	30	E3	127	23
April 23	3	E2	133	30	E3	110	16
April 23	4	E4	126	23	E1	127	27
April 23	5	E4	125	25	E1	121	19
April 23	6	E4	121	20	E1	127	24
April 23	7	E4	125	24	E1	122	18
April 23	8	E4	121	20	E1	126	24
April 23	9	E4	138	33	E1	132	26
April 30	1	T6	117	18	T3	124	22
April 30	2	T6	128	24	T3	130	22
April 30	3	T6	126	25	T3	133	26
April 30	4	T6	126	24	T3	161	53
April 30	5	T6	132	23	T3	147	39
April 30	6	T2	118	17	T5	125	22
April 30	7	T2	132	28	T5	133	29
April 30	8	T2	141	35	T5	134	27
April 30	9	T2	133	29	T5	129	23
May 10	1	T4	123	22	T1	128	24
May 10	2	T4	143	34	T1	130	25
May 10	3	T4	127	23	T1	131	28
May 10	4	T4	122	19	T1	127	28
May 10	5	T4	136	31	T1	127	23
May 10	6	T4	119	18	T1	118	20
May 10	7	T2	123	22	T5	107	12
May 10	8	T2	136	27	T5	139	31
May 10	9	T2	128	23	T5	114	17
Mean			124	24		125	24

Table 2. Statistics associated with dominant fish. The percent of food acquired, initiation of agonistic interactions, and occupation of preferred habitat by dominant fish is also presented. The size difference is the length of the dominant fish divided by the length of the subordinate times 100. Dominant fish that are smaller than the subordinate have a minus sign before the size difference.

Rearing Type	Clip (UC=1)	Date	Cell #	Food (%)	Behavior (%)	Habitat (%)	Size Difference (%)
SNT	1	April 13	1	100	None	100	4.2
SNT	1	April 13	2	95	100	95	4.5
SNT	1	April 13	3	35	50	62	16.7
OCT	1	April 23	1	85	100	100	-2.2
OCT	1	April 23	2	87	100	100	5.5
OCT	1	April 23	3	85	100	100	20.9
SNT	0	April 23	4	85	80	100	0.1
OCT	1	April 23	5	100	78	100	3.3
SNT	0	April 23	6	75	86	90	5.0
OCT	1	April 23	7	100	86	100	2.5
SNT	0	April 23	8	90	96	93	4.1
OCT	1	April 23	9	100	100	100	4.5
OCT	0	April 30	1	70	90	82	-5.6
OCT	0	April 30	2	100	89	100	-1.5
OCT	0	April 30	3	90	100	100	-5.3
SNT	1	April 30	4	85	100	100	27.8
SNT	1	April 30	5	100	88	100	11.4
SNT	1	April 30	6	90	94	100	5.9
SNT	1	April 30	7	100	100	100	0.1
OCT	0	April 30	8	100	100	100	5.2
OCT	0	April 30	9	90	100	100	3.1
OCT	1	May 10	1	95	100	100	-3.9
OCT	1	May 10	2	60	83	95	10.0
SNT	0	May 10	3	95	100	100	3.1
SNT	0	May 10	4	100	63	100	4.1
OCT	1	May 10	5	100	100	100	7.1
SNT	0	May 10	6	70	74	100	-0.1
OCT	1	May 10	7	70	89	73	15.0
SNT	0	May 10	8	100	80	100	2.2
SNT	0	May 10	9	100	100	100	-10.9

The initial responses of SNT and OCT fish to a model predator were similar (Table 3). The most common responses of fish to predators were erratic flights, remaining motionless, and swimming to cover. Approximately half of the fish showed little or no response to the model predator. SNT fish exhibited a strong antipredator response (57% of trials) slightly more often than OCT fish (48% of trials).

Table 3. Initial behavioral responses of OCT and SNT fish to a model predator.

Date	Cell	Erratic flight	Motion-less	Swim to cover	Swim toward predat.	Stay in cover	Drop to bottom	No resp.	Weak resp.
13-Apr	1		OCT					BOTH	
	2			SNT			OCT		OCT
	3	BOTH							BOTH
23-Apr	1					BOTH			
	2		BOTH					OCT	
	3	OCT	SNT						OCT
	4			BOTH					
	5			BOTH					
	6		OCT	SNT				OCT	SNT
	7	OCT				SNT			OCT
	8	OCT						SNT	
	9					SNT		OCT	
30-Apr	1	BOTH							SNT
	2		SNT		OCT			BOTH	
	3	SNT	OCT					OCT	
	4	BOTH							
	5	SNT				OCT			
	6			OCT			SNT		
	7			BOTH					
	8	SNT	OCT					OCT	
	9					OCT			SNT
10-May	1		OCT	SNT					
	2	OCT	SNT					SNT	OCT
	3					OCT		SNT	
	4			BOTH					BOTH
	5		SNT					SNT	OCT
	6			BOTH					OCT
	7			SNT		OCT			SNT
	8		BOTH					BOTH	
	9						BOTH		
Sum	OCT	7	7	6	1	5	2	8	8
	SNT	6	6	9	0	3	2	7	6
	Total	13	13	15	1	8	4	15	14

Discussion

Size was the most important variable influencing dominance but rearing history explained most of the remaining dominance patterns not explained by size. The relationship between size and dominance has been well established in our previous studies and the broader scientific literature (Abbott et al. 1985, Rhodes and Quinn 1998, McMichael et al. 1999). The small number of trials where smaller OCT fish dominated bigger SNT fish precludes any definitive conclusions. However, it is consistent with the idea that the higher degree of natural rearing, the lower the short-term dominance. Conventionally reared hatchery coho salmon dominated size matched wild salmon even when wild salmon had prior residence (Rhodes and Quinn 1998). The SNT fish that we used were reared under conditions that were intermediate between conventional hatchery and natural environments and they were less dominant than OCT fish. This preliminary finding provides an indication that the production of hatchery fish in more natural environments could reduce impacts on wild fish through the reduction in dominance by hatchery fish. However, more extensive testing is needed before this finding can be validated.

The main goal of this work was to determine if different hatchery rearing treatments influenced dominance relationships among hatchery and wild fish. Unfortunately, we had limited access to wild fish so we could not test dominance relationships with them directly. The relationships between OCT and SNT fish suggest that dominance will be primarily determined by relative size and secondarily by rearing treatment. During experiments in 2000, the dominance of SNT and wild fish will be compared and if sufficient numbers of wild fish are available then dominance of OCT and wild fish will be tested too. It is well known that conventionally reared hatchery fish will dominate smaller wild fish (Rhodes and Quinn 1998). However, SNT fish appear to be less dominant than OCT fish, which may mean that they may have smaller impacts on wild fish than OCT fish. However, this study suggests that reducing the size advantage of hatchery fish over wild fish is likely to decrease impacts to wild fish more than rearing history.

The poor responses of OCT and SNT fish to a model predator suggests that predator avoidance training could greatly enhance survival if predation is a major source of mortality. Only about 50% of the fish showed strong anti-predator behavior. The Yakima Basin is known to be host to a variety of bird and fish predators (Chapter 2 and 3 of this report; Phinney 1998) and predation is thought to be the dominant factor influencing smolt to smolt survival in the Yakima. Cursory observations of hatchery fish in the semi-natural exit channel to the Clark Flats acclimation site indicated that many hatchery fish exhibited very conspicuous behavior which would make them easy targets for predators (T. Pearsons, observation). Hatchery fish were observed feeding off the surface of the water in areas that were shallow and without cover. Other hatchery fish were inconspicuous and were using wood in the channel for cover. SNT fish may be less conspicuous to predators if they have colors that make them more cryptic. However, if crypsis was different among OCT and SNT fish during 1999, it did not appear to benefit SNT fish because OCT and SNT fish had similar smolt to smolt survivals. This could be due to excellent water conditions and low predation rates in 1999. Different results could occur during years of low water and high predation.

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References

Abbott, J. C., R. L. Dunbrack, and C. D. Orr. 1985. The interaction of size and experience in dominance relationships of juvenile steelhead trout (*Salmo Gairdneri*). Behaviour 92:241-253.

Berejikian, B. A., S. B. Mathews, and T. P. Quinn. 1996. Effects of hatchery and wild ancestry and rearing environments on the development of agonistic behavior in steelhead trout (*Oncorhynchus mykiss*) fry. Canadian Journal of Fisheries and Aquatic Sciences 53: 2004-2014.

Huntingford, F. A., N. B. Metcalfe, J. E. Thorpe, W. D. Graham, and C. E. Adams. 1990. Social dominance and body size in Atlantic salmon parr, *Salmo salar L*. Journal of Fish Biology 36:877-881.

Maynard, D. J., T. A. Flagg, and C. V. W. Mahnken. 1995. A review of seminatural culture strategies for enhancing postrelease survival of anadromous salmonids. American Fisheries Society Symposium 15:307-314.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 1999. Behavioral interactions among hatchery-reared steelhead smolts and wild *Oncorhynchus mykiss* in natural streams. North American Journal of Fisheries Management 19:948-956.

Peery, C. A., and T. C. Bjornn. 1996. Small-scale investigations into chinook salmon supplementation strategies and techniques: 1992-1994. Technical Report 96-3. Idaho Cooperative Fish and Wildlife Research Unit.

Phinney, D. D., S. B. Mathews, and T. N. Pearsons. 2000. Development of a bird predation index. Annual Report FY 1998 submitted to Bonneville Power Administration, Portland, Oregon.

Rhodes, J. S., and T. P. Quinn. 1998. Factors affecting the outcome of territorial contests between hatchery and naturally reared coho salmon parr in the laboratory. Journal of Fish Biology 53:1220-1230.

Ruzzante, D. E. 1994. Domestication effects on aggressive and schooling behavior in fish. Aquaculture 120:1-24.

White, R. J., J. R. Karr, and W. Nehlsen. 1995. Better roles for fish stocking in aquatic resource management. American Fisheries Society Symposium 15:527-547.

Chapter 3

Lower Yakima River Predatory Fish Monitoring: Progress Report 1999, Bass and Catfish

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Abstract

We estimated the number of salmonids that smallmouth bass ate during the spring of 1999 in the Yakima River. Predator surveys were conducted weekly from March 25 through June 10 in two sections of the lower Yakima River and in small areas of hypothetically high predation, termed "hotspots". Abundance was estimated using a relationship between catch per unit effort and population estimates, which were calculated using maximum likelihood estimators of mark and recapture data. Diet was determined by lavaging smallmouth bass and identifying consumed fish in the lab by examining diagnostic bones. Daily consumption was calculated by estimating the average number of salmonids that a bass ate per day and extrapolating that number to the number of bass in the lower 68 kilometers of the Yakima River. Daily estimates were then summed to yield total consumption during the spring. In addition, data from 1998 was reanalyzed using procedures used to analyze data collected in 1999. Abundance of bass >150 mm increased during the spring from a low of 8,066 on March 25 to a high of 35,378 on June 10. The increases in abundance were primarily due to immigration of fish from the Columbia River. Daily consumption of salmonids was relatively low until late April and peaked in late May. Consumption dramatically decreased in June, despite the fact that bass abundance and water temperatures were highest during this period. This decrease is likely to be due to bass shifting their behaviors from feeding to spawning. Smallmouth bass ate an estimated 171,031 salmonids during the spring. Only 3,795 of these were estimated to be spring chinook. The remainder were mostly fall chinook salmon. In contrast to 1998 salmonid consumption estimates, 1999 estimates were over 2.5 times lower (1998 estimates: 442,085 salmonids, 2,863 spring chinook salmon). Horn Rapids Dam (Wanawish) has the potential to be the area of highest predation in the Yakima River because of the large number of bass that congregate below the Dam. Other presumptive hotspots such as Roza Dam and the Chandler bypass pipe had very low densities of bass or northern pikeminnow during 1999. We suspect that predation on salmonids during 1998 and 1999 was low relative to other years that have warmer water temperatures and lower flows.

Introduction

Predatory fish surveys were initiated in 1997 and 1998 as part of an effort to develop and monitor a predation impact index relative to spring chinook salmon (Busack et al. 1997, Pearsons et al., McMichael et al. 1998, McMichael et al. 1999). After the 1998 field season, we determined that the Horn Rapids index section was redundant information and that we needed to reapportion more effort to studying northern pikeminnow. This resulted in allocating two reaches for studying northern pikeminnow and two reaches for studying bass and catfish. The Yakama Nation works on the pikeminnow reaches and the Sunnyside Dam hotspot and their results are presented in chapter 4. This chapter represents the work performed by the Washington Department of Fish and Wildlife and includes the two smallmouth bass reaches, Roza, Chandler, and Horn Rapids hotspots, and channel catfish predation trials.

Data from 1998 indicated that smallmouth bass were capable of consuming a substantial number of age-0 fall chinook salmon, but that they did not consume large numbers of yearling spring chinook salmon (McMichael et al. 1999). Findings from both 1997 and 1998, indicated that large numbers of large smallmouth bass migrated from the Columbia River into the Yakima River prior to the emigration of most salmonid smolts. As was described in the monitoring plan (Busack et al. 1997), we sampled during the estimated peak and last quartile of spring chinook salmon smolt migration during 1998. We decided to change our sampling strategy for 1999 to weekly sampling because 1) of the possibility of incorrectly estimating the peak and last quartile of spring chinook migration, 2) of the possibility that hatchery releases (e.g., fall chinook and coho salmon) will be conducted at different times each year and may artificially influence the predation index, and 3) the high temporal variation in diet contents. We also found that catch per unit effort appeared to be a good index of abundance.

In addition to changes in field sampling we also changed the way we calculate the predation index. In 1998, we used the predation index presented by Ward et al. (1995). The reasons that we used the Ward et al. (1995) index were 1) because it was already developed, 2) we did not think that we could consistently calculate valid population estimates, 3) we would have something that we could compare our estimates to. However, we found that we could calculate valid population estimates and that the index had some properties that we found undesirable. For example, the number is not easy to interpret (e.g., what does 1.13 mean?), and it does not appear to be additive across species. The qualities of a predation index that we thought were important were 1) additive across species so that bird, bass, catfish, and pikeminnow indices could be summed, 2) easy to interpret, 3) as similar as possible to total consumption, and 4) repeatable during all environmental conditions and across years. We attempted to use total salmonid consumption as our predation index instead of the Ward et al. (1995) index. We also attempted to use daily temperature information in consumption calculations as opposed to single day temperatures extrapolated over longer time periods.

Suspected "hotspots" of predation were sampled during 1997 and 1998, but preliminary analyses suggested that predation was not particularly high at these sites. Sampling at Roza Dam and the Chandler Juvenile Fish Facility discharge pipe resulted in few predators during 1998. Low numbers of predators may have been due to high stream discharges.

In 1997 and 1998 channel catfish appeared to be very abundant and capable of consuming large numbers of juvenile salmonids. Despite testing a variety of approaches (e.g., angling, gillnetting, electrofishing, and trapping) we have not found acceptable ways to calculate abundance or to collect sufficient numbers of fish that are suitable for gut analysis. The only method that we have used that yields large numbers of channel catfish is trapping (e.g., hoop nets and slat traps). Trapping is unsuitable for calculating population estimates because tagged individuals are unlikely to be equally prone to recapture as untagged fish, and the presence of large females in the trap has a large influence on numbers of fish trapped. Stomach contents from fish in traps are also not ideal because the traps catch hungry fish (e.g., baited with cheese), and trapped fish are digesting food for an unknown duration of time. Therefore we attempted a new approach to index channel catfish consumption during 1999 that involved controlled conditions.

Busack et al. (1997) outlined the specific need for determining the abundance of predators and their consumption rates of spring chinook salmon smolts in the spring chinook salmon monitoring plan for the Yakima Fisheries Project. The overall goal of our study was to continue to calculate predation indices for the main predatory fish species during the majority of the spring smolt emigration period in the lower Yakima River. This report supercedes all of our previous reports about smallmouth bass predation in the lower Yakima River.

Methods

Study Area

The study area and fish fauna was previously described by McMichael et al. (1999). Population estimates were conducted by boat electrofishing in two sections and catch per unit effort estimates were conducted in three presumptive hot spots. The two sections sampled by electrofishing drift boat were; 1. the end of Grosscup Road to Van Giesen Road bridge (Vangie), and 2. Chandler Power House to Benton City (Benton). The Vangie section was 8.0 km long, while the Benton section was 7.8 km long. These sections were used to extrapolate to their larger corresponding reaches. The Benton reach is 39.9 km long and is located between Prosser Dam and Horn Rapids Dam. The Vangie reach is 28.1 km long and is located between Horn Rapids Dam and the mouth of the Yakima River. In this report, we refer to the sampled area as the "section" and the area it represents as the "reach". A northern pikeminnow hot spot was sampled by angling immediately below Roza Dam (rkm 180) and two smallmouth bass hot spots were sampled at the Chandler fish bypass exit about 1 km downstream of Prosser Dam (rkm 76) and by angling immediately below Horn Rapids Dam (rkm 28.1)(Figure 1).

