UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVCE
GREATER ATLANTIC REGIONAL FISHERIES OFFICE
55 Great Republic Drive Gloucester, MA
01930-2276

SEP - 7 2018

Monte TerHaar
Chair, Pejepscot Hydroelectric Project
Dispute Resolution Panel
Federal Energy Regulatory Commission
888 First Street, N.E.
Washington, D.C. 20426

RE: NMFS response to Request for information for the Pejepscot Hydroelectric Project (P-4784-095) study plan dispute

Dear Mr. TerHaar,

On August 29, 2018, you, acting in capacity as the Chair of the Study Dispute Resolution Panel (Panel), issued a request for information for the Pejepscot Hydroelectric Project Study Plan Dispute.

Attached for filing, please find our responses to the Panel's questions. If you have any further questions or need additional information, please contact Matt Buhyoff at (Matt.Buhyoff@noaa.gov) or 207-866-4238.

Sincerely,

Julia Crocker

Julia E. Crocker
Endangered Fish Recovery Branch Chief
Protected Resources Division

Attachment 1: NMFS response to Panel questions
Attachment 2: Requested and additional references

Attachment 1: National Marine Fisheries Service Response to Panel Questions

SEP - 7 2018

1. **The Panel's recommendation must be based on information which is in the record for this proceeding. In your August 21, 2018 letter you recommend study methods similar to those outlined by Counihan et al., 2012. You also reference the Don Pedro Project No. 2299. Please provide a copy of the information from these two sources which you wish to include in the record.**

The sources the Panel has requested are included in Attachment 2 of this document.

2. **While you describe the goals of the study, you do not describe any details on the study design. You do not identify specific species to be studied, rather refer to "non-native predatory fish", and "native anadromous species". The Panel requests specific details on the study design including identifying the exact species of all target fish, procedures used, and timing and duration of study.**

Our understanding is that study planning in FERC's integrated licensing process (ILP) is intended as a collaborative effort between the requestor, the licensee, and other interested stakeholders[1]. While we provide some additional guidance and detail here for potentially suitable methodology, we note that there are a variety of potential study designs that could provide the information relevant to the project effects on predation of anadromous species. As was intended with our original study request, we would prefer to consult with the licensee and any interested resource agencies on an acceptably rigorous study design that also addresses the licensee's site-specific concerns and limits the effort and cost associated with the implementation of the study to the greatest extent practicable.

Our December 28, 2017 Study Request identified largemouth bass, smallmouth bass, and northern pike as the non-native predatory fish that were most recently documented in the project area. We reiterate here that the predation by those species is of primary interest to our requested study.

We recommend an evaluation of predation upon Atlantic salmon, river herring (alewife and blueback herring) and American shad. We note that the study methodology that we originally requested would also provide potentially valuable information regarding the consumption of other non-target prey items, including other native anadromous species such as American eel.

In general, obtaining a predation estimate requires three sources of information, which could be obtained in a single study season. Additional information is included as a sub-heading under each source of information:

[1] FERC, Office of Energy Projects. 2012. A Guide to Understanding and Applying the Integrated Licensing Process Study Criteria

1. A survey of the fish community to identify the relative abundance of the target predator species.
    a. Sampling to obtain species assemblage/relative abundance would occur at three periods: spring, summer, and fall.
2. An evaluation of the risk of predation utilizing telemetry data to evaluate downstream migration speed.
    a. This information will be provided by the approved telemetry passage studies.
3. A method to identify and quantify predation events.
    a. Ideally, the method for obtaining this information would be developed in consultation with the licensee, based upon site-specific information. We have identified three possible methods through which to develop an estimate of predation:
        i. Gut content analysis/development of a bioenergetics model.
            1. We included guidance on this method in our December 28, 2017 study request.
                a. We anticipate that this method would require three nighttime (12-hour) electrofishing sampling events (spring, summer, and fall) and associated laboratory analysis.
        ii. Use of acoustic tags with predation detection technology (attachment 2)[2,3].
            1. Eliminates the need for much of the post-sampling analysis required for the above bioenergetics method.
        iii. Use of predation event recorders[4].
            1. Provides the ability to associate predation events spatially and complements information from telemetry surveys.
            2. Eliminates the need for much of the post-sampling analysis required for the above bioenergetics method.
            3. Statistical power of results are less affected by rare prey species.