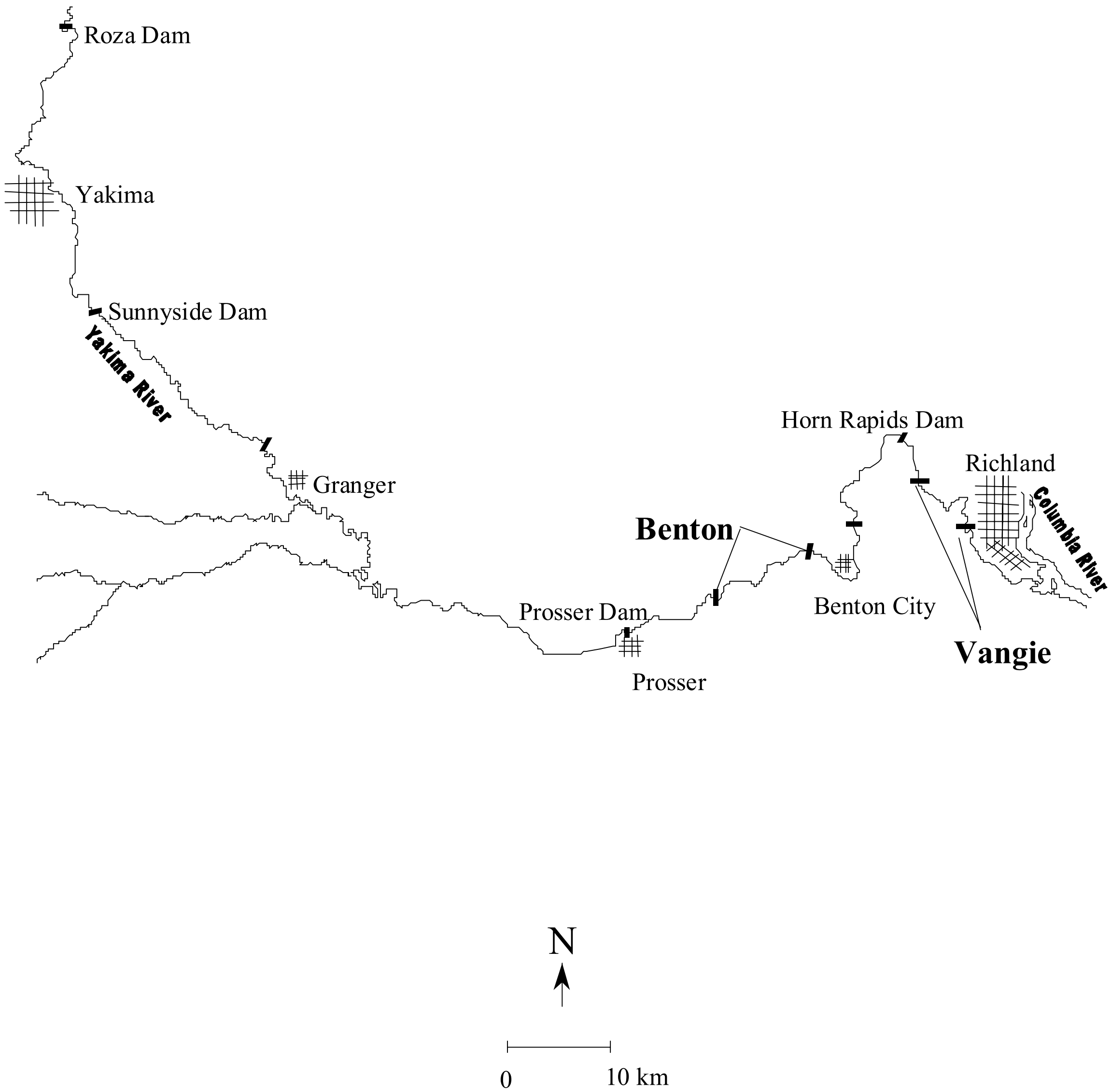

Figure 1. Map of the study area in the lower Yakima River showing index sections in bold type.

Abundance Estimates

Abundance estimates were conducted on smallmouth bass captured by boat electrofishing. We used catch per unit effort (CPUE; smallmouth bass $\geq$ 150mm FL/min) as an indicator of abundance in both sample sections during 12 sample weeks between March 25 and June 10, 1999. In addition, mark-recapture population estimates were done in each sample section between April 27 and 30, 1999. Regression analysis was used to examine the relationship between population estimates and CPUE for 1998 and 1999 data combined. The regression equation was then applied to raw CPUE data to estimate population size for each of the 13 sample weeks in 1999.

Electrofisher settings were about 400 V pulsed DC (PDC; Coffelt's CPS setting) at between 2 and 5 Amps during spring sampling. All predatory fish over 100 mm FL were netted and fishes $\geq$ 200 mm were marked with a serially numbered anchor tag. During mark-recapture population estimates the recapture runs followed 1 day after the marking runs and all predatory fish $\geq$ 100 mm were fin clipped on the marking runs. The electrofishing runs were generally along the banks, especially during high flows. The numbers of each species of fishes that were electrofished were visually assessed and recorded by the person netting.

Fish were processed every kilometer during all electrofishing runs. Length (mm), weight (g), and condition of fish, i.e. bird scars, hook scars, and electrofishing injuries were recorded for all fish. A subsample of all predatory fish $\geq$ 150 mm was examined for stomach contents.

Hot Spots

The Roza Dam "hot spot" was sampled on April 13 by three anglers beginning 1 hour before sunrise and continuing until either the catch dropped to 2 fish per hour or until noon, whichever came first. Pikeminnow were held in plastic totes until 5 to 10 were accumulated and then length (mm), weight (g), and condition of fish was recorded. All fish were then sacrificed and stomach samples containing fish were immediately frozen for later examination in the lab. CPUE was calculated for the sampling date.

The Horn Rapids Dam "hot spot" was sampled on March 12, 13, and 19 by two to three anglers for one hour per day. Smallmouth bass were held in large plastic tubs until sampling was completed. Length (mm), weight (g), and condition of fish was recorded and all fish $\geq$ 200 mm were anchor tagged. A subsample of fish was examined for stomach contents by gastric lavage (Light et al. 1983) and samples were immediately frozen for later examination in the lab. CPUE was calculated for the three sample dates.

Diet Samples

Diet samples were collected from smallmouth bass, channel catfish, and northern pikeminnow that were captured by electrofishing. Diet samples for smallmouth bass were obtained by gastric lavage and channel catfish and northern pikeminnow samples were obtained by sacrificing the fish. All diet samples were placed in whirl-paks with 10 ml of saturated sodium bicarbonate and tagged with date, stomach number, species, length, weight, and the section where the fish was captured and then placed on dry ice. Samples were kept frozen until they were ready to be examined in the laboratory (1 to 3 months).

In the lab, the diet samples were weighed to the nearest 0.1 g, then transferred into a pancreatin solution to digest soft tissues, revealing only bones, and finally placed in various size glass and nalgene containers. The analysis of the contents consisted of placing the contents of a single sample into a petri dish and counting and identifying fish to the lowest possible taxonomic classification based on diagnostic bones. For bone identification, a series of keys and sketches produced and provided by the Biological Resources Division station located in Cook, Washington, were used. Standard equations presented by Hansel et al. (1988), as well as some equations that we developed were used to calculate estimated length of fish in the stomach samples based on dimensions of bones measured to the nearest 0.05 mm with an ocular micrometer. Length-weight regressions based on live fish we collected concurrently with the predatory fishes, as well as equations presented by Vigg et al. (1991), were then used to calculate estimated weight of each prey fish at the time of ingestion.

Prey preference for smallmouth bass was examined by subtracting the percentage of a given prey species observed while electrofishing (availability) from the percentage of that species observed in smallmouth bass guts (use).

Temperature (T) was obtained from thermographs placed in each section and set to record the water temperature at four hour intervals. Using an equation derived from Rogers and Burley (1991) we back-calculated the average time since ingestion of salmonid prey by smallmouth bass (*DT*).

$$DT = -200\ln(-E^{0.513}S^{-0.513}+1)S^{0.29}e^{-0.15T}W^{-0.23} \qquad [1]$$

E = amount of prey evacuated (g)[back-calculated weight at time of ingestion – weight of stomach contents sampled],
S = prey meal weight [back-calculated weight at time of ingestion](g),
T = water temperature (C)[24 hour mean from midnight to midnight for sampling day], and
W = predator weight (g)

Digestion time was used to reveal the time(s) of day that predators were eating salmonid prey items and the length of time they were in the gut before we sampled them. Based on those results we then elected to use the average temperature for the 24-hour period prior to the mean time that samples containing single salmonid prey were eaten (11:00 AM). This new temperature variable will be called *T2* and is used in our consumption equations.

Consumption

We used the equation presented by Tabor et al. (1993) to calculate evacuation time (*ET90*; days) for smallmouth bass and modified it to solve for *ET90* in hours. This is the number of hours for a given meal to be 90 percent evacuated at a given temperature and predator weight:

$$ET90 = (24.542 S^{0.29} e^{-0.15 T2} W^{-0.23}) x (24) \tag{2}$$

For northern pikeminnow, we used the equation presented by Beyer et al. (1988) to calculate evacuation time (*ET90*; hours). This is also the number of hours for a given meal to be 90 percent evacuated at a given temperature and predator weight:

$$ET90 = 1147 S^{0.61} T2^{-1.60} W^{-0.27} \tag{3}$$

For channel catfish, we calculated evacuation time by the following equation (derived from data presented by Schrable et. al. (1969)). This equation only uses temperature as a variable. In the future, we hope to find an equation that uses meal size and predator weight.

$$ET90 = -4.93525 + e^{3.91943 - 0.02289 T2} \tag{4}$$

Equations 2-4 were used to obtain average daily evacuation times by using daily *T2* data and the *S* and *W* values obtained by our weekly sample. For example, the *S* and *W* we get on our Friday sample is used to calculate Friday through Thursday's daily evacuation times along with the actual *T2* for each day.

To calculate estimated consumption rate *C* (salmonids per predator per day) we used the equation presented by Ward et al. (1995):

$$C = n(24 / ET90) \tag{5}$$

n = mean number of salmonids observed in predator gut samples per day, and
ET90 = mean daily evacuation time for a salmonid meal (hours) from equations 2-4.

Extrapolations

Weekly population estimates of smallmouth bass $\geq$ 150 mm FL (the minimum size found to consistently contain salmonids) were generated by the regression equation based on the relationship between mark-recapture population estimates and CPUE for the Benton and Vangie study sections. To estimate the daily number of salmonids eaten within each study section by smallmouth bass (*SE*) we used the following equation:

$$SE = PExFxC \qquad [6]$$

PE = weekly population estimate of smallmouth bass $\geq$ 150 mm FL within the study section,
F = fraction of smallmouth bass stomachs examined that contained at least one salmonid, and
C = estimated daily consumption rate per predator from equation 5.

To estimate the number of salmonids consumed daily by smallmouth bass in the lower 68 km of the Yakima River (the range of high bass densities) (S_{tot}), we added the number of salmonids consumed in the Benton and Vangie reaches. We used the following equation to estimate consumption in each of the reaches:

$$S_{tot} = (PE / SL)xRLxFxC \qquad [7]$$

SL = length of the study section (km), and
RL = length of reach being extrapolated to (km).

Channel Catfish Tanks

In a feasibility effort to examine the relationship between consumption of salmonids by channel catfish and river temperature and turbidity, we captured and held 3 adult (1453 to 1634 g) channel catfish in 3 separate 568 l plastic tanks through which ambient river water was pumped. The tanks were located within the fenced area over the adult ladder on the right bank at Horn Rapids Dam. A total of 20 hatchery-reared fall chinook salmon were placed in each tank on April 9, 1999. One catfish, captured by hook and line, was placed into tank 1 on April 16 and the other 2 were captured by gill net and placed in tanks 2 and 3 on April 21, 1999. Tanks were checked weekly and the number of salmon eaten were recorded for each tank and replaced so that each tank had 20 salmon. The catfish tank experiment was terminated on June 3, 1999.

Results

Smallmouth Bass

Abundance Estimates

A positive statistically significant relationship between CPUE and population estimate was found for 1998 and 1999 (Figure 2). We used the relationship between CPUE and population estimates to generate population estimates for periods where only CPUE estimates were available. Otherwise, we used the population estimate derived from mark-recapture data.

Abundance of bass >150 mm increased during the spring from a low of 8,066 on March 25 to a high of 35,378 on June 10 (Figure 3). Population estimates during 1998 also showed an increasing trend and were similar to 1999 estimates. Mark-recapture population estimate statistics for smallmouth bass in the Benton and Vangie sections are presented in Table 1.

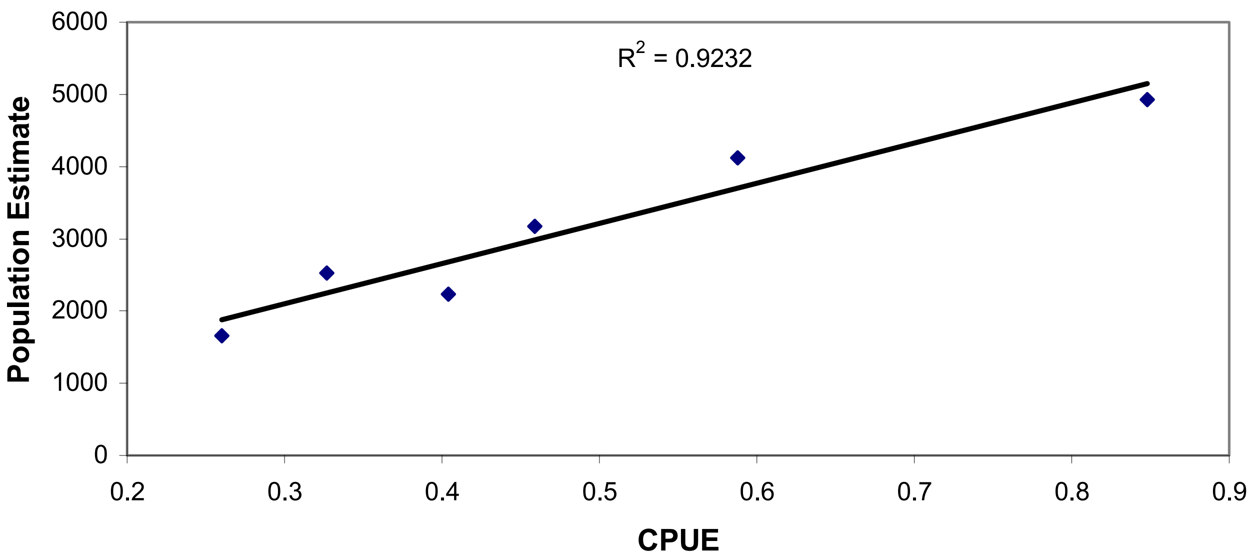

Figure 2. Relationship between CPUE and population estimates in the Benton and Vangie sections during 1998 and 1999.

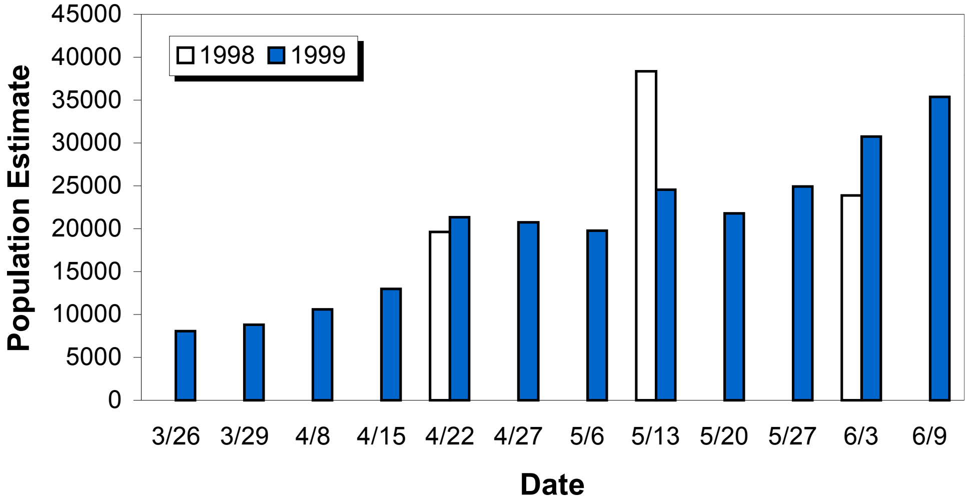

Figure 3. Estimated population size of smallmouth bass ≥ 150 mm FL in the lower 68 km of the Yakima River versus date in 1998 and 1999.

Table 1. Unexpanded population estimate data for smallmouth bass (SMB) in two sections of the Yakima River. Dates (1999), species/size class (mm FL), estimate, standard deviations (SD), capture efficiency (Effic.), and validity of the estimate are shown for each river section/date.

Dates	Species/size	Section	Estimate	SD	Effic.	Valid
4/27-28	SMB/≥100	Benton	3454	834.1	5.4%	Yes
4/27-28	SMB/≥150	Benton	2483	687.7	6.4%	Yes
4/27-28	SMB/≥200	Benton	1500	605.7	6.8%	Yes
4/29-30	SMB/≥100	Vangie	3325	475	7.6%	Yes
4/29-30	SMB/≥150	Vangie	2237	424.8	9.5%	Yes
4/29-30	SMB/≥200	Vangie	1523	410.8	10.3%	Yes

The four-fold increase in abundance that occurred between March 26 and June 10 is from a combination of immigration of large fish from the Columbia River and from recruitment of smaller fish into the predator sized category (e.g., >150 mm FL). Fish moving into the Yakima River from the Columbia River seem to contribute to the increases in abundance more than recruitment of fish into the predator size class based on size structure trends (Figure 4) and recaptures of fish. Five of 133 (3.8%) of smallmouth tagged in the Columbia River in the fall of 1997 were recaptured in the Yakima River in the spring of 1998. Although, fish did grow during the time of our sampling, only a small number of fish were close enough in size to be able to grow enough to reach 150 mm and the pattern of abundance could not explain the pattern observed in fish greater than 150 mm (Figure 5). However, the pattern of upstream fish movement in the Yakima River was consistent with the pattern of increased abundance (Figure

6). Downstream movement was not prevalent until after the end of our abundance sampling, although differential sampling effort (i.e. angler effort may be greater in the Columbia during the summer) could also explain the observed pattern.

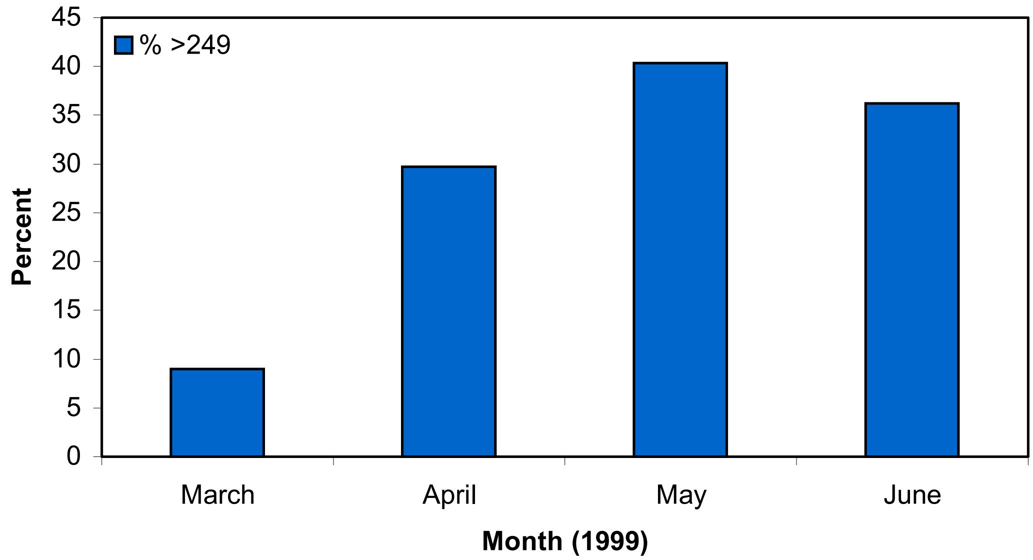

Figure 4. Percent of smallmouth bass captured during electrofishing in 1999 that were 250 mm or larger by month.

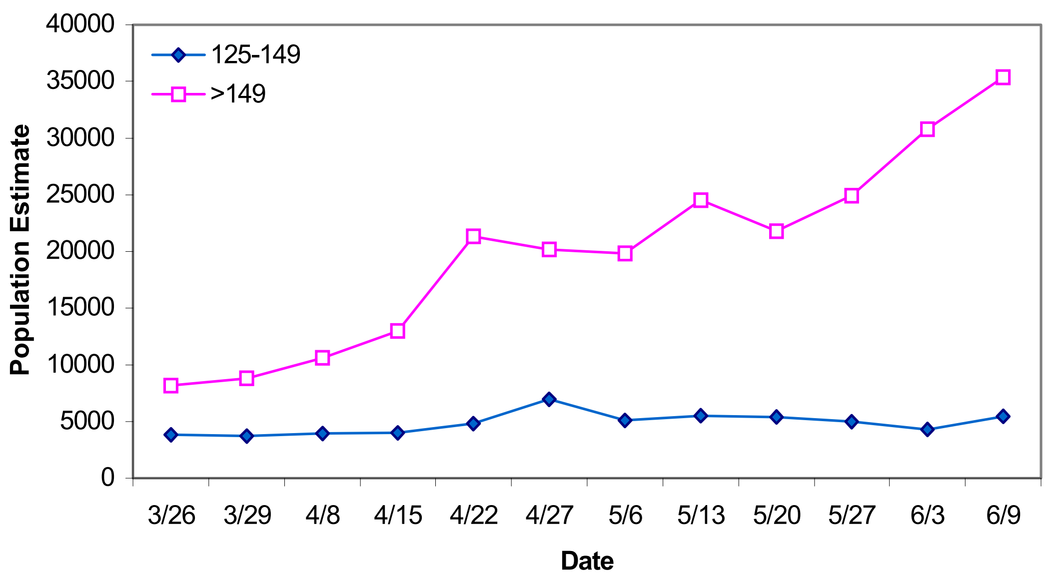

Figure 5. Estimated numbers of smallmouth bass greater than 149 mm and 125 to 149 mm (group that could potentially recruit into the 150 and greater population) for the lower Yakima River. Numbers were estimated using the CPUE relationship.

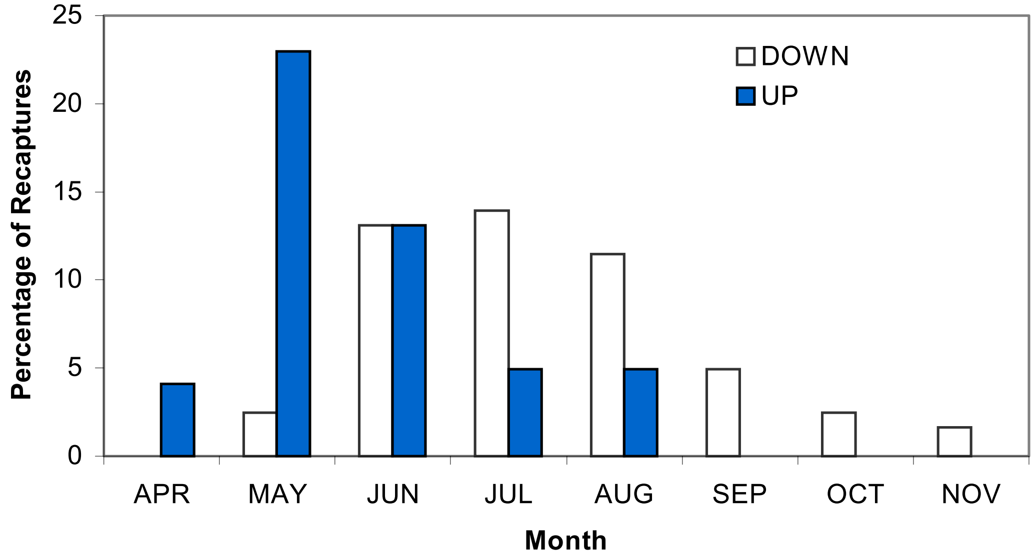

Figure 6. Movement of tagged smallmouth bass in the Yakima River based on electrofishing and angling recapture data from 1997 to 1999. Fish were only used if they moved more than 5 km and were at large less than 250 days.

Diet

Diel feeding by bass was not uniformly distributed. The most sustained time of feeding for bass was from around 7:00 AM to 2:00 PM, but feeding activity was also high between 7:00 PM and 9:00 PM, and between 12:00 AM and 3:00 AM hours (Figure 7). Over 75% of the salmonids in the gut were eaten within 24 hours of collection (Figure 8), but one non-salmonid fish was eaten over four days prior to collection. About 75% of fish that were found in the stomachs would take over 24 hours to digest (Figure 9). Fish were eaten throughout the entire sampling period but fall chinook were not found in the guts until mid-April (Table 2) and spring chinook were rarely found in the gut. However, a spring chinook was found in the gut on the first survey in March and during the last survey in June. The percentage of stomachs that had fish and salmonids in the gut peaked on May 27 in the Benton Section and May 28 in the Vangie section and then decreased substantially in June (Table 2). Ten fish taxa were identified in the guts of smallmouth bass (Table 3). Fall chinook and mountain whitefish were the dominant fish species found in the guts, making up 70% of the fish in the gut (Table 3).

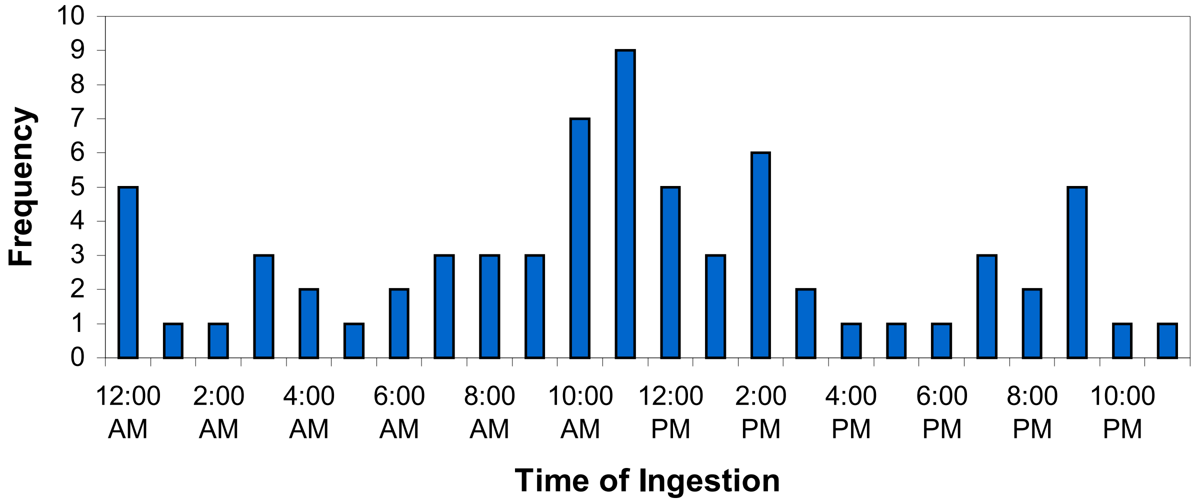

Figure 7. Estimated time of ingestion of single salmonids eaten by smallmouth bass during 1999.

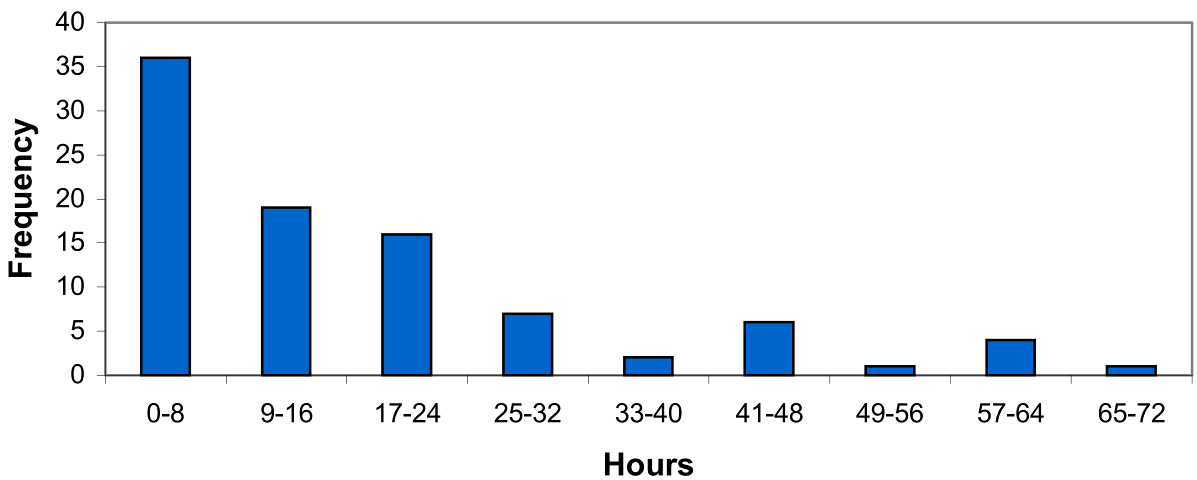

Figure 8. Estimated length of time that single salmonids had been in the stomach of smallmouth bass when bass were captured.

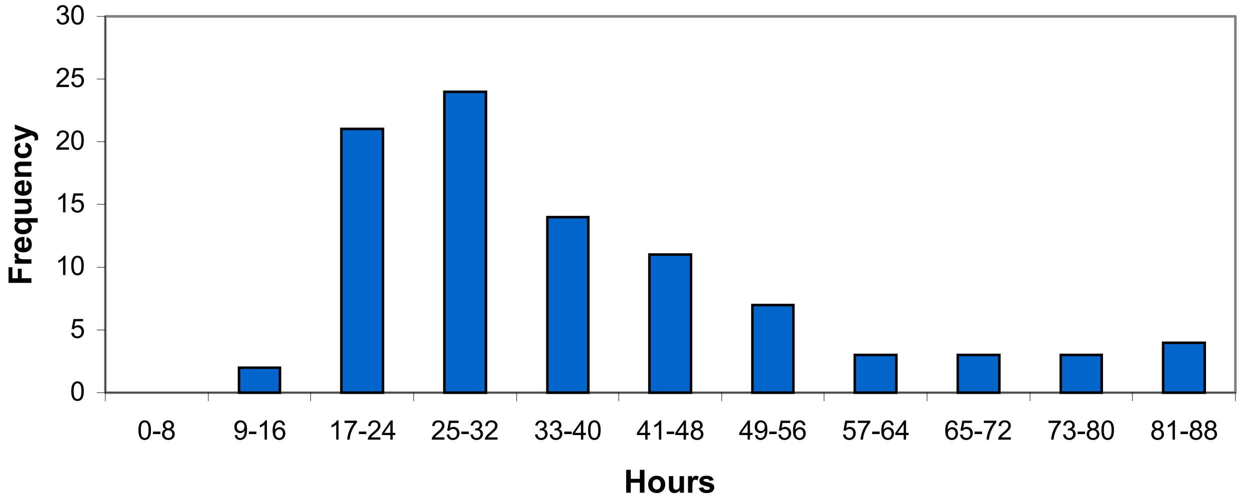

Figure 9. Estimated length of time that it takes to digest 90% of single salmonids found in smallmouth bass.

Table 2. Summary results of diet analyses for smallmouth bass ($\geq$ 150 mm FL) sampled in the Benton, Horn and Vangie reaches on April 21-23, May 12-14 and June 4-5, 1998. The number of stomachs examined (N), the number (percent) of fish=s guts in each sample that were empty, or contained invertebrates, fish, anadromous salmonids, and/or spring chinook salmon (SPC). The fish category includes salmonids. The salmonid category does not include SPC

Date	Section	N	Empty	Invert	Fish	Salmonids	SPC
3/26	Benton	15	46.7	40.0	20.0	0.0	0.0
3/29	Benton	23	65.2	21.7	13.0	0.0	0.0
4/08	Benton	41	46.3	36.8	19.5[a]	0.0	0.0
4/15	Benton	38	31.6	55.3	21.1	10.5	0.0
4/22	Benton	63	58.7	28.6	14.3	4.8	1.6
4/28	Benton	88	55.7	31.8	19.3	19.3	2.3
5/06	Benton	56	21.4	73.2	16.1	8.9	0.0
5/13	Benton	58	15.5	77.6	20.7	27.6	0.0
5/20	Benton	52	17.3	71.2	25.0	17.3	0.0
5/27	Benton	50	52.0	30.0	34.0	32.0	0.0
6/03	Benton	93	57.0	30.1	18.3	10.8	0.0
6/09	Benton	116	15.5	79.3	5.2	0.9	0.0
3/25	Vangie	14	42.9	42.9	14.3	0.0	7.1
3/30	Vangie	19	68.4	26.3	5.3	0.0	0.0
4/09	Vangie	18	61.1	11.1	27.8[a]	0.0	0.0
4/16	Vangie	44	59.1	27.3	15.9	11.4	0.0
4/23	Vangie	41	58.5	14.6	34.1	17.1	0.0
4/30	Vangie	100	47.0	32.0	26.0	20.0	0.0
5/07	Vangie	34	35.3	50.0	17.6	2.9	0.0
5/14	Vangie	65	33.8	58.5	18.5	13.8	0.0
5/21	Vangie	46	30.4	45.7	37.0	19.6	0.0
5/28	Vangie	35	34.3	22.9	60.0	22.9	0.0
6/04	Vangie	67	35.8	52.2	22.4	4.5	0.0
6/10	Vangie	78	11.5	78.2	16.7	2.6	1.3

[a] Stomach samples were lost before they could be analyzed. Data is based on comments recorded at the time of collection.

Table 3. Species composition of fish found in smallmouth bass stomachs collected in the lower Yakima River March 25 through June 10, 1999. Total number of prey fish in sample (N), and number of each prey species are presented for each date in each section.

		Prey Species[a]												
Date	Section	N	DAC	SUC	CHM	SMB	CCF	FAC	SPC	MWF	CCP	LAMP	SAL	NSA
3/26	Benton	5	2	1	1					1				
3/29	Benton	3		1			2							
4/08	Benton[b]													
4/15	Benton	11				3	3	4						1
4/22	Benton	11	1				1	3	1	3				2
4/28	Benton	27				3		17	2	5				
5/06	Benton	9	1	1			1	5						1
5/13	Benton	18						16		1				1
5/20	Benton	14	2				1	9		1				1
5/27	Benton	19				2		16		1				
6/03	Benton	18	1	2		3		10		2				
6/09	Benton	7	3				1	1		2				
3/25	Vangie	2					1		1					
3/30	Vangie	1					1							
4/09	Vangie[b]													
4/16	Vangie	13		1			1	4		6			1	
4/23	Vangie	18		1		1	1	7		7		1		
4/30	Vangie	35		1	1	1		20		11				1
5/07	Vangie	8				1		1		4				2
5/14	Vangie	14	1			1		8		4				
5/21	Vangie	18	4					9	1	4				
5/28	Vangie	32					1	8		22				1
6/04	Vangie	15		1		2		3		8				1
6/10	Vangie	25				2	2	2	1	3	15			
Totals		323	15	9	2	19	16	143	6	85	15	1	1	11
Percent total		100	4.6	2.8	0.6	5.9	5	44	1.9	26	4.6	0.3	0.3	3.4

[a] DAC = dace spp., SUC = sucker spp., CHM = chiselmouth, SMB = smallmouth bass, CCF = channel catfish, FAC = fall chinook salmon, SPC = spring chinook salmon, MWF = mountain whitefish, CCP = common carp, LAMP = unidentified lamprey , SAL = unidentified salmonid., NSA = unidentified non-salmonid .

[b] Stomach samples were lost before they could be analyzed. Data is based on comments recorded at the time of collection.

Availability

Chinook salmon, suckers, common carp, chiselmouth, dace, and smallmouth bass were the most abundant fish that we observed in the lower Yakima River (Table 4, 5). The numbers of fish that we observed gradually increased during the sampling period. Fall chinook salmon were relatively rare until April 27-28th and spring chinook salmon were fairly common until the end of April (Figure 10).

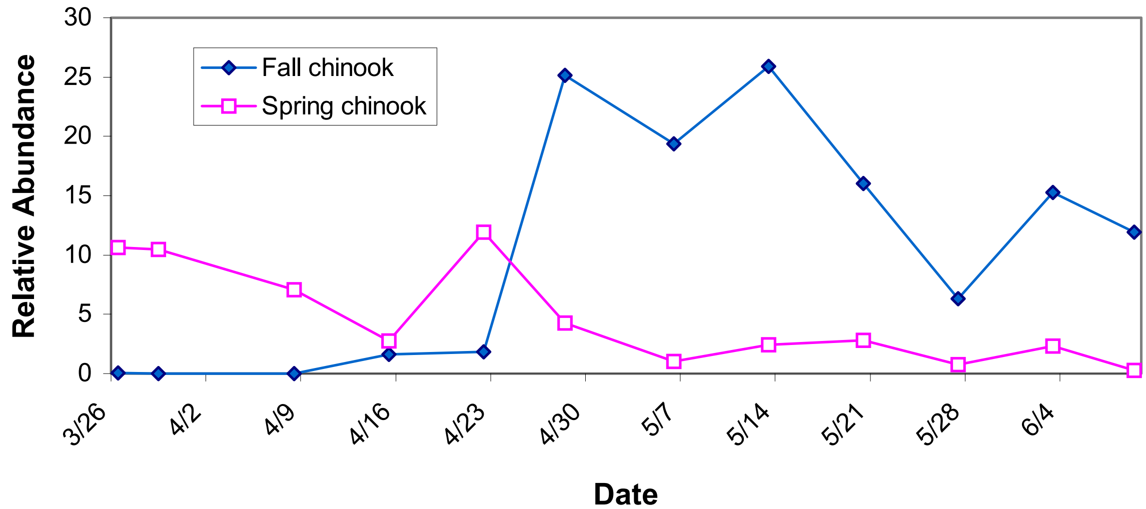

Figure 10. Relative abundance (percent of all fish observed) of spring chinook salmon smolts and fall chinook parr and smolts in the Benton and Vangie sections of the lower Yakima River versus sample date, 1999.

Table 4. Visually estimated percent composition of species in the Benton section (rkm 49.3 – 57.1). Total number of fish observed per day is listed for reference.