3. Please provide the most recent estimates of numbers of Atlantic salmon expected to occur in the project area. Provide any evidence you have that a sufficient number of Atlantic salmon exist in the project area to conduct the requested study.

---

[2] Acoustic Fish Tags Document Predation. 2017. FISHBIO Fisheries research monitoring and conservation. Available at https://fishbio.com/field-notes/the-fish-report/acoustic-fish-tags-document-predation. Date accessed: 9/6/2018.

[3] Shultz, Andrew; V. Afentoulis; C. Yip; M. Johnson. 2017. Efficacy of an Acoustic Tag with Predation Detection Technology. North American Journal of Fisheries Management 37:574-581, 2017

[4] Demetreas, N.J.; D. Huff; C. Michel; J. Smith; G. Cutter; S. Hayes; S. Lindley. 2016. Development of underwater recorders to quantify predation of juvenile Chinook salmon (*Oncorhychus tshawytscha*) in a river environment. National Marine Fisheries Service Fisheries Bulletin, p. 179.

A minimal amount of Atlantic salmon fry stocking occurs upstream of the Pejepscot project annually. Since 2007, production in the Androscoggin River from natural spawning has been variable, ranging from 44 adult salmon counted in 2011 to 0 fish in 2012. Using a Population Viability Analysis, we estimate that production due to fry stocking alone would produce between 9 and 174 salmon smolts in the project area annually[5]. Assuming a maximum of 44 adult fish passing upstream of project, natural production via adult spawning could contribute between 217 and 10,049 additional smolts to the project area. Therefore, in any given year, depending on natural spawning productivity, we could reasonably expect between 9 and 10,223 smolts in the project area.

As we indicated in our August 1, 2018 letter request for dispute resolution, we would like to reiterate that any study to estimate predation on juvenile Atlantic salmon in the Pejepscot impoundment would not be limited by the natural abundance of salmon smolts. Our partners in the recovery of Atlantic salmon, the U.S. Fish and Wildlife Service (U.S. FWS), operate an Atlantic salmon hatchery program in Maine. Upon request, the U.S. FWS routinely allocates salmon smolts for scientific studies that seek information to support recovery efforts – in this case, a more complete understanding of the detrimental effects of a hydroelectric dam in Atlantic salmon critical habitat. Estimating the minimum sample size necessary to produce statistically rigorous results with any accuracy would require performing a sensitivity analysis. Given the limited site-specific details available to us and the short time allowed to provide the panel with a response, we are unable to perform that analysis. However, we note that Demetras et al. 2016 (Attachment 2) developed predation rate information by utilizing as few as 216 Chinook salmon smolts. Hydropower licensees in Maine routinely perform passage efficiency studies using 150-250 hatchery smolts.

4. **You estimate the study would cost between $15,000 and $30,000. Please describe how these cost [*sic*] would be allocated, the level of effort to complete the study.**

Given that we are not private practitioners, our estimate of cost was based upon speculation regarding the minimum amount of effort that may be necessary to produce an estimate of predator relative abundance and predation using a bioenergetics method. We assumed a rate of $120/hour for a biologist and a $45/hour rate for a technician. We estimated sampling would require three separate events requiring a biologist and a technician, where each event is allotted 24 hours (not necessarily consecutive hours). We estimated that data processing would require 10 hours of a biologist and 40 hours of a technician. We estimated that reporting would require 30 hours of a biologist and 40 hours of a technician. Given these assumptions, we estimated a cost of up to $20,280 for labor and up to an additional $9,720 to cover incidental costs.

5. **Criteria 5 for the content of a study request requires an explanation of any nexus between project operations and effects on the resource to be studied. It also requires an explanation of how the study results would inform the development of license requirements. Please provide specific examples of how the results of an impoundment mortality study would be used to inform a license requirement, and identify specific**

---

[5] Legault, Chris. 2005. Population Viability Analysis of Atlantic Salmon in Maine, USA. Transactions of the American Fisheries Society 134:549-562, 2005

structures or operation changes which could be directed by the data collected. Give an example of a license article based on the information provided by the study results.