Species.[a]	March 26	March 29	April 8	April 15	April 22	April 27[c]
BRT	0.0	0.21	0.36	0.15	0.14	0.05
CCF[b]	0.0	0.21	0.0	0.3	0.14	0.0
CCP	25.93	7.04	17.57	15.11	16.24	9.6
CHM	6.85	23.6	9.6	10.07	7.04	26.3
COH	0.0	0.0	0.0	0.0	0.0	0.7
DAC	3.73	0.41	0.18	0.3	2.3	2.75
FAC	0.0	0.0	0.0	2.67	2.59	12.8
MWF	1.66	6.0	3.26	3.26	1.87	2.7
NPM	1.66	2.07	0.72	1.04	1.72	1.55
PMK	0.0	0.0	0.0	0.0	0.14	0.0
PMO	0.0	0.0	0.0	0.0	0.0	0.1
RSS	0.0	0.0	0.0	0.0	0.0	0.85
SCU	0.0	0.0	0.0	0.0	0.0	0.0
SMB	18.88	14.7	34.24	39.11	24.28	18.8
SND	0.0	0.0	0.0	0.0	0.0	0.0
SPC	15.56	15.11	9.06	3.26	19.11	7.8
SUK	24.69	25.67	21.92	23.26	20.26	14.6
WCR	0.0	0.21	0.18	0.0	0.0	0.0
WSH	1.04	4.35	2.9	1.33	4.02	1.4
YLP	0.0	0.0	0.0	0.0	0.0	0.0
Totals	482	483	552	675	696	2000

[a] BRT (brown trout), CCF (channel catfish), CCP (common carp), CHM (chiselmouth), COH (coho salmon), DAC (dace spp.), FAC (fall chinook), MWF (mountain whitefish), NPM (northern pikeminnow), PMK (pumpkinseed), PMO (peamouth), RSS (redside shiner), SCU (prickly sculpin), SMB (smallmouth bass), SND (sandroller), SPC (spring chinook), SUK (sucker spp.), WCR (white crappie), WSH (wild steelhead), YLP (yellow perch).
[b]Channel catfish are relatively unsusceptible to capture by electrofishing, therefore, they represent a larger but unknown proportion of the total fish community than is represented by these data.
[c] Mark-recapture run using 2 boats and combining visual data.

Table 4 continued. Visually estimated percent composition of species in the Benton section (rkm 49.3 – 57.1). Total number of fish observed per day is listed for reference.

Species.[a]	April 28[c]	May 6	May 13	May 20	May 27	June 3	June 9
BRT	0.17	0.0	0.0	0.0	0.12	0.0	0.0
CCF[b]	0.0	0.36	0.11	0.0	0.12	0.0	0.0
CCP	5.74	9.94	12.18	19.84	15.13	11.26	6.11
CHM	18.09	4.73	2.99	10.25	31.48	13.42	14.86
COH	0.12	0.12	0.0	0.0	0.0	0.58	0.81
DAC	2.43	8.61	12.18	8.3	2.54	6.64	23.04
FAC	24.52	32.73	28.39	20.75	3.27	11.98	5.53
MWF	2.32	1.45	0.8	1.95	5.21	1.73	1.5
NPM	1.57	0.36	0.23	1.3	1.82	2.6	1.15
PMK	0.0	0.0	0.0	0.13	0.0	0.0	0.0
PMO	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RSS	0.12	0.0	0.0	0.0	0.12	0.0	0.0
SCU	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SMB	24.7	25.21	25.4	14.4	13.56	22.51	25.58
SND	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPC	7.01	1.58	3.22	4.80	0.97	4.18	0.58
SUK	11.36	14.79	14.14	17.64	25.42	24.96	20.74
WCR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WSH	1.8	0.12	0.11	0.52	0.12	0.0	0.0
YLP	0.0	0.0	0.0	0.0	0.0	0.14	0.0
Totals	1725	825	870	771	826	693	868

[a] BRT (brown trout), CCF (channel catfish), CCP (common carp), CHM (chiselmouth), COH (coho salmon), DAC (dace spp.), FAC (fall chinook), MWF (mountain whitefish), NPM (northern pikeminnow), PMK (pumpkinseed), PMO (peamouth), RSS (redside shiner), SCU (prickly sculpin), SMB (smallmouth bass), SND (sandroller), SPC (spring chinook), SUK (sucker spp.), WCR (white crappie), WSH (wild steelhead), YLP (yellow perch).

[b]Channel catfish are relatively unsusceptible to capture by electrofishing, therefore, they represent a larger but unknown proportion of the total fish community than is represented by these data.

[c] Mark-recapture run using 2 boats and combining visual data.

Table 5. Visually estimated percent composition of species in the Vangie section (rkm 12.2 – 20.2). Total number of fish observed per day is listed for reference.

Species.[a]	March 25	March 30	April 9	April 16	April 23	April 29[c]
BRT	0.0	0.0	0.0	0.0	0.0	0.0
CCF[b]	0.0	0.4	4.23	0.35	0.12	0.26
CCP	36.64	25.45	24.5	37.13	26.44	16.64
CHM	5.17	10.3	2.67	9.15	7.59	12.03
COH	0.0	0.0	0.0	0.0	0.0	0.04
DAC	0.14	0.2	0.67	0.17	0.24	0.22
FAC	0.14	0.0	0.0	0.52	1.1	24.64
MWF	2.01	4.85	4.45	1.55	3.79	0.57
NPM	0.29	0.0	0.22	0.17	0.98	0.44
PMK	0.0	0.0	0.0	0.0	0.0	0.13
PMO	0.0	0.0	0.0	0.0	0.12	0.0
RSS	0.43	4.04	0.22	0.35	1.83	0.18
SCU	0.0	0.0	0.0	0.0	0.0	0.0
SMB	10.49	16.77	28.51	21.59	27.91	23.23
SND	0.14	0.0	0.0	0.0	0.0	0.0
SPC	5.75	5.86	5.12	2.25	4.77	2.99
SUK	37.93	30.71	25.17	25.91	24.85	18.23
WCR	0.0	0.0	0.0	0.17	0.0	0.0
WSH	0.57	1.21	3.34	0.35	0.24	0.26
YLP	0.0	0.0	0.89	0.17	0.0	0.0
Totals	696	495	449	579	817	2277

[a] BRT (brown trout), CCF (channel catfish), CCP (common carp), CHM (chiselmouth), COH (coho salmon), DAC (dace spp.), FAC (fall chinook), MWF (mountain whitefish), NPM (northern pikeminnow), PMK (pumpkinseed), PMO (peamouth), RSS (redside shiner), SCU (prickly sculpin), SMB (smallmouth bass), SND (sandroller), SPC (spring chinook), SUK (sucker spp.), WCR (white crappie), WSH (wild steelhead), YLP (yellow perch).
[b]Channel catfish are relatively unsusceptible to capture by electrofishing, therefore, they represent a larger but unknown proportion of the total fish community than is represented by these data.
[c] Mark-recapture run using 2 boats and combining visual data.

Table 5 continued. Visually estimated percent composition of species in the Vangie section (rkm 12.2 – 20.2). Total number of fish observed per day is listed for reference.

Species.[a]	April 30[c]	May 7	May 14	May 21	May 28	June 4	June 10
BRT	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CCF[b]	0.32	0.0	0.13	0.71	1.14	0.2	1.0
CCP	20.55	31.0	20.2	26.92	11.54	10.17	15.28
CHM	8.09	4.61	4.04	8.26	18.19	14.95	6.13
COH	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DAC	0.48	0.48	0.0	1.42	0.0	0.41	3.36
FAC	25.93	6.04	23.36	11.25	9.36	18.51	18.29
MWF	1.54	2.07	2.02	0.71	8.21	9.56	7.06
NPM	0.64	0.32	0.38	1.14	0.42	0.31	0.23
PMK	0.05	0.0	0.13	0.0	0.0	0.0	0.0
PMO	0.05	0.0	0.0	0.43	0.1	0.0	0.0
RSS	0.16	0.0	0.0	0.28	0.0	0.1	0.58
SCU	0.0	0.0	0.0	0.14	0.21	0.1	0.23
SMB	22.1	23.69	33.71	22.51	13.2	18.72	24.77
SND	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPC	1.54	0.48	1.64	0.85	0.52	0.41	0.0
SUK	18.32	31.0	13.89	25.07	36.9	26.45	22.92
WCR	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WSH	0.11	0.0	0.0	0.14	0.21	0.0	0.0
YLP	0.05	0.0	0.13	0.0	0.0	0.1	0.0
Totals	1878	629	792	702	962	983	864

[a] BRT (brown trout), CCF (channel catfish), CCP (common carp), CHM (chiselmouth), COH (coho salmon), DAC (dace spp.), FAC (fall chinook), MWF (mountain whitefish), NPM (northern pikeminnow), PMK (pumpkinseed), PMO (peamouth), RSS (redside shiner), SCU (prickly sculpin), SMB (smallmouth bass), SND (sandroller), SPC (spring chinook), SUK (sucker spp.), WCR (white crappie), WSH (wild steelhead), YLP (yellow perch).

[b]Channel catfish are relatively unsusceptible to capture by electrofishing, therefore, they represent a larger but unknown proportion of the total fish community than is represented by these data.

[c] Mark-recapture run using 2 boats and combining visual data.

Selectivity

Similar to 1998, smallmouth bass preferred eating fall chinook salmon and mountain whitefish and avoided suckers, chiselmouth, smallmouth bass and spring chinook salmon (Figure 11). The appearance of preference for channel catfish is probably incorrect due to the low capture efficiency for channel catfish. The lack of preference for sucker species and chiselmouth may be explained by the large size of the juveniles (that were included in the ›availability= estimates), as they may have been too large for most smallmouth bass to prey upon.

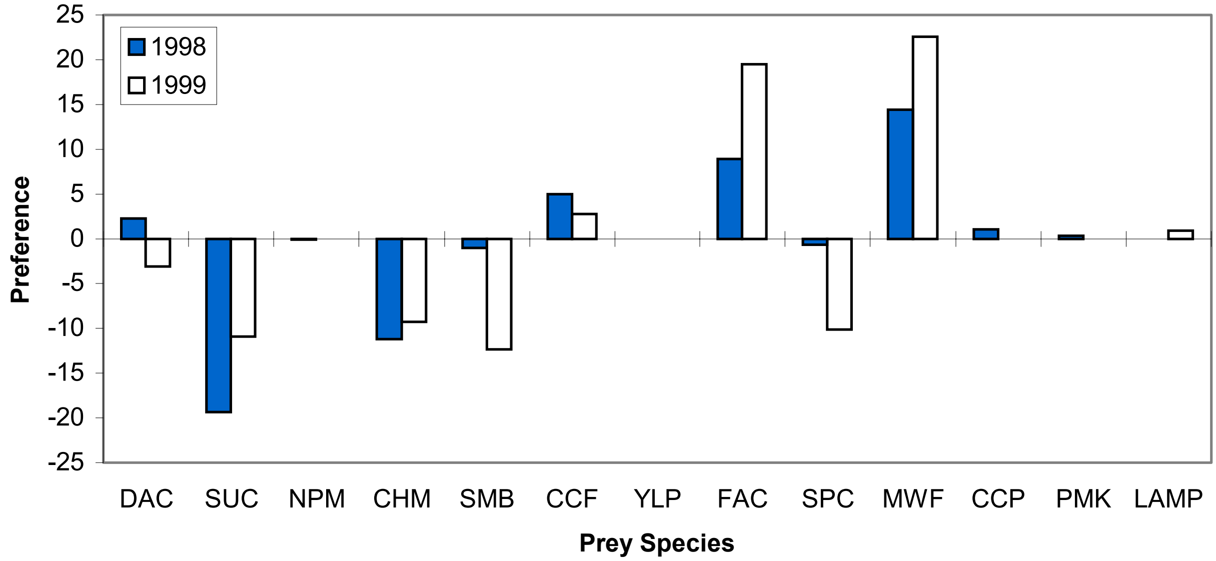

Figure 11. Prey species preference of smallmouth bass in the lower Yakima River during the spring of 1998 and 1999. Preference was determined by subtracting the percent of a given prey species observed during electrofishing (availability) from the percent of that prey species observed in smallmouth bass guts (use). A positive value suggests a preferred prey species, while negative values suggest prey items that were not preferred.

Consumption

Daily consumption of salmonids by bass was most prevalent during the month of May when abundance of bass, consumption rates on salmonids, and water temperatures were high (Figure 12). A dramatic decrease in daily consumption occurred in the latter part of May-June of both 1998 and 1999. Between March 25 and June 10, 1999, smallmouth bass ate 171,031 salmonids. Only 3,795 of these were spring chinook salmon. During the same period in 1998, smallmouth bass ate 442,085 salmonids, of which 2,863 were spring chinook salmon.

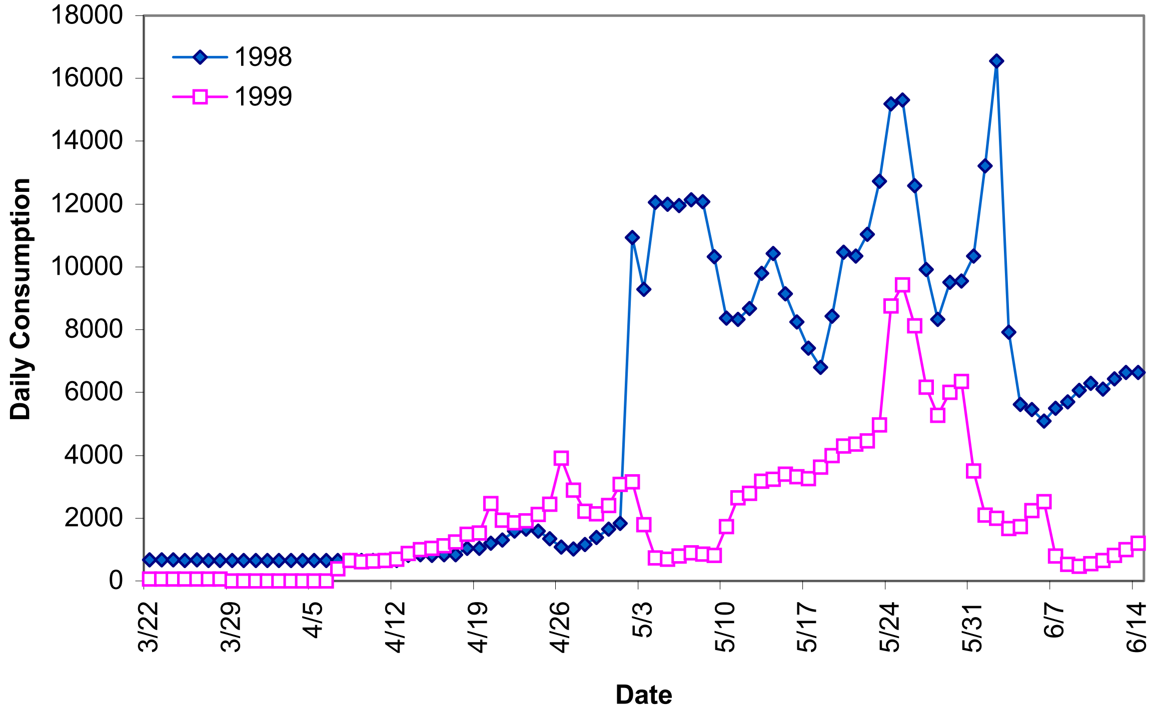

Figure 12. Estimates of daily salmonid consumption by smallmouth bass during 1998 and 1999 in the Yakima River between Prosser Dam and the confluence of the Columbia River.

Channel Catfish

The diets of channel catfish were similar during 1998 and 1999 despite the difference in collection methods between the two years. A higher percentage of channel catfish ate invertebrates and a lower percentage ate crayfish and seeds during 1999 (Table 6) In contrast to 1998, no fall chinook and 1 spring chinook salmon were found in the guts in 1999 (Table 7).

Adult-sized channel catfish were difficult to capture by electrofishing during the spring period; only 2 were captured by electrofishing in 1997, 27 were captured in 1998, and 34 were captured in 1999. The adult channel catfish captured in 1999 had a mean length of 509 mm FL and a range of 314 to 811 mm FL. We also captured 21 juvenile channel catfish in 1999 (mean length = 70 mm, range = 54 - 95 mm).

Table 6. Composition of channel catfish stomachs collected in the lower Yakima River, April through June 1998 and 1999. Total number of stomachs in sample (N), and number of times (with percentage below) each category was found in a stomach is presented. Anadromous salmonids are included in the fish category. The invertebrate (Invert.) category includes crayfish.

		Food Category							
Year	N	Empty	Fish	Salmonid	Invert.	Crayfish	Seeds	Bird	Rodent
1998	137	70 (51.0)	26 (19.0)	4 (2.9)	43 (31.3)	31 (22.6)	21 (15.3)	3 (2.2)	2 (1.5)
1999	24	6 (25.0)	5 (20.8)	1 (4.2)	16 (66.7)	1 (4.2)	1 (4.2)	0 (0.0)	0 (0.0)

Table 7. Species composition of fish found in channel catfish stomachs collected in the lower Yakima River April through June 1998 and 1999. Total number of fish in stomachs (N), and number (with percentage below) of prey species is presented.

Prey Species[a]													
CCF	CCP	CHM	DAC	FAC	SUC	MWF	NSA	NPM	SAL	SCU	SMB	SPC	WSH
1998 (N=21)													
8	3	2	1	77	8	3	7	2	2	1	6	0	1
6.6	2.5	1.7	0.8	63.6	6.6	2.5	5.8	1.7	1.7	0.8	5.0	0.0	0.8
1999 (N=7)													
0	0	1	1	0	2	1	0	0	0	0	1	1	0
0.0	0.0	14.3	14.3	0.0	28.5	14.3	0.0	0.0	0.0	0.0	14.3	14.3	0.0

[a]CCF = channel catfish, CCP = common carp, CHM = chiselmouth, DAC = dace spp., FAC = fall chinook salmon, SUC = sucker spp., MWF = mountain whitefish, NSA = non-salmonid spp., NPM = northern pikeminnow, SAL = salmonid spp., SCU = sculpin spp., SMB = smallmouth bass, SPC = spring chinook, WSH = wild steelhead.

Channel catfish fed at the lowest water temperatures that occurred during the study. There were no statistically significant relationships between either water clarity and the weekly mean number of salmon consumed by the catfish, or water temperature and the weekly mean number of salmon consumed by catfish in experimental tanks. The effect of experimental day (a surrogate for a predator=s foraging experience within the vessels) was also not significant. The catfish in tank one ate a total of 13 salmon during the seven week experiment and it lost 121 g in weight, while the fish in tanks two and three ate 25 and 35 salmon respectively and gained 109 and 93 g, respectively. Table 8 provides a summary of the data we collected from the catfish tank experiments. Low sample sizes, the observation that catfish fed at the lowest temperatures, and problems associated with fish feeding experience limit the utility of these experiments and therefore they do not need to be repeated in the future.

Table 8. Summary data of channel catfish tank feeding experiments during the spring of 1999.

Date	Mean Number Eaten (range)	Water Temp (C)	Water Clarity (secchi, mm)
4/28/99	0.67 (0-1)	10.4	665
5/06/99	2.00 (1-4)	12.5	455
5/12/99	2.00 (1-4)	13.4	290
5/19/99	4.67 (0-10)	15.0	366
5/27/99	10.33 (7-12)	13.9	830
6/03/99	4.67 (3-7)	13.1	610

AHot Spot@ Sampling

Success at capturing northern pikeminnows at the Roza Dam and Chandler fish bypass ›hot spot= was very low again in 1999. Hook and line sampling for northern pikeminnow immediately below Roza Dam yielded low catch rates, and none of the pikeminnows examined had eaten salmonids. We caught 15 northern pikeminnows in 2.83 h the morning of April 13, 1999 (CPUE = 0.029 fish/min) below Roza Dam. The mean length of the fish was 418 mm (328-481 mm) and 40% were empty, while 47% contained at least one non-salmonid fish (sculpins and dace). At the Chandler site, multiple electrofishing passes were made on two dates. No piscivorous fish were observed 50 m above and 150 m below the Chandler fish bypass.