An impoundment mortality study, in combination with information from approved telemetry-based passage studies would first allow for the attribution of general background mortality to a discreet source (predation) that is project-related, and therefore firmly identify that effect as the responsibility of the licensee to account for in any protection, mitigation and enhancement (PM&E) measures, mandatory conditions, or reasonable and prudent measures/alternatives[6]. As described above, the studies would provide, at the least, three categories of information: 1) the plausibility of predation via an evaluation of predatory species composition and abundance in the headpond; 2) project-related predation risk associated with the rate of movement of anadromous prey species through the impoundment[7]; and, 3) an estimate of the level of mortality associated with predation.

Given the information provided by these studies, we can envision possible license requirements that fall under several classes within the three categories we identified above, as follows. Please note that we are not advocating for any of these potential license requirements and they are not indicative of our expectations for this project at this time; they are simply to illustrate the range of potential possibilities:

1) Predatory species composition and abundance
    a. Operational modifications/conditions to reduce predator abundance. Information from #3 would inform the target species and level of effort required.
        i. Direct predator removal (catch and kill)
        ii. Springtime impoundment drawdowns to eradicate predator nests
        iii. Critical evaluation of any potential license condition that would enhance predator abundance
2) Project-related predation risk
    a. Improve project operations and/or structures to reduce migratory delay downstream for the purpose of reducing the vulnerability to predation
        i. Dam removal
        ii. Installation of Alden-type weir(s)
        iii. Increase/partition flow to prioritize the downstream bypass
        iv. Install/create additional downstream bypasses
        v. Install/construct an angled guidance structure to aid in route-finding
        vi. Install a floating surface collection facility
        vii. Shut down generating units during migration periods and require additional spill
        viii. Prioritize operation of generating units to maximize survival

---

[6] Background mortality is the non-attributable estimate that the approved telemetry studies will produce. Please refer to our response to the Panel's question 7 for additional clarification on this point.
[7] This is information that the approved telemetry studies can provide.

b. Improve upstream passage efficiency to enhance productivity for the purpose of offsetting losses due to mortality and increasing beneficial prey-buffering effects.
    i. Dam removal
    ii. Installation of an additional fishway
    iii. Increase/partition flow to prioritize attraction flow to current fishway
    iv. Modify unit operation to benefit upstream passage
    v. Install lighting to aid in attraction
    vi. Decrease fish lift hopper cycle timing
    vii. Install funnel to prevent fish from dropping out of the fishway
c. Fund or implement projects in the Androscoggin River upstream of the project to enhance productivity for the purpose of offsetting losses due to mortality and increasing beneficial prey-buffering effects.
    i. Fund or implement projects that increase connectivity to historic spawning areas for native anadromous species upstream of the Pejepscot Project.
    ii. Fund or implement projects that improve habitat for native anadromous species upstream of the Pejepscot Project.
d. Fund or implement supplementation in the Androscoggin River or Merrymeeting Bay habitat recovery unit commensurate to predation losses.
    i. Fund or implement an egg/smolt/parr supplementation program
    ii. Fund or implement interim trap and truck operations

3) Project-related predation mortality
    a. Reduce project-related mortality by improving downstream passage structures and/or modifying project operations to offset losses due to predation.
        i. Dam removal
        ii. Installation of Alden-type weir(s)
        iii. Increase/partition flow to prioritize the downstream bypass
        iv. Install/create additional downstream bypasses
        v. Install/construct an angled guidance structure to aid in route-finding
        vi. Install a floating surface collection facility
        vii. Shut down generating units during migration periods and require additional spill
        viii. Prioritize operation of generating units to maximize survival

We would like to note our position that in its evaluation of potential license conditions, nothing mandates that the Commission consider license requirements that relate only to "specific structures or operation changes" that address protection from project-affected predation risk, as the Panel seems to suggest. The Commission's own *Guidance on Environmental Measures in License Applications* states: "proposed PM&E [protection, mitigation, and enhancement] measures could include modifications to project facilities and operations; construction, operation, and maintenance of new facilities; *or protection or mitigation measures for addressing project-related effects*" (emphasis added). As such, the potential license conditions under 2(b) are mitigation and enhancement measures; 2(c) and 2(d) are mitigation and enhancement measures that do not directly relate to project structures or operations; and 3(a) are mitigation and enhancement measures associated with mortality due to predation.

6. **In the study request, you call attention to how the impoundment creates an ecosystem that is more lacustrine providing more favorable conditions to invasive species that may affect survival of native anadromous fish. Please provide any scientific-supported evidence that describe ways in which dam operations might be modified to minimize the effects of predation created by these conditions.**

Guenther and Spacie (2005) demonstrated that fish assemblages in impounded reaches exhibited greater piscivore richness and abundance, compared with unimpounded reaches[8]. Dams can significantly delay Atlantic salmon smolt outmigration, especially in low water years, because the individual fish must search and find an available passage route. Delays can lead to direct mortality of Atlantic salmon and other species (Blackwell and Juanes 1998; Venditti et al., 2000)[9][10]. In addition to delay associated with route finding, impounded reaches slow the rate of migration overall, thereby increasing predation risk (Stitch et al., 2015)[11]. In addition to creating delay and slowing migration, Tabor and Wurtsbaugh (2011) demonstrated that the homogenous habitat itself that is created and maintained by impounding river reaches increased the risk of predation for juvenile salmonids[12]. The 2016 Draft Recovery Plan for Atlantic Salmon lists predation as one of ten secondary listing factors that threaten the continued existence of the Gulf of Maine (GOM) Distinct Population Segment (DPS) of Atlantic salmon[13]. Specifically, the recovery plan states: "the impact of predation on the GOM DPS is important because of the imbalance between the low numbers of adults returning to spawn and the increase in population sizes of both native and nonnative predators. Increased numbers of predators combined with decreased abundance of alternative prey have likely increased predation mortality on juvenile Atlantic salmon, especially at the smolt life stage." Regarding the effect of predation on an endangered species, in an evaluation of the potential impacts of smallmouth bass predation on endangered salmon in the northwest United States, Carey et al., (2011) conclude that "even low predation rates by smallmouth bass at individual locations could accumulate into a substantial impact over an entire

---

[8] Cameron B. Guenther & Anne Spacie. 2006. Changes in Fish Assemblage Structure Upstream of Impoundments within the Upper Wabash River Basin, Indiana, Transactions of the American Fisheries Society, 135:3, 570-583

[9] Blackwell, B. F. and F. Juanes. 1998. Predation on Atlantic salmon smolts by striped bass after dam passage. North American Journal of Fisheries Management 18: 936-939.

[10] David A. Venditti, Dennis W. Rondorf & John M. Kraut. 2000. Migratory Behavior and Forebay Delay of Radio-Tagged Juvenile Fall Chinook Salmon in a Lower Snake River Impoundment, North American Journal of Fisheries Management, 20:1, 41-52

[11] Daniel Stich, M. Kinnison, J. Kocik, and J. Zydlewski. 2015. Initiation of migration and movement rates of Atlantic salmon smolts in fresh water. Can. J. Fish. Aquat. Sci. 72: 1-13 (2015)

[12] Roger A. Tabor & Wayne A. Wurtsbaugh. 1991. Predation Risk and the Importance of Cover for Juvenile Rainbow Trout in Lentic Systems, Transactions of the American Fisheries Society, 120:6, 728-738

[13] National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS). 2016. Draft Recovery Plan for the Gulf of Maine Distinct Population of Atlantic Salmon. 63 pgs.

salmon run[14]." Similarly, Davis et al., (2011) note that for blueback herring, "even relatively small reductions in annual mortality can therefore produce appreciable population growth on a decadal scale[15]."

We provide several examples above of potential license conditions that could improve the timeliness of downstream migration. Increasing project spill or installing structures such as surface collectors to facilitate outmigration and reduce predation risk are extremely common license conditions at hydroelectric facilities (see Cushman, FERC No. P-460; Swift No. 1, FERC No. 2111; Priest Rapids, FERC No. P-2114; Orono, FERC No. 2710; Stillwater, FERC No. 2534; Milford, FERC No. 2534, etc.), well supported in scientific literature (Carey et al., 2011; Johnson and Dauble, 2007[16]; Zimmerman and Ward, 1999[17]), and the implementation of these conditions are possible within the operational constraints at the Pejepscot Project.