Discussion

Smallmouth bass ate considerably fewer fall chinook and more spring chinook salmon during 1999 than during 1998. The lower number of fall chinook consumed might be explained by the relatively cooler water temperatures that occurred in 1999 relative to 1998 (Figure 13). Water temperatures were 1^{o} C lower during April and May, and 3^{o} C lower in June. It is unlikely that differences in the abundance and size structure of bass or the availability of prey between years could explain the observed difference because they appeared to be similar in 1999 and 1998. The higher number of spring chinook consumed may be due to increased prey availability caused by the first releases of hatchery spring chinook salmon from the upper Yakima basin. However, we speculate that the relatively small difference of spring chinook salmon consumed between 1998 and 1999 may not actually be different because the 95% confidence intervals would undoubtedly overlap. Water discharge was considerably higher during 1998 and 1999 than the 10 year average which may have resulted in lower than average annual consumption (Figure 14).

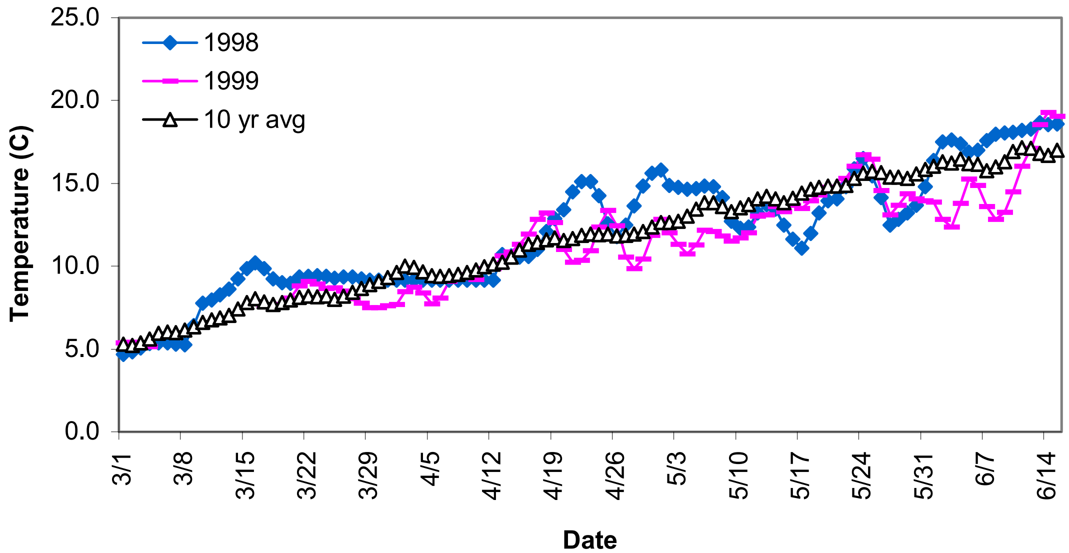

Figure 13. Daily average water temperatures at Benton City and ten year average water temperatures at Prosser.

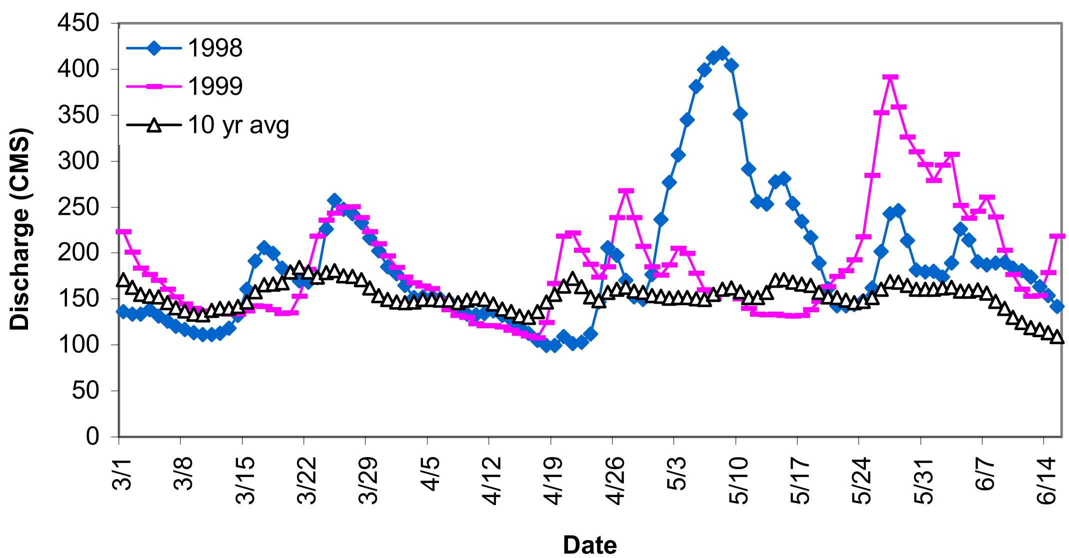

Figure 14. Daily average discharges at Benton City and ten year average discharges at Benton City.

The temporal pattern of predation was similar during 1998 and 1999 and occurred in three general stages. The first stage, which occurred prior to May, consisted of the initiation of predation, but the daily consumption was relatively low. The second stage occurred during the month of May and consisted of relatively high daily consumption. The third stage occurred during the latter part of May and June and consisted of considerable decreases in daily consumption. The low consumption observed during the first stage is likely to be due to low temperatures and low predator abundance. The high consumption during the second stage is likely to be due to increases in predator abundance and stream temperature. The third stage is not as obvious because predator abundance and stream temperatures continued to increase as during stage two, but consumption decreased. The decrease in consumption may be due to a variety of factors such as: switching to larger prey fish, gape limitation of bass as salmonids increase in size, decreased salmonid availability, decreased size composition of bass population, increased flow, increased turbidity, or changes in activities of adult bass associated with spawning. With the exception of the last factor, all of the others were not consistent with the pattern that we observed. Large bass may switch dominant behaviors from feeding to spawning during the end of the spring. Indeed, the condition factor of bass over 300 mm decreased from the middle of May until mid June, which suggests that fish had spawned during this time (Figure 15). During the same time the condition factor of fish less than 300 mm increased. Smallmouth bass that are greater than 300 mm are likely to be engaged in spawning and fish less than 300 mm are less likely to be involved in spawning.

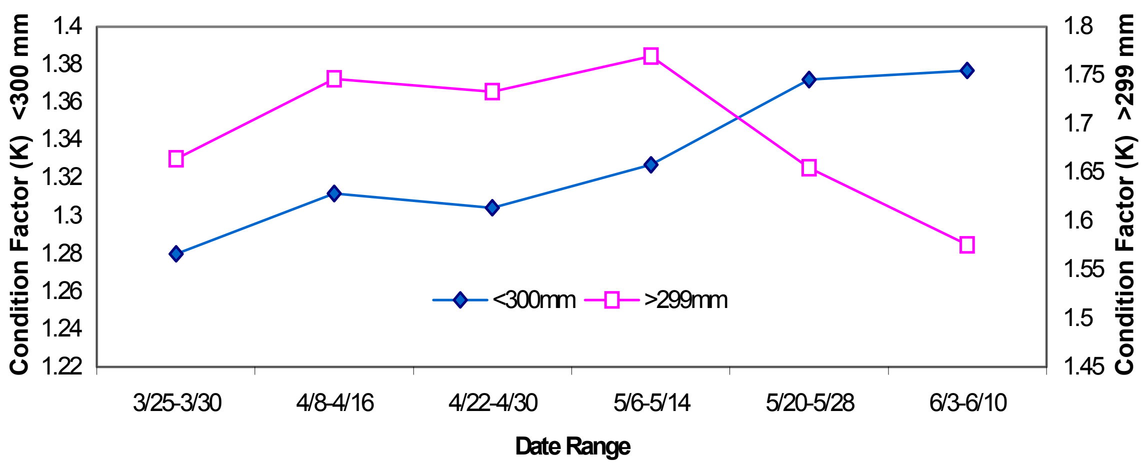

Figure 15. Seasonal trends in condition factors for smallmouth bass greater or less than 300 mm.

Two of the presumptive hotspots that we sampled during 1998 and 1999 did not appear to be areas of abnormally high predation. This may be due to the high flows that were observed during these years. This may be particularly true at the Chandler fish bypass where there is little slow water for fish predators to hold at high water. Additionally, large numbers of northern pikeminnow are killed at the Roza Adult Facility which may be decreasing the number of northern pikeminnow below the Dam.

Recommendations

Some sampling adjustments were made in 1999. We sampled weekly throughout the spring chinook salmon smolt emigration period (March 25 to June 10). This sampling schedule enabled us to better track weekly changes in predation on both spring and fall chinook salmon juveniles. We recommend that weekly CPUE and diet sampling during the entire spring chinook salmon smolt emigration period be continued and two mark-recapture population surveys be conducted. The CPUE and diet sampling should begin earlier than occurred in 1999, because the high availability of spring chinook salmon during the first survey and because predation on spring chinook occurred during the first survey. In addition the surveys should be extended a bit longer because of the late migration of hatchery spring chinook. The first set of the mark-recapture population estimates should be conducted near the peak of the wild spring chinook salmon emigration (last week of April) and the second set should be done during the third week of May when hatchery-origin spring chinook salmon are expected (based on observations in 1999) to be emigrating in higher numbers. We recommend continuing hotspot sampling annually at a very low level of effort below Roza Dam (one day/year at the spring peak of spring chinook salmon smolts past Roza Dam) to detect whether there is a drastic response in these predators following supplementation. Sampling below the Chandler fish bypass should be postponed until lower flows occur. Additionally, we recommend adding a ›hot-spot= smallmouth bass sampling site immediately below Horn Rapids Dam that should be sampled every-other week between April 1 and June 15. This recommendation is based on preliminary findings from 3 short hook and line sampling efforts there in May, 1999, when 254 bass (mean length = 335 mm, range = 222-526 mm) were caught by hook and line in the area between the spill crest and a line 40 m downstream of the dam on the right bank of the river. The mean CPUE for smallmouth bass on these days was 0.31 fish/min (range = 0.13 - .54 fish/min), which is more than 10 times higher than the CPUE for northern pikeminnow below Roza Dam in 1998 and 1999. Until better methods of sampling channel catfish are identified, catfish should be relegated to incidental monitoring.

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References

Beyer, J. M., G. Lucchetti, and G Gray. 1988 Digestive tract evacuation in northern squawfish (*Ptychocheilus oregonensis*). Canadian Journal of Fisheries and Aquatic Sciences 45:548-553.

Busack, C., and five coauthors. 1997. Yakima fisheries project: spring chinook supplementation monitoring plan. Bonneville Power Administration, Portland, Oregon. DOE/BP-64878-1.

Hansel, H. C., S. D. Duke, P. T. Lofy, and G. A. Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society 117:55-62.

Light, R. W., P. H. Alder, and D. E. Arnold. 1983. Evaluation of gastric lavage for stomach analyses. North American Journal of Fisheries Management 3:81-85.

McMichael, G. A., A. L. Fritts, and J. L. Dunnigan. 1999. Lower Yakima River predatory fish monitoring: progress report 1998. Pages 93-127 *in* ODFW and NMFS. 1999. Management implications of co-occurring native and non-native introduced fishes: Proceedings of the workshop. October 27-28, 1998, Portland, Oregon. Available from NMFS, 525 NE Oregon St., suite 510, Portland, OR 97232.

McMichael, G. A., A. L. Fritts, and J. L. Dunnigan. 1998. Lower Yakima River predatory fish census: feasibility study 1997. Pages 229-254 *in* Pearsons, T. N, and five coauthors. 1998. Yakima River species interactions studies, progress report 1995-1997. Bonneville Power Administration, Portland, Oregon.

Pearsons, T. N., and five coauthors. 1998. Yakima River species interactions studies, progress report 1995-1997. Bonneville Power Administration, Portland, Oregon.

Rogers, J. B., and C. C. Burley. 1991 A sigmoid model to predict gastric evacuation rates of smallmouth bass (*Micropterus dolomieui*) fed juvenile salmon. Canadian Journal of Fisheries and Aquatic Sciences 48:933-937.

Shrable, J. B., O. W. Tiemeier, and C. W. Deyoe. 1969. Effects of temperature on rate of digestion by channel catfish. The Progressive Fish Culturist 13:131-138.

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

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. 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.

Chapter 4

Lower Yakima River Predation Indexing: Northern Pikeminnow

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Abstract

We conducted population estimates of northern pikeminnow *Ptychocheilus oregonensis* using mark recapture methodology during April, May and June in three sections of the Yakima River above Prosser Dam. Northern pikeminnow abundance (fish > 200 mm fork length/km) was highest directly below Sunnyside Dam in the vicinity of the fish bypass facility. The abundance of northern pikeminnow > 200 mm fork length/km in free flowing sections of the Yakima River ranged from 116.1 – 220.8 fish/km. Most recaptured northern pikeminnow (n = 111; 94.5%) were recaptured in the same section that they were originally tagged, suggesting limited northern pikeminnow movement during the period of this study. Salmonid consumption by northern pikeminnow was higher during the May and June sampling periods than the April period at all sites. Throughout the salmonid outmigration season (April 12 – June 21, 1999) 4.1% of the northern pikeminnow sampled contained salmonids. We classified all salmonids as yearling smolts (spring chinook *Oncorhynchus tshawytscha* or coho *Oncorhynchus kisutch*) based on predicted fork length from diagnostic bones. We were unable to confidently differentiate between spring chinook or coho or hatchery versus wild origin fish based on diagnostic bones or the presence or absence of tags. We estimated a total of 60,583 yearling salmonids were consumed by northern pikeminnow from Prosser Dam to Roza Dam from April 12 – June 21, 1999. Development of a northern pikeminnow predation index in future years should utilize weekly salmonid consumption estimates since this portion of the predation index is likely more variable throughout the outmigration period than predator abundance.

Introduction

The Yakima/Klickitat Fisheries Project (YKFP) is an aggressive and proactive management attempt to increase natural production of anadromous salmonids within the Yakima River Basin and provide valuable information about supplementation efforts to the rest of the Columbia River Basin. An extensive monitoring plan for spring chinook *Oncorhynchus tshawytscha* (Busack et. al 1997) was developed by an interdisciplinary team of scientists, and is an integral portion of the YKFP. Several types of ecological interactions which may impact the dynamics within the Yakima River Basin and the success of the spring chinook supplementation program have been proposed for monitoring (Busack et. al 1997), including the impact of piscivorous fish. Several species of piscivorous fish are known to exist within the Yakima River system, including channel catfish *Ictalurus punctatus*, smallmouth bass *Micropterus dolomieui*, northern pikeminnow *Ptychocheilus oregonensis*, and largemouth bass *Micropterus salmoides*. Previous work (McMichael et. al 1998) confirmed earlier observations (Patten et. al 1970) that the spatial distribution of piscivorous fishes within the Yakima River can roughly be described along a longitudinal profile. Channel catfish are most abundant in the Yakima River near Richland. Smallmouth bass are relatively the most abundant predatory species below Prosser Dam, and upstream of Prosser Dam the abundance of smallmouth bass decreases and northern pikeminnow becomes the most abundant predatory fish. Dunnigan (1997) suggests that the observed longitudinal profile of species may in part be described by differences in water temperature, and to a lesser degree, ecological interactions between species in the lower Yakima River.

Northern pikeminnow predation on migrating salmonid smolts in the Columbia and Snake rivers has been shown to be substantial, and often highest directly below large hydroelectric dams where smolts are often concentrated and disoriented (Ward et. al 1995; Tabor et al. 1993; Beamesderfer and Rieman 1991; Vigg et. al 1991). During the spring and early summer months of some years northern pikeminnow abundance below several of the irrigation diversion dams located on the Yakima River is higher than other sections of the Yakima River from Prosser Dam to Roza Dam (McMichael et. al 1998; Dunnigan 1997). The mechanism for northern pikeminnow congregation below irrigation diversion dams along the Yakima River is not entirely understood. Yakima River diversion dams may function as constriction points for northern pikeminnow moving upstream in search of spawning locations. Alternative mechanisms could focus on northern pikeminnow foraging behavior. Vigg et. al (1991) suggest that many factors affect the dynamics of predation including: metabolic requirements, predator distribution, prey availability, predator size, and spawning behavior, but that temperature is probably the single most important variable which influences predation rates.

Field data collected in 1999 represented the third year of predator work in the Yakima River. Efforts above Prosser Dam in 1997 were largely feasibility work to establish monitoring sites and determine if predator abundance was high enough to warrant further investigation. In 1998, field activities were expanded to include estimates of predator abundance and smolt consumption, with the ultimate goal being the development of a spring chinook predation index for northern pikeminnow above Prosser Dam. However, development of a smolt predation index was somewhat limited by our ability to perform population estimates within the selected sampling sites (McMichael et. al 1998). This report summarizes field and laboratory efforts conducted in 1999 for the development of a smolt predation index.

Methods

Study Area

Population estimates for predatory fishes were conducted by jetboat electrofishing in three sections (Figure 1): 1. Granger Site - from approximately 2.1 km upstream of the Granger boat ramp to a point 2.0 km downstream of the boat ramp (Rkm 130-134.1), 2. Toppenish Site - from Rkm 145.6 upstream to Rkm 153.4, and 3. Sunnyside Dam site - a small area 0.18 km long immediately below Sunnyside Dam (Sunnyside; Rkm 167.0). Northern pikeminnow stomach samples were collected by electrofishing at all three sites listed above in addition to areas approximately 1.6 km above and below the Granger and Toppenish sites.

The lower Yakima River flows through irrigated farm land in an otherwise arid area in central Washington state. During the late spring and summer, much of the water in the lower Yakima River is utilized for irrigation and then returned to the river. Summer water levels can be extremely low below Sunnyside Dam, with summer water temperatures in this section of the Yakima River often approaching the upper lethal limits for salmonids (> 25^{o} C; Bidgood and Berst 1969). Non-native warm and cool water species such as smallmouth bass *Micropterus dolomieui*, channel catfish *Ictalurus punctatus*, pumpkinseed *Lepomis gibbosus,* bluegill *L. macrochirus*, yellow perch *Perca flavescens*, walleye *Stizostedion vitreum,* largemouth bass *M. salmoides*, black crappie *Pomoxis nigromaculatus*, brown bullhead *I. nebulosus,* carp *Cyprinus carpio*, and goldfish *Carassius auratus* are present in the lower Yakima River. Many of the native species previously found in this lower reach, such as sandroller *Percopsis transmontana* and Pacific lamprey *Lampetra tridentata* (Patten et. al 1970), are now very rare.

Predator Population Estimates/Movement

We collected piscivorous fish using daytime electrofishing by jetsled using a Coffelt model Mark 22 electrofishing unit, operating with an electrical output ranging from 200-350 volts at 5-8 amps. We recorded total time (minutes) electrical current was exposed to the water as a measure of effort. We measured fork length (FL, mm), weighed (g), and released all piscivorous fish captured on the same bank of the river within 1.0 km of the site of capture. All captured fish greater than 199 mm FL were marked with individually numbered Floy anchor tags and a fin clip. All captured fish 100-199 mm FL were marked with a fin clip, and fish less than 100 mm FL were released unmarked. Electrofishing at all sites was conducted during the period intended to coincide with the estimated peak (April 15-17) and last quartile (May 5-7) of spring chinook salmon smolt emigration, and during the first week of June. The peak and last quartile were estimated by examining smolt emigration data collected at the Chandler juvenile fish facility between 1983 and 1996 (Yakama Nation, unpublished data).

We estimated absolute abundance of piscivorous fish at the three transects using a mark-recapture population estimate technique (Ricker 1958) which assumes populations of piscivorous fish are “closed”, suggesting no births, deaths or migrations occurred during sampling periods. Additional assumptions were that marked and unmarked fish have equal mortality rates, marked fish were randomly distributed throughout the transect, marks were not lost, and all marked fish

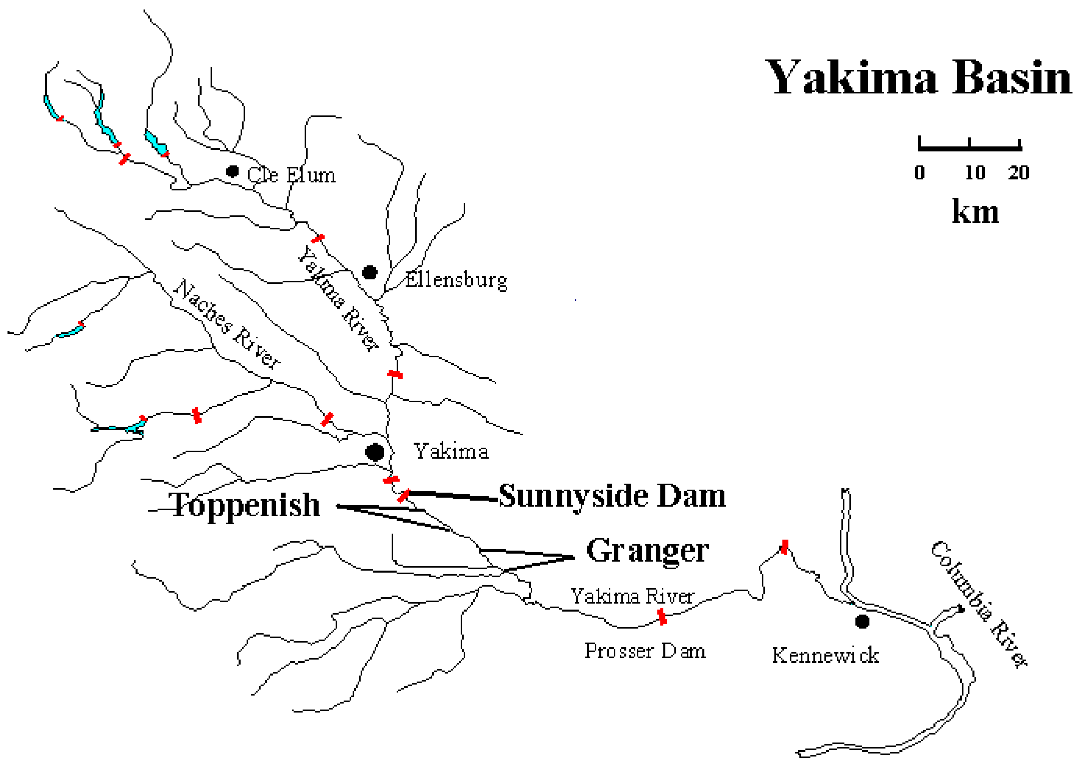

Figure 1. Map of the lower Yakima River. Sample locations are in bold type.

captured were recognized and counted (Lagler 1956). In order to tag sufficient numbers of fish to perform valid population estimates, we generally performed 2 consecutive marking periods (days) and a single recapture period at Sunnyside and Granger and 2 consecutive marking and recapture periods (days) at Toppenish. The period of time between the first marking period and the last recapture period never exceeded 5 days.

We used the Petersen Estimator as modified by Chapman (Ricker 1958) to estimate absolute abundance of northern pikeminnow at the three transects:

$$N = \frac{(M+1) \bullet (C+1)}{R+1} - 1 \qquad [1]$$

Where: N = population estimate,
C = total fish captured in the recapture sample(s),
M = number of marked fish at the start of recapture sample period and
R = number of marked fish in the recapture sample(s).

We used the following formula to calculate bounds (B) for 95% confidence intervals for N:

$$B = 1.96 \times \sqrt{\frac{N^2 \bullet (C-R)}{(C+1) \bullet (R+2)}} \qquad [2]$$

Diet sampling

Diet samples were collected from predator fish that were captured via jet boat electrofishing during recapture periods for the population estimates. In some instances an additional day of diet sampling was conducted up to one day after the final recapture period up to 1.6 km above and/or below the Granger and Toppenish sites to supplement diet samples for each site respectively. Diet samples were combined across days and above and below the sample site if the proportion of predators containing salmonids was not statistically different between samples (p = 0.05; Zar 1999).

Digestive tracts were excised from northern pikeminnow. Diet samples for smallmouth bass were obtained by gastric lavage (Light et al. 1983). All diet samples were placed in whirl-paks and tagged with date, stomach number, species, length, weight, and the section where the fish was captured and then placed on dry ice. Samples were kept frozen until lab analyses (1 to 5 months).

In the laboratory, any fish remains that were found in the predators were digested using a digestive enzyme (Taylor and Van Dyke 1985), stained (Cailliet et al. 1986), and identified to the lowest possible taxon with the use of diagnostic bones (Hansel et al. 1988). Standard equations were used to calculate estimated length of each fish in the stomach samples based on dimensions of diagnostic bones (Hansel et al. 1988). Length-weight regressions based on live fish we collected concurrently with the predatory fishes, as well as equations presented by Vigg et al. (1991), were then used to estimate weight of each prey fish at the time of ingestion.

We estimated the digestion time (DT; hours) to 90% digestion of northern pikeminnow prey items using the equation presented by Beyer et al. (1988) and modified by Rieman et al. (1991):

$$DT = 1{,}147 \cdot M_i^{0.61} \cdot T^{-1.60} \cdot W^{-0.27} \qquad [3]$$

Where M_i = meal size (g) at time of ingestion of salmonid prey item i,
T_i = water temperature {C}, and
W = predator weight (g).

We estimated mean daily water temperature using an Onset Hobo Temp that recorded river temperature every 80 minutes in the study section. We used mean daily water temperature (from the period 00:01-24:00) to estimate digestion time, since mean daily water temperatures varied little during the sections and time period of this study (approximately 0.6 degrees C variance within a day). We used the 90% digestion time for all prey items rather than the 100% digestion time to avoid the problem of lengthy estimates of digestion time due to indigestible prey items that remain in the gut for long time periods. We calculated meal turn-over (Windell 1978; Rieman et al. 1991) to estimate consumption rate (C; salmonids per predator per day) for each predator fish containing salmonids using the following formula:

$$C = n(24 / DT) \qquad [4]$$

Where n = number of salmonids observed in the predator's gut.

Estimation of the original weight of each predator prey item at time of ingestion (M_i) is difficult, tedious, and requires regression equations to estimate FL of prey items from diagnostic bones (Hansel et al. 1988), and length-weight regressions to estimate weight from FL for all prey species. We examined an alternative consumption index presented by Ward et al. (1995), which substitutes (S)(GW) for the M_i term in equation 3. Where S = the number of salmonids in the predator's gut and GW = the predator gut weight (g) at time of capture. Estimates of the number of salmonids per predator per day (C from equation 4) were also calculated using the alternative equation presented above.

Predation Index (Extrapolation)

We estimated the total number of northern pikeminnow >200 mm FL using mark-recapture techniques within the three sampling sections above Prosser Dam during the period April 12-June 21, 1999 (period of salmonid emigration). Sampling to estimate predator abundance and salmonid consumption were conducted concurrently (see above). We estimated the total daily number of salmonids consumed (SC) by northern pikeminnow within each study section using the following formula:

$$SC = N \cdot F \cdot C \qquad [5]$$

Where N = population estimate from equation 1,
F = fraction of predators containing at least one salmonid in the gut, and
C = estimated daily salmonid consumption per predator from equation 4.

To estimate the total number of salmonids consumed by northern pikeminnow from Prosser Dam (Rkm 75.6) to Roza Dam (Rkm 205.8) we stratified this section of river into two strata based on similar characteristics within each strata. The lower stratum was from Prosser Dam to Rkm 136.7, and the upper stratum was from Rkm 136.7 to Roza Dam. We used abundance and salmonid consumption estimates from the Granger and Toppenish sites to extrapolate total salmonid consumption for the lower and upper strata respectively. The salmonid emigration period was temporally stratified into 3 time periods (see Population Estimates section above), in each time period we attempted to estimate predator abundance and salmonid consumption. We used the following formula to estimate the total number of salmonids consumed by northern pikeminnow >200 FL within a strata:

$$S_{ij} = \left(\frac{N_{ij} \cdot RL \cdot F_{ij} \cdot C_{ij}}{SL} \right) \cdot D_j \qquad [6]$$

Where S_{ij} = total number of salmonids consumed in stratum i over period j,
SL = the length (km) of the study section i,
RL = length of river (km) being extrapolated to,
N_{ij} = population estimate from equation 1 for stratum i in period j,
F_{ij} = the fraction of northern pikeminnow containing at least one salmonid in stratum i for period j,
C_{ij} = estimated daily salmonid consumption per predator in stratum i for period j, and
D_j = total number of days in period j.

Extrapolations were performed in a similar manner for the alternative consumption index that substituted the predator gut weight and number of salmonids per gut for prey weight at time of ingestion (see above). Estimates of total consumption from the Sunnyside Dam site were not extrapolated to any other portions of the Yakima River.

Results

Predator Population Estimates/Movement

Population estimates of northern pikeminnow (>200 mm FL) in the Toppenish site from mid-April to early June ranged from 933 to 1722 (Table 1). Low catch rates and lack of recaptures for northern pikeminnow precluded performing population estimates for this species during April and June sampling at Granger and also the April sampling period at the Sunnyside site. The May population estimates of northern pikeminnow (>200 mm FL) in the Granger and Sunnyside sites were 476 and 83 fish respectively (Table 1). Capture efficiency for northern pikeminnow <200 mm FL was low for the 1999 smolt emigration, and subsequently we were unable to perform population estimates for the smaller size classes of northern pikeminnow. During the 1999 sampling season only 5.4% of the northern pikeminnow captured using electrofishing techniques were less than 200 mm FL (Figure 2), although the relative proportion of northern pikeminnow <200 mm FL increased as the sampling season progressed. The proportions of northern pikeminnow <200 mm FL between the April, May and June sampling periods between all three sites were 1.3, 3.9, and 16.1% respectively (Figure 3).

Few large or smallmouth bass were captured in the three electrofishing sites above Prosser Dam in 1999. For the sampling season (April 12 – June 10, 1999) a total of 3 largemouth and 4 smallmouth bass were captured at the Granger site and 1 smallmouth bass at the Toppenish site. Despite low capture rates, we were able to calculate a population estimate for smallmouth bass at the Granger site during the May sampling period (Table 1). However, we were unable to calculate any population estimates for largemouth bass at any of our sampling sites. No smallmouth or largemouth bass were captured at Sunnyside Dam.

We found little evidence that northern pikeminnow moved significantly between sites. During the 1999 field season, we recaptured 152 northern pikeminnows originally tagged in 1997 through 1999 ranging from 1- 716 days after they were tagged. In 1999, most northern pikeminnows were recaptured in the Toppenish site. Most northern pikeminnows (n=111; 94.9%) were recaptured in the same site that they were originally tagged. The average number of days between marking and recapture was 59.3 days. We caught 4 fish that were captured out of the site that they were originally tagged in, however, these fish were recaptured within 2 km of the section they were tagged in. Angler harvest of northern pikeminnow in the Yakima River appears to be low, since 1997, we have tagged and released 1037 northern pikeminnow, with only 2 fish reported captured by anglers.

While conducting electrofishing mark-recapture population estimates for northern pikeminnow at the Sunnyside, Toppenish and Granger sites, we observed a total of nine, eleven and thirteen different species respectively (Table 2). The four most abundant species in all three sections (in decending order of abundance) were sucker spp. (largescale *Catostomus macrocheilus* and bridgelip C. *columbianus* combined), mountain whitefish (*Prosopium williamsoni*) and chiselmouth (*Acrocheilus alutaceus*). Our visual counts indicated that mountain whitefish abundance decreases from the Sunnyside to Granger sites (Table 2).

Table 1. Population estimate data for northern pikeminnow (NPM) and smallmouth bass (SMB) in three sections of the Yakima River, 1999. Sample dates, species size class (mm FL), population estimate, 95% confidence interval (CI), and estimate of capture efficiency (Eff.). Numbers in parentheses following the population estimate and confidence interval are number of fish per km.

Date	Section	Species	Estimate	CI	Eff.
4/12-14	Sunnyside	NPM >200 mm	No Est.		
5/3-5	Sunnyside	NPM >200 mm	83 (461.1)	26 – 164 (144.4 – 911.1)	10.8%
4/12-16	Toppenish	NPM >200 mm	933 (119.6)	495 – 1371 (63.5 - 175.8)	6.6%
5/3-6	Toppenish	NPM >200 mm	1722 (220.8)	505 – 2939 (64.7 – 376.8)	3.1%
6/7-10	Toppenish	NPM >200 mm	1220 (156.4)	493 – 1947 (63.2 – 249.6)	5.5%
4/20-22	Granger	NPM >200 mm	No Est.		
5/10-12	Granger	NPM >200 mm	476 (116.1)	87 – 869 (21.2 – 212.0)	6.0%
5/10-12	Granger	SMB >200 mm	4 (1.0)	3 – 7 (0.7 – 1.7)	25.0%
6/2-3	Granger	NPM >200 mm	No Est.		

Table 2. Visually estimated fish species composition. Values in order include total season number, percent composition of seasonal total [in parentheses], and the mean number per km for season total (in parentheses) in the Yakima River at the Sunnyside Dam, Toppenish, and Granger sample sites, 1999. Data was collected by boat electrofishing.

Species*	Sunnyside Dam Rkm 167.0	Toppenish Rkm 145.6-153.4	Granger Rkm 130-134.1
CCF	0 [0%] (0.0)	1 [0%] (0.01)	0 [0%] (0)
CCP	29 [2%] (32.2)	592 [2%] (6.3)	591 [3%] (12.0)
CHM	140 [8%] (155.5)	3232 [13%] (34.5)	2653 [13%] (59.9)
COH	0 [0%] (0)	92 [>1%] (1.0)	213 [1%] (4.3)
DAC	6 [>1%] (6.7)	15 [>1%] (0.2)	5 [>1%] (0.1)
FCH	0 [0%] (0)	0 [0%] (0)	167 [1%] (3.4)
LGM	0 [0%] (0)	0 [0%] (0)	1 [>1%] (0.02)
MWF	830 [45%] (922.22)	7770 [31%] (83.0)	3363 [16%] (68.4)
NPM	23 [1%] (25.55)	460 [2%] (4.91)	214 [1%] (4.4)
RSS	30 [2%](33.33)	672 [3%] (7.18)	2551 [12%] (51.9)
SCK	113 [6%] (125.6)	1051 [4%] (11.2)	1139 [6%] (23.2)
SMB	0 [0%] (0)	0 [0%] (0.00)	3 [>1%] (0.1)
STH	2 [>1%] (2.2)	8 [>1%] (0.9)	1 [>1%] (0.02)
SUC	670 [36%] (744.4)	10854 [44%] (115.96)	9726 [47%] (197.68)

*CCF (channel catfish), CCP (common carp), CHM (chiselmouth), COH (coho salmon), DAC (dace spp.), FCH (fall chinook), LGM (largemouth bass), MWF (mountain whitefish), NPM (northern pikeminnow), RSS (redside shiner), SCK (spring chinook), SMB (smallmouth bass), STH (steelhead), and SUC (sucker spp.)

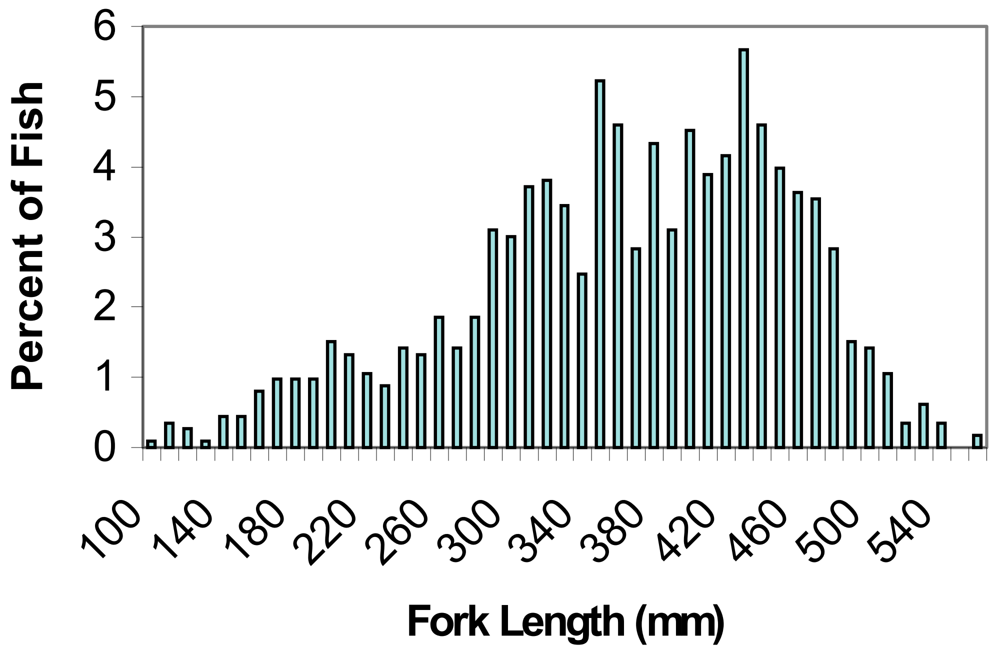

Figure 2. Length frequency for northern pikeminnow captured by boat electrofishing in the lower Yakima River between April 12 and June 10, 1999, total sample size was 492.