However, we again note our position that there is no requirement that license conditions pertain only to the "protection" from project effects via the modification dam structures or operations to address predation risk. As we suggest in our list of potential license conditions above, license conditions can also mitigate for project effects or enhance current conditions, i.e. by addressing mortality associated with predation.

7. **The licensee has proposed several telemetry-based passage studies to directly assess both upstream and downstream passage effectiveness for anadromous fish, and these studies have been approved. Please describe what information the proposed study would provide, and the potential mitigation measures, that would not be covered by the approved upstream/downstream passage studies.**

As we describe in our answer for question two above, the approved telemetry studies will provide information regarding a variable associated with the risk of predation in the impoundment. Specifically, the timeliness of migration through the project impoundment and downstream of the project dam.

---

[14] Michael P. Carey, Beth L. Sanderson, Thomas A. Friesen, Katie A. Barnas & Julian D. Olden. 2011. Smallmouth Bass in the Pacific Northwest: A Threat to Native Species; a Benefit for Anglers, Reviews in Fisheries Science, 19:3, 305-315

[15] Justin P. Davis, Eric T. Schultz & Jason C. Vokoun (2012) Striped Bass Consumption of Blueback Herring during Vernal Riverine Migrations: Does Relaxing Harvest Restrictions on a Predator Help Conserve a Prey Species of Concern?, Marine and Coastal Fisheries, 4:1, 239-251

[16] Gary E. Johnson & Dennis D. Dauble. 2006. Surface Flow Outlets to Protect Juvenile Salmonids Passing Through Hydropower Dams, Reviews in Fisheries Science, 14:3, 213-244

[17] Zimmerman, M. P. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the lower Columbia and Snake rivers. Trans. Amer. Fisheries Soc., 128:: 1036–1054.

As we have indicated in responses to several of the Panel's questions above, the telemetry study will not have the capability to distinguish different sources of mortality in the project impoundment. Telemetry studies can produce an estimate of "background mortality." Background mortality estimates are not attribute-specific; the background mortality estimated by a telemetry study can be the result of any number of sources. Sources of mortality in a background mortality estimate may include, but are not limited to, injuries related to the implantation of tags in study fish and other stressors related to handling (referred to broadly as handling mortality), anthropogenic sources (fishing, boating, point-source pollution), and terrestrial sources of mortality (i.e. avian and mammal predators). Without the ability to attribute the sources of background mortality to project-related effects (i.e. predation by non-native predators), it is impossible to define the project effects that the licensee should account for in any PM&E measures, mandatory conditions, or reasonable and prudent measures/alternatives.

Attachment 2: Requested and Additional References

Listed in Order:

Counihan, T.D., Hardiman, J.M., Burgess, D.S., Simmons, K.E., Holmberg, G., Rogala, J.A., and Polacek, R.R., 2012 Assessing native and introduced fish predation on migrating juvenile salmon in Priest Rapids and Wanapum Reservoirs, Columbia River, Washington, 2009–11: U.S. Geological Survey Open-File Report 2012-1130, 68 p

Don Pedro Project FERC No. 2299. 2013. Predation Study Report. Prepared for Turlock Irrigation District and Modesto Irrigation District. Prepared by FISHBIO, January 2013. FERC Accession Number: 20130117-5087

Demetreas, N.J.; D. Huff; C. Michel; J. Smith; G. Cutter; S. Hayes; S. Lindley. 2016. Development of underwater recorders to quantify predation of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in a river environment. National Marine Fisheries Service Fisheries Bulletin, p. 179.

USGS
science for a changing world

Prepared in cooperation with the Washington Department of Fish and Wildlife

Assessing Native and Introduced Fish Predation on Migrating Juvenile Salmon in Priest Rapids and Wanapum Reservoirs, Columbia River, Washington, 2009–11

Open-File Report 2012–1130

U.S. Department of the Interior
U.S. Geological Survey

Assessing Native and Introduced Fish Predation on Migrating Juvenile Salmon in Priest Rapids and Wanapum Reservoirs, Columbia River, Washington, 2009–11

By Timothy D. Counihan and Jill M. Hardiman, U.S. Geological Survey; Dave S. Burgess and Katrina E. Simmons, Washington Department of Fish and Wildlife; Glen S. Holmberg, U.S. Geological Survey; and Josh A. Rogala and Rochelle R. Polacek, Washington Department of Fish and Wildlife