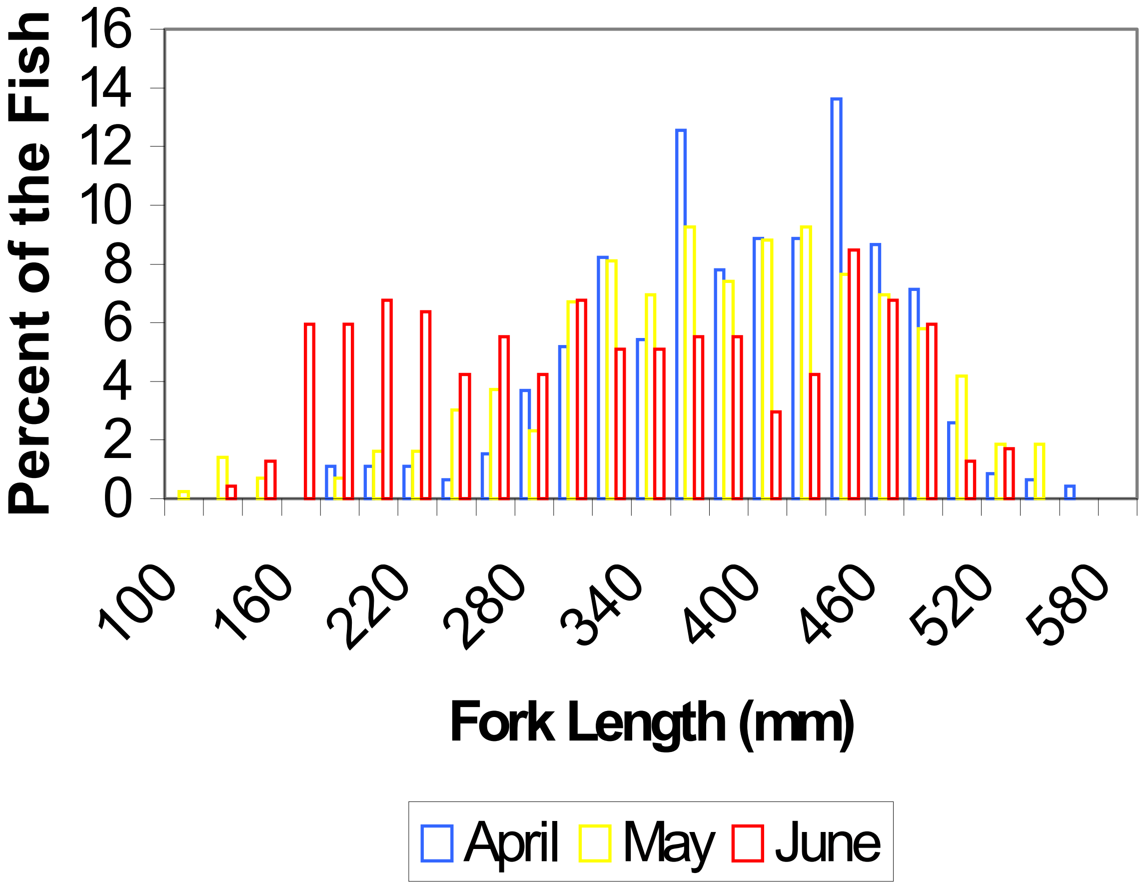

Figure 3. Length distribution (mm) of northern pikeminnow April – June 1999, captured by boat electrofishing.

Diet Sampling

Out of 492 northern pikeminnow >200 mm examined, 20 (4.1%) contained remains of salmonids (Table 3). Salmonid consumption by northern pikeminnow was generally higher during the May and June sampling periods than the April period at all sites (Table 3). Differences in the proportion of salmonids per predator between sites within the sampling season were not apparent. We examined 28 northern pikeminnow between 150-200 mm FL, and found that none of the smaller fish had consumed salmonids. Based on the predicted fork length of salmonids from regression relationships of diagnostic bones, we classified all salmonids observed in the northern pikeminnow as yearling smolts (spring chinook, or coho smolts). We were not able to confidently distinguish between coho and spring chinook based on diagnostic bones. Similarly, although we did find both coded wire tags (CWT) and PIT tags in some northern pikeminnow guts, we are skeptical to use tag recovery to estimate relative hatchery/wild salmonid origin. We recovered a total of 3 PIT tags that belonged to spring chinook salmon from the stomachs of 3 northern pikeminnow. In one instance the northern pikeminnow contained only the PIT tag, and no diagnostic bones. All hatchery spring chinook that were PIT tagged were also tagged with length and half CWT, however we only found a CWT present in 1 out of 3 of the stomachs containing the PIT tags. Additionally, a small proportion (<10%) of the hatchery coho released in the Yakima basin were marked with either CWT or PIT tags. Length frequency distributions of hatchery coho (mean FL = 146.3 mm) and spring chinook (mean FL = 140.0 mm) after May 17 were largely overlapping and were therefore of little value to classify fish remains as either chinook or coho (Figure 4).

Although salmonids represented a small proportion of the northern pikeminnow diet in our study, fish (all species) was a relatively major component of northern pikeminnow diets, constituting approximately 25% of their diet. Crayfish and other invertebrates were also important types of prey items for northern pikeminnow, constituting a combined proportion of approximately 31% of the total prey items (Table 3). We did not evaluate the relative caloric or biomass contribution of each type of prey item to the diets of northern pikeminnow. We identified 11 separate species of prey fish consumed by northern pikeminnow (Table 4). The four most abundant prey species consumed by northern pikeminnow were dace *Rhinichthys* spp., sucker *Catostomus* spp., salmon *Oncorhynchus* spp., and redside shiner *Richardsonius balteatus* (respectively; Table 4).

Few bass were collected for stomach analyses. We examined the stomach contents from 4 smallmouth bass (>200 mm FL) collected from the Granger site between 4/22 and 5/12, and found that none contained salmonids. Three of the smallmouth bass contained fish prey items, including redside shiner and sucker spp. Similarly, of the 2 largemouth bass collected within the Granger site, neither fish contained fish prey items.

Predation Index (Extrapolation)

We estimated a total of 60,583 yearling salmonids were consumed by northern pikeminnow from Prosser Dam to Roza Dam from April 12 to June 21, or approximately 865 smolts per day. We used the Granger and Toppenish abundance and consumption data to extrapolate from Prosser Dam to Rkm 136.7, and from Rkm 136.7 to Roza Dam respectively (Table 5). Mean daily salmonid consumption per predator was generally higher at the Granger site than the Toppenish

Table 3. Summary of the diet analyses for northern pikeminnow (>200 mm fork length) sampled in the Sunnyside, Toppenish, and Granger sites on April 14-21, May 5-13, and June 2-10, 1999. The number of stomachs examined (N), the number (percent) of the fish's guts in each sample that were empty, or contained invertebrates (Invert.), fish eggs, vegetation (Veg.), crayfish, rodent, fish (all species including salmonids), unknown items (Unk), and salmonids (Sal.; not including mountain whitefish) are presented. Row totals may exceed the sample number (N) due to single predator fish consuming multiple prey items.

Date	Section	N	Empty (%)	Invert. (%)	Fish Eggs (%)	Veg. (%)	Crayfish (%)	Rodent (%)	Fish (%)	Unk. (%)	Sal. (%)
4/14	Sunnyside	8	0 (0)	1 (12.5)	1 (12.5)	1 (12.5)	0 (0)	0 (0)	5 (62.5)	0 (0)	0 (0)
4/15-16	Toppenish	151	49 (32.4)	27 (17.9)	5 (3.3)	18 (11.9)	27 (17.9)	0 (0)	34 (22.5)	1 (0.7)	3 (2.0)
4/21	Granger	43	20 (46.5)	13 (30.2)	0 (0)	1 (2.3)	2 (4.7)	1 (2.3)	9 (20.9)	0 (0)	1 (2.3)
4/22	Granger	10	3 (30.0)	2 (20.0)	0 (0)	0 (0)	0 (0)	1 (10.0)	4 (40.0)	0 (0)	2 (20.0)
5/5	Sunnyside	7	3 (42.9)	0 (0)	0 (0)	0 (0)	0 (0)	1 (14.3)	3 (42.9)	0 (0)	2 (28.6)
5/6-7	Toppenish	126	44 (34.9)	26 (20.6)	0 (0)	2 (1.6)	16 (12.7)	1 (0.8)	39 (30.9)	0 (0)	5 (4.0)
5/12-13	Granger	50	14 (28.0)	18 (38.0)	0 (0)	4 (8.0)	3 (6.0)	3 (6.0)	10 (20.0)	2 (4.0)	2 (4.0)
6/2-3	Granger	17	8 (47.1)	4 (23.5)	0 (0)	0 (0)	0 (0)	0 (0)	4 (23.5)	1 (5.9)	1 (5.9)
6/10	Toppenish	80	20 (25.0)	12 (15.0)	0 (0)	0 (0)	19 (23.8)	1 (1.3)	27 (33.8)	1 (1.3)	4 (5.0)
Total	All	492	161 (32.7)	103 (20.9)	6 (1.2)	26 (5.3)	67 (13.6)	8 (1.6)	135 (27.4)	5 (1.0)	20 (4.1)

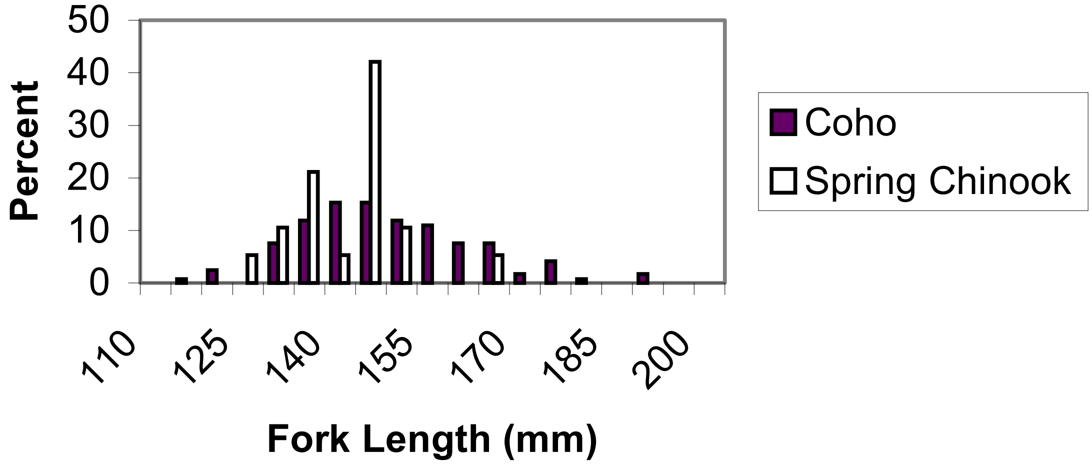

Figure 4. Length frequency distribution of hatchery coho (mean FL = 146.3mm) and spring chinook (mean FL = 140.0mm).

Table 4. Species composition of fish found in northern pikeminnow collected in the Granger, Toppenish, and Sunnyside sites April – June, 1999. Total number of fish in the sample (N), and the number of each prey species, followed by the percent of the number of the fish in the sample in parentheses. Totals represent the total number of prey species present. Row totals may exceed the sample number (N) due to single predator fish consuming multiple prey species.

			Species*													
Site	Date	N	CCP	CHM	CHN	COT	DAC	MWF	NPM	PSS	RSS	SAL	SUC	UNK	NSA	Total
Sunnyside	4/14	5				3 (60)		2 (40)	1 (20)							6
	5/5	3			1 (33)			1 (33)				1 (33)				3
Granger	4/21	9		1 (11)		1 (11)					5 (56)	2 (22)	1 (11)	1 (11)	1 (11)	9
	4/22	5	1 (20)		1 (20)				2 (40)			1 (20)		1 (20)		6
	5/12-13	10							2 (20)		1 (10)	2 (20)	3 (30)	2 (20)		10
	6/2	4					1 (25)	1 (25)				2 (50)		1 (25)		5
Toppenish	4/15-16	35		12 (34)		7 (20)	1 (3)	6 (17)			3 (9)	3 (9)	6 (17)		3 (9)	41
	5/6-7	39		4 (10)	1 (3)	7 (18)	1 (3)	2 (5)	2 (5)		9 (23)	6 (15)	12 (31)		1 (3)	45
	6/10	27				3 (11)	30 (111)		5 (19)	2 (7)	3 (11)	5 (19)	5 (19)	1 (4)	1 (4)	55
Total	all	137	1 (1)	17 (12)	3 (2)	21 (15)	33 (24)	12 (9)	12 (9)	2 (1)	21 (15)	22 (16)	27 (20)	6 (4)	6 (4)	141

*CCP = common carp, CHM = chiselmouth, CHN = chinook, COT = cottus spp., DAC = dace spp., MWF = mountain whitefish, NPM = northern pikeminnow, PSS = pumpkin seed, RSS = redside shiner, SAL = salmonid spp. (not including MWF), SUC = sucker spp., UNK = unknown spp., and NSA = non-salmonid spp. The last 2 categories represent specimens that could not be positively identified using diagnostic bone identification, but were placed in these categories by a weight of evidence approach.

Table 5. Mean daily salmonid consumption per salmonid piscivorous predator per day (Daily Consumpt. Rate), mean daily salmonid consumption within each section, and total extrapolated salmonid consumption for each river section the data was extrapolated over (Extrapolation Range), using the northern pikeminnow population estimate (Pop. Est.), percent of the northern pikeminnow containing salmonids (%w/ salmon) during the sample date. All consumption estimates were calculated using the estimated original weight at time of consumption for all prey items (Beyer et al. 1988; Rieman et al. 1991).

Sample Date	Extrapolation Dates	Extrapolation Range (Rkm)	Section	Pop. Est.	%w/ salmon	Daily Consumpt. Rate	Mean Daily Consumpt. (Section)	Total Consumption (Extrapolated)
4/12-14	4/12-30	165.8	Sunnyside	No Est.	0	0	0	0
4/12-16	4/12-30	136.8-205.8	Toppenish	933	2.0	0.811	15.13	2,570
4/20-22	4/12-30	75.6-136.8	Granger	No Est.*	11.2	1.615	86.10	22,660
5/3-5	5/1-6/21	165.8	Sunnyside	83	28.6	0.912	21.65	113
5/3-6	5/1-16	136.8-205.8	Toppenish	1722	4.0	0.522	35.96	4,821
5/10-12	5/1-16	75.6-136.8	Granger	476	4.0	0.812	15.46	3,223
6/2-3	5/16-6/21	75.6-136.8	Granger	No Est.*	5.9	1.057	29.68	11,549
6/7-10	5/16-6/21	136.8-205.8	Toppenish	1220	5.0	0.775	47.28	15,647
Season Total								60,583

*Population Estimates for Granger during periods 4/12-30 and 5/16-6/12 were not available, in order to calculate salmonid consumption levels during these periods, we applied the 5/10-12 population estimate for the Granger section.

site. Due to low capture efficiency, we were unable to calculate population estimates for northern pikeminnow for Granger during the 4/20 and 6/2 sampling periods. Thus, in order to calculate consumption estimates during these time periods, we utilized the population estimate obtained during the 5/10-12 sampling period at Granger.

Although we were unable to differentiate between coho and spring chinook using diagnostic bones recovered from northern pikeminnows, we can assess the likelihood of a given sample being either spring chinook or coho based on sample date. Approximately 1 million hatchery coho were released in the Yakima sub-basin in 1999, with approximately 500,000 released on May 17 and the remaining fish released on May 27. The YKFP released approximately 410,000 hatchery spring chinook beginning April 1, 1999. Smolt passage at the Chandler Juvenile Fish Monitoring Facility (CJMF) also suggests that the majority of the hatchery salmonids in the river prior to May 17, 1999 were spring chinook (Figure 5). Thus, most salmonids observed in the northern pikeminnow guts prior to May 17 were likely spring chinook. Assuming that all salmonids found in the northern pikeminnow prior to May 17 were spring chinook, then as many as 33,387 juvenile spring chinook may have been consumed during this period. Estimates of salmonid consumption from May 17 – June 21 (27,196 smolts) represent a combination of both coho and spring chinook since sample date, diagnostic bones, length frequency distribution, nor experimental marks were reliable methods to differentiate salmonid prey species during this period.

The potential worst case scenario for hatchery spring chinook salmon predation would be to assume that all salmonids observed in the northern pikeminnow gut samples were hatchery spring chinook. If this assumption were true, then approximately 15% of the 1999 Cle Elum Hatchery spring chinook production was consumed by northern pikeminnows between Prosser and Roza dams. The total number of wild spring chinook smolts passing the CJMF during the 1999 spring outmigration period was 245,019 smolts, but this is likely an underestimate of the total number of wild spring chinook passing CJMF for the season due to periods of high discharge during the outmigration which result in low and variable entrainment at the CJMF (Doug Neeley, personal communication). Nevertheless, assuming a minimal wild spring chinook season passage at CJMF and the total hatchery release number, approximately 5% of the Yakima River spring chinook (hatchery and wild combined) were consumed prior to May 17, 1999. If we assume that all salmonids consumed after May 16 were spring chinook, then approximately 9% of the Yakima River spring chinook were consumed by northern pikeminnow during the 1999 out migration. This is almost certainly an overestimate. Although the relative proportion of coho/spring chinook observed in northern pikeminnow samples collected after May 17 is unknown, it likely consisted of some portion of coho. If we assume that all salmonids observed in the northern pikeminnow samples collected after May 17 were coho salmon then approximately 3% of the hatchery coho were consumed by northern pikeminnow in the Yakima River between Prosser and Roza dams between May 17 – June 21.