Prepared in cooperation with the Washington Department of Fish and Wildlife

Open-File Report 2012–1130

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit *http://www.usgs.gov* or call 1-888-ASK-USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit *http://www.usgs.gov/pubprod*

To order this and other USGS information products, visit *http://store.usgs.gov*

Suggested citation:
Counihan, T.D., Hardiman, J.M., Burgess, D.S., Simmons, K.E., Holmberg, G., Rogala, J.A., and Polacek, R.R., 2012 Assessing native and introduced fish predation on migrating juvenile salmon in Priest Rapids and Wanapum Reservoirs, Columbia River, Washington, 2009–11: U.S. Geological Survey Open-File Report 2012-1130, 68 p.

Contents

Figures

Tables

Conversion Factors and Abbreviations and Acronyms

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)

I to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.62137	mile (mi)
	Area	
hectare (ha)	0.003861	square mile (mi^2)
hectare (ha)	2.47105	acre
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Abbreviations and Acronyms

Abbreviation or Acronym	Definition
BiOp	Biological Opinion
BRZ	Boat Restricted Zone
CPUE	Catch per unit effort
EPA	U.S. Environmental Protection Agency
EMAP	Environmental Monitoring and Assessment Program
FERC	Federal Energy Regulatory Commission
GIS	Geographic information system
GPP	Generator Powered Pulsator
GPS	Global Positioning System
Grant PUD	Public Utility District No. 2 of Grant County, Washington
n	number
PRCC	Priest Rapids Coordinating Committee
PRP	Priest Rapids Project
RM	River mile
SE	Standard error
SOP	Standard Operating Procedures
spp	species
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife

Assessing Native and Introduced Fish Predation on Migrating Juvenile Salmon in Priest Rapids and Wanapum Reservoirs, Columbia River, Washington, 2009–11

By Timothy D. Counihan[1], Jill M. Hardiman[1], Dave S. Burgess[2], Katrina E. Simmons[2], Glen S. Holmberg[1], Josh A. Rogala[2], and Rochelle R. Polacek[2]

Abstract

Hydroelectric development on the mainstem Columbia River has created a series of impoundments that promote the production of native and non-native piscivores. Reducing the effects of fish predation on migrating juvenile salmonids has been a major component of mitigating the effects of hydroelectric development in the Columbia River basin. Extensive research examining juvenile salmon predation has been conducted in the lower Columbia River. Fewer studies of predation have been done in the Columbia River upstream of its confluence with the Snake River; the most comprehensive predation study being from the early 1990s. The Public Utility District No. 2 of Grant County, Washington initiated a northern pikeminnow removal program in 1995 in an attempt to reduce predation on juvenile salmonids. However, there has been no assessment of the relative predation within the Priest Rapids Project since the removal program began. Further, there is concern about the effects of piscivores other than northern pikeminnow (*Ptychocheilus oregonensis*), such as channel catfish (*Ictalurus punctatus*), smallmouth bass (*Micropterus dolomieu*), and walleye (*Sander vitreus*, formerly *Stizostedion vitreum*). The Public Utility District No. 2 of Grant County, Washington and the Priest Rapids Coordinating Committee requested that the U.S. Geological Survey, in collaboration with the Washington Department of Fish and Wildlife, assist them in evaluating the effects of native and introduced predatory fish on migrating juvenile salmon. From 2009 to 2010, we conducted sampling in the 103 kilometers (64 river miles) of the Columbia River from the tailrace of Rock Island Dam downstream to the tailrace of Priest Rapids Dam. To assess predation, we used electrofishing to collect northern pikeminnow, smallmouth bass, and walleye to analyze their diets during 2009 and 2010. In 2009, we used methods to allow comparisons to a previous study conducted in 1993. During 2009, we also used an alternate sampling strategy using habitat data and geographic information system software to select sites and allocate samples. In 2010, we used the data collected during 2009 to further refine our sampling design, with the intent of using the data collected during 2010 to formulate a design strategy for implementation during 2011. Based on the results of 2011, we would then propose a strategy for future studies. However, during 2011, our efforts were redirected to specifically address factors that may be affecting steelhead trout survival in the Priest Rapids Reservoir, Columbia River.