Using the index of salmonid consumption presented by Ward et al. (1995), we estimated a total of 94,834 smolts were consumed by northern pikeminnow between April 12 – June 21, 1999 between Prosser and Roza dams (Table 6). The index overestimated total seasonal smolt consumption by 56% compared to the method that uses the original weight of prey items (see above), although the total number of smolts consumed using both methods were significantly

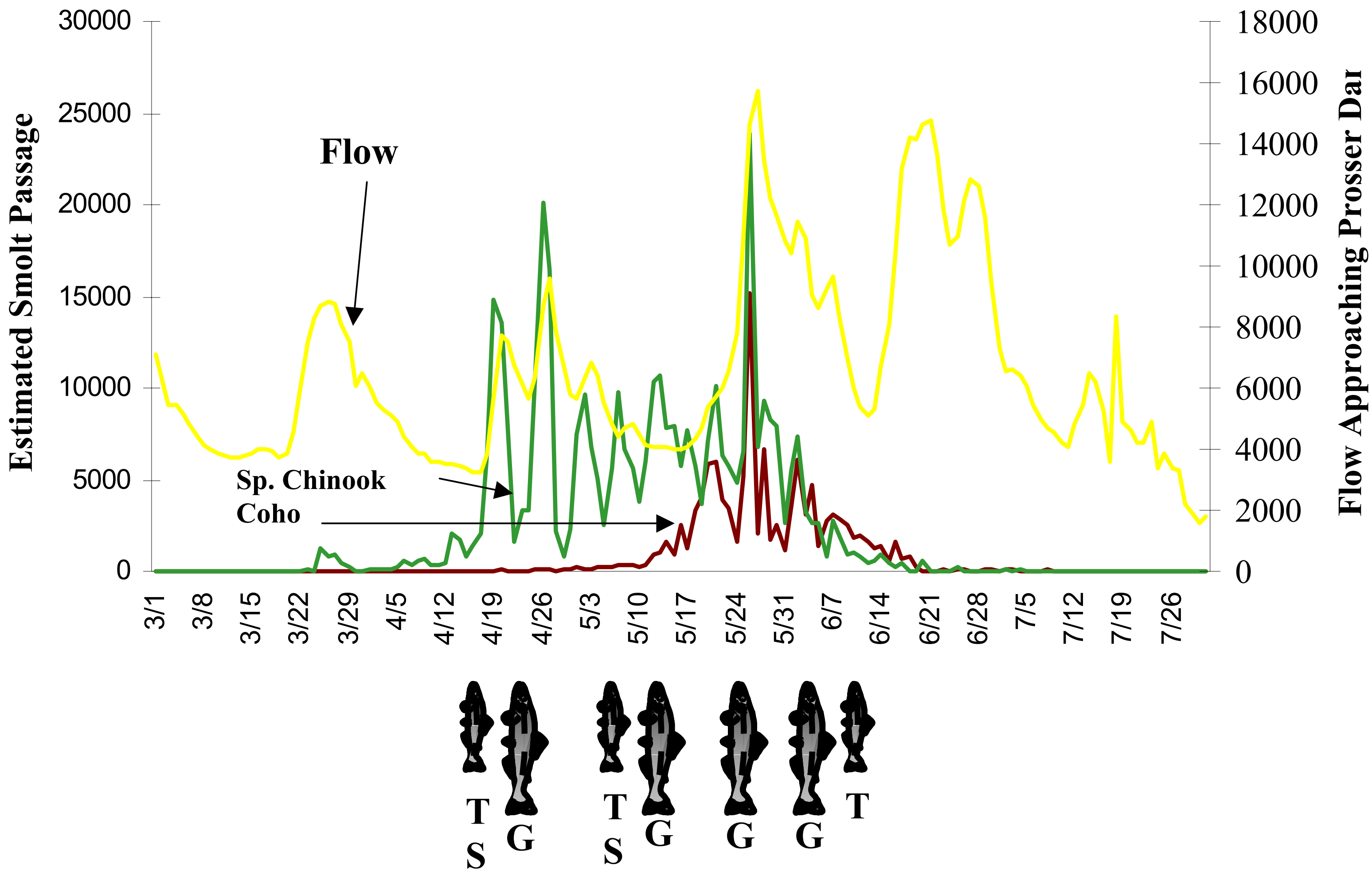

Figure 5. Spring Chinook smolt passage at Chandler Juvenile Fish Monitoring Facility (CJMF) during spring sampling in 1999. Fish on the x axis represent sampling dates at the Toppenish (T), Granger (G) and Sunnyside Dam (S) sites.

Table 6. An index of mean daily salmonid consumption per salmonid piscivorous predator per day (Daily Consumpt. Rate), mean daily salmonid consumption within each section, and total extrapolated salmonid consumption for each river section the data was extrapolated over (Extrapolation Range), using the northern pikeminnow population estimate (Pop. Est.), percent of the northern pikeminnow containing salmonids (%w/ salmon) during the sample date. All consumption estimates are indices that were calculated using the predator gut weight at time of capture and the mean number of salmonids per predator gut (Ward et al. 1995).

Sample Date	Extrapolation Dates	Extrapolation Range (Rkm)	Section	Pop. Est.	%w/ salmon	Daily Consumpt. Rate	Mean Daily Consumpt. (Site)	*Total Consumption (Extrapolated)*
4/12-14	4/12-30	165.8	Sunnyside	No Est.	0	0	0	0
4/12-16	4/12-30	136.8-205.8	Toppenish	933	2.0	1.236	23.06	5,071
4/20-22	4/12-30	75.6-136.8	Granger	No Est.[*]	11.2	1.749	93.24	24,540
5/3-5	5/1-6/12	165.8	Sunnyside	83	28.6	6.032	143.19	748
5/3-6	5/1-16	136.8-205.8	Toppenish	1722	4.0	0.549	37.82	5,071
5/10-12	5/1-16	75.6-136.8	Granger	476	4.0	2.133	40.61	8,468
6/2-3	5/16-6/12	75.6-136.8	Granger	No Est.[*]	5.9	1.769	49.68	19,332
6/7-10	5/16-6/12	136.8-205.8	Toppenish	1220	5.0	1.623	99.00	32,757
Season Total								94,834

*Population Estimates for Granger during periods 4/12-30 and 5/16-6/12 were not available, in order to calculate salmonid consumption levels during these periods, we applied the 5/10-12 population estimate for the Granger section.

correlated (r^2 = 0.82; p = 0.002; Figure 6). The index of consumption overestimated smolt consumption in each instance ranging from 5% to 562% (Toppenish 5/3 – 6 and Sunnyside 5/3 – 5 respectively; Tables 5 and 6).

Low gut sample numbers of both small and largemouth bass reduced our ability to detect predation on salmonids by either of these species (see above section). Therefore, we did not calculate estimates of salmonid consumption for either large or smallmouth bass.

Discussion

We were able to calculate population estimates with relatively narrow confidence intervals for northern pikeminnow >200 mm FL for all 3 sampling periods at the Toppenish site in 1999. Unfortunately, the 1999 outmigration season was the first season that the Toppenish site was sampled, and therefore direct comparison between years for this site is not possible. We were able to calculate population estimates at the Granger and Sunnyside sites during the periods May 10-12 and May 3-5 periods respectively. However due to a lack of recaptures at these sites in 1997 (Dunnigan 1997) and 1998 (McMichael et al. 1998) comparison of northern pikeminnow abundance between years is difficult. We were unable to calculate population estimates for northern pikeminnow <200 mm FL. Although the proportion of northern pikeminnow in our catch increased throughout the 1999 sampling season (Figure 3), we believe that sampling via electrofisher is biased toward larger fish and therefore not a reliable method to estimate abundance of smaller fish. Additionally, the incidence of predation on yearling salmonids by northern pikeminnow <200 mm FL seems to be very low based on results from 1998 (McMichael et al. 1998) and 1999.

All three population estimates calculated for the Toppenish site were higher than the single estimate calculated for the Granger site (Table 1). Perhaps more importantly than the population estimate, the number of northern pikeminnow >200 mm FL per km during the same approximate time period is nearly 2 times higher in the Toppenish site than the Granger site (Table 1). We attribute this greater abundance of northern pikeminnow in the Toppenish site to differences in physical habitat between sites. The Toppenish site has a higher frequency of back-eddy/shear-type habitat. Conversely, the habitat in the Granger site is homogeneous habitat which largely lacks substantial quantities of low velocity micro-habitat which northern pikeminnow have been shown to prefer (Beamesderfer 1983; Faler et al. 1988; Isaak and Bjornn 1996). Indeed, Mesa and Olson (1993) found that northern pikeminnow (300 – 490 mm FL) were unable to maintain prolonged swimming speeds at water velocities between 102-115 cm/s for periods greater than 14-28 min. Nevertheless, we feel it is important to maintain the current samples sites for future work because the Granger site typifies the habitat within the Yakima River from Prosser Dam to Rkm 136.7 (the lower stratum for extrapolation), and the Toppenish site typifies the upper stratum used for extrapolation. The April 20-22 and June 2-3 sampling periods at Granger coincided with periods of mean discharge (at Prosser Dam) of 7,313 and 11,182 cubic feet per second (cfs; respectively). In comparison, the discharge during the period when a population estimate was performed at Granger (May 10-12) was less than 4,500 cfs (Figure 5). Flow conditions during all three sampling periods at the Toppenish site were generally lower (Figure 5), and therefore increasing our capability to perform population estimates. During periods of high discharge in the Yakima River, we believe that northern pikeminnow in an effort to conserve

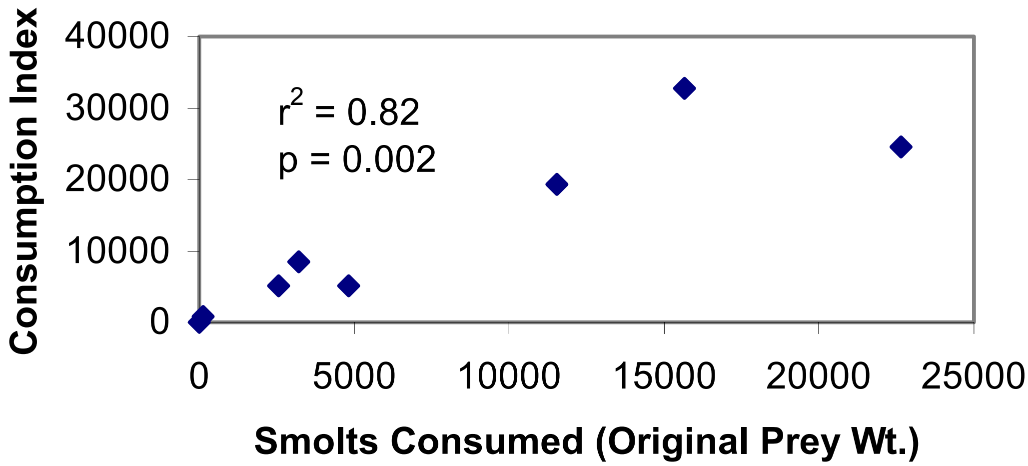

Figure 6. The estimated number of yearling smolts consumed using the meal overturn concept (original prey weight of all prey items; Beyer et al. 1988; Rieman et al. 1991) and the consumption index (Ward et al. 1995).

energy expenditure may seek low velocity micro-habitat which may include near bottom areas where substrate may provide refuge from high flow areas, thus making electrofishing census techniques largely ineffective.

The number of fish per km in the Sunnyside site was nearly 2 and 4 times higher than the Toppenish and Granger sites respectively during the early May sampling period (Table 1). The mechanism for increased abundance of northern pikeminnow at the Sunnyside site is not known. Fish may be congregating below Sunnyside Dam due to the smolt bypass facility, similar to the situation at many mainstem Columbia and Snake River hydro-projects (Poe et al. 1991; Isaak and Bjornn 1996). Regardless of the mechanism of congregation below Sunnyside Dam, the salmonid consumption (% predators containing salmonids) at the Sunnyside site during the early May sampling was significantly higher than either the Toppenish or Granger sites (Table 3).

Our results indicate that the overall northern pikeminnow predation on salmonids during the 1999 emigration season was relatively low. We estimated that a total of 60,583 salmonids were consumed from Prosser to Roza dams during the period April 12 – June 21. The minimum number of hatchery and wild spring chinook and coho emigrating from the Yakima sub-basin in 1999 was approximately 1,655,000 smolts, with approximately 3.7% of those consumed by northern pikeminnow. Survival estimates of Yakima River PIT tagged hatchery and wild spring chinook and hatchery coho released in 1999 also indicate that survival of yearling smolts to McNary Dam was relatively high, sometimes exceeding 50% (Dunnigan 2000).

Lack of recaptures in the 1998 sampling season prohibited calculating northern pikeminnow population estimates at either the Granger or Sunnyside Dam sites. Lack of population estimates for the 1998 field season also preclude estimating total salmonid loss and comparison between years. Based on the proportion of northern pikeminnow >200 mm containing salmonids, consumption at the Granger site was similar between 1998 and 1999 for sampling conducted in April, but significantly lower ($p = 0.008$) in 1999 than 1998 at Granger for sampling conducted in May (McMichael et al. 1998). Differences in relative consumption may in part be explained by differences in water temperature between years. The mean daily temperature at Prosser Dam for the period April 10-20 was nearly identical between 1998 and 1999 (10.6 and 10.1 C, respectively), however the difference in mean daily temperature for the period May 1-10 between 1998 and 1999 was 2.2 degrees Celsius (14.4 and 12.2 C respectively). While the temperature difference during the May sampling periods between years was relatively small, the temperatures in 1998 are closer to the preferred temperature range of 16 to 22 C reported for northern pikeminnow, and should have resulted in an increased metabolic rate for northern pikeminnow during that period (Brown and Moyle 1981; Vigg et al. 1991). Another difference observed between 1998 and 1999 was the relative proportion of sub-yearling chinook in the presence of gut samples taken from northern pikeminnow between years. In 1998, approximately 50% of all salmonids consumed by northern pikeminnow in the Granger site were sub-yearling chinook, yet in 1999 we did not observe any sub-yearling chinook in the northern pikeminnow in any of our samples. Differences in estimated fall chinook consumption by northern pikeminnow between years are difficult to interpret since estimates of sub-yearling chinook entrainment at CJMF were variable during much of the 1999 migration period (D. Neeley, personal communication). Without an estimate of the total number of sub-yearling chinook passing CJMF, it is difficult to speculate whether or not differences between years may be dependent upon the density of the juvenile chinook. Visual estimates of the total number of sub-yearling chinook observed during the May electrofishing surveys between years were similar for 1999 (Table 2; 167) and 1998 (221; McMichael et al. 1998).

Recommendations

We had relatively good success conducting population estimates of northern pikeminnow in the lower Yakima River in 1999 compared to 1997 and 1998, and we recommend that the 2-3 day mark and recap methodology used in 1999 be continued. We believe that movement of northern pikeminnow between sites is relatively limited especially when the mark-recapture population estimate is restricted over a period of 5 days or less. We base this conclusion on the movement data and population estimates between periods. Recapture data (both year to year and site to site) suggest that northern pikeminnow have relatively high fidelity to sections of the river. Population estimates for the Toppenish site between sampling periods in 1999 remained relatively constant, further suggesting limited movement patterns for this species in the Yakima River. Accurate estimates of the total seasonal loss of salmonids by northern pikeminnow predation are dependent upon accurate estimates of abundance and consumption. Given the limited evidence of northern pikeminnow variation in abundance throughout the spring out-migration, we recommend that future field efforts focus on refining estimates of predator consumption throughout the migration period, by increasing the periodicity of sampling to estimate consumption. Increasing the frequency of sampling to estimate salmonid consumption will likely require sampling areas that are not included in the sections of the river that population estimates are performed due to the relatively large sample sizes needed to precisely estimate consumption levels (Table 7). Additionally, investigation of non-lethal stomach sampling methods for northern pikeminnow should be explored. We should also continue to monitor length frequency and age structure of northern pikeminnow in the Yakima River to ensure that lethal sampling does not alter the age or size structure of these fish.

The consumption index presented by Ward et al. (1995) overestimated the total number of salmonids in 1999 by 56% compared to the alternative method. Even so, the effort required to calculate this estimate is low compared to the alternative method. Therefore, we recommend that the index of consumption be calculated for future northern pikeminnow work in the Yakima, in order to investigate the long term monitoring potential of this index.

Table 7. Sample sizes needed to estimate the proportion of northern pikeminnow (NPM) containing salmonids for a given confidence interval bound.

Estimated NPM Proportion Containing Salmonids	Confidence Interval Bound +/-				
	0.25	0.1	0.05	0.025	0.01
0.50	15	96	384	1537	9604
0.25	12	72	288	1152	7203
0.10	6	35	138	553	3457
0.05	3	18	73	292	1825
0.025	1	9	37	150	936
0.01	1	4	15	61	380

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References

Beamesderfer, R.C. 1983. Reproductive biology, early life history, and microhabitat of northern squawfish (*Ptychocheilus oregonensis*) in the St. Joe River, Idaho. Master's thesis. University of Idaho, Moscow.

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.

Beyer, J.M., G. Lucchetti, and G. Gray. 1988. Digestive track evacuation in northern squawfish (*Ptychocheilus oregonensis*). Canadian Journal of Fisheries and Aquatic Sciences 45:548-553.

Bigood, B.F., and A.H. Berst. 1969. Lethal temperatures for Great Lakes rainbow trout. Journal of the Fisheries Research Board of Canada 26:456-459.

Brown, L.R., and P.B. Moyle. 1981. The impact of squawfish on salmonid populations: a review. North American Journal of Fisheries Management 1:104-111.

Busack, C., B. Watson, T. Pearsons, C. Knudsen, S. Phelps, and M. Johnston. 1997. Yakima Fisheries Project: Spring Chinook supplementation Monitoring Plan. Internal Yakama Indian Nation Report. Yakama Indian Nation, Toppenish, Washington.

Cailliet, G.M., M. S. Love, and A.W. Ebeling. 1986. Fishes - A field and laboratory manual on their structure, identification and natural history. Waveland Press, Incorporated. Prospect Heights, Illinois.

Dunnigan, J.L. 1997. Predator fish abundance in the lower Yakima River. Yakama Nation internal report. Toppenish, Washington.

Dunnigan, J.L. 2000. Yakima coho monitoring and evaluation 1999 annual report. Bonneville Power Administration annual project report. Portland OR.

Faler, M.P., L.M. Miller, and K.I. Welke. 1988. Effects of variation in flow on distribution of northern squawfish in the Columbia River below McNary Dam. North American Journal of Fisheries Management 8:30-35

Hansel, H.C., S.D. Duke, P.T. Lofy, and G.A. Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society 117:55-62.

Isaak, D.J., T.C. Bjornn. 1996. Movement of northern squawfish in the tailrace of a lower SnakeRiver dam relative to the migration of juvenile anadromous salmonids. Transactions of the American Fisheries Society 125:780-793.

Lagler, K.F. 1956. Freshwater fishery biology. Wm. C. Brown Company, Dubuque, Iowa. Light, R. W., P. H. Alder, and D. E. Arnold. 1983. Evaluation of gastric lavage for stomach analyses. North American Journal of Fisheries Management 3:81-85.

McMichael, G.A., A. Fritts, and J.L. Dunnigan. 1998. Lower Yakima River predatory fish census: feasibility study 1997. Bonneville Power Administration annual project report. Portland OR.

Mesa, M.G., T.M. Olson. 1993. Prolonged swimming performance of northern squawfish. Transactions of the American Fisheries Society 112:1104-1110.

Patten, B.H., R.B. Thompson, and W.D. Gronlund. 1970. Distribution and abundance of fish in the Yakima River, Washington, April 1957 to May 1958. U.S. Department of the Interior Fish and Wildlife Service. Fish Bulletin No. 603.

Poe, T.P., C. Hansel, S. Vigg, 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.

Ricker, W.E. 1958. Handbook of computations for biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 119.

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

Taylor, W.R., and G.C. Van Dyke. 1985. Revised procedures for staining and clearing small fishes and other vertebrates for bone and cartilage study. Cybium 9:107-119.

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, J.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.

Windell, J.T. 1978. Estimating food consumption rates of fish populations. Pages 227-254 *in* T. Bagenal, editor. Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, London.

Zar, J.H. 1999. Biostatistical analysis. Prentice Hall Publishing. Upper Saddle River New Jersey.