[1] U.S. Geological Survey
[2] Washington Department of Fish and Wildlife

We used the catch and diet data collected in 2009 and 2010 to estimate relative abundance, consumption, and predation indices for northern pikeminnow and smallmouth bass. Despite extensive sampling in the study area in 2009 and 2010, very few channel catfish and walleye were captured. The mean total lengths of northern pikeminnow were much lower than those observed in 1993; suggesting that efforts to remove northern pikeminnow in the study area may be shifting the population towards smaller fish. The northern pikeminnow predation index values were lower in 2009 than in the 1993 study. The reduced predation levels observed may be due to the prevalence of smaller pikeminnow in our catches than in catches reported in 1993. Predation by smallmouth bass was lower in 2009 than in 2010, and generally was greater than predation for northern pikeminnow. Predation for northern pikeminnow was concentrated in the tailrace areas of Priest Rapids, Wanapum, and Rock Island Dams; predation for smallmouth bass was concentrated in the forebay and mid-reservoir sections of the study area. Our results indicate areas where control measures for smallmouth bass could be concentrated to reduce predation in the Priest Rapids Project.

Introduction

Hydroelectric development in the Columbia River basin has transformed the Columbia River from a high-gradient riverine system to a series of impoundments created by hydroelectric dams. Anadromous juvenile salmonids migrating through the Columbia River experience a variety of hazards that affect their survival as they migrate from freshwater rearing habitats to the ocean. Direct effects associated with dam passage (for example, instantaneous mortality, injury, and loss of equilibrium) and indirect effects (such as predation, disease, and physiological stress) contribute to the total mortality of seaward-migrating salmonids. Many studies (Raymond, 1979; Stier and Kynard, 1986; Iwamato and others, 1994; Muir and others, 1995; Bickford and Skalski, 2000; Timko and others, 2007a, 2007b) have been conducted to estimate dam, reach, and route-specific (that is through spillways, bypass areas, and turbines) survival of juvenile salmon to help identify the potential sources of mortality. Based on these studies and the endangered or threatened status of anadromous salmonid stocks in the Columbia River basin, management actions are being implemented to improve survival of juvenile salmonid migrants. In some instances, management strategies are in response to stipulated criteria as part of Federal Energy Regulatory Commission (FERC) hydroelectric project relicensing agreements. For instance, as part of the FERC license issued to the Public Utility District No. 2 of Grant County, Washington (Grant PUD) for the operation of the Priest Rapids Project on April 17, 2008 (Federal Energy Regulatory Commission, 2008), performance standards (passage survival rates) were established for Grant PUD in the National Marine Fisheries Service 2004 Biological Opinion (National Marine Fisheries Service, 2004), as adapted in the “Terms and Conditions” of the 2008 Biological Opinion (National Marine Fisheries Service, 2008). The 2006 Priest Rapids Project Salmon and Steelhead Settlement Agreement (U.S. Fish and Wildlife Service and others, 2006) requires that the same survival standards be met for salmonid species not listed under the Endangered Species Act.

Grant PUD is working to improve juvenile salmonid survival through their hydroelectric developments and the river environment affected by the construction and operation of these structures, collectively referred to as the Priest Rapids Project (PRP). Management actions to improve survival include altering dam operations, modifying the physical structure of hydroelectric projects, and reducing predator effects. For instance, surface flow alternatives to promote egress through the near-dam environment have resulted in improved passage at Priest Rapids and Wanapum Dams, where surface bypass systems are in operation; a prototype top-spill bypass was installed at Priest Rapids Dam in 2006 (Harmon and Parks, 1980; Ransom and Steig, 1995; Coutant and Whitney, 2000; Johnson and others, 2005; Robichaud and others, 2005; Timko and others, 2007a, 2007b). In 2008, modifications to the operation of the prototype top-spill included additional bottom and sluiceway spill at adjacent gates, which increased passage effectiveness and warranted further testing (Sullivan and others, 2001). These alterations have resulted in some improvements in fish collection efficiency and survival.

Predation in the Columbia River is a significant factor affecting survival of downstream migrating salmonids (Beamesderfer and Rieman, 1991; Burley and Poe, 1994; Ward and others, 1995; Petersen and Ward, 1999; Petersen, 2002). Beamesderfer and others (1996) estimated that about 16.4 million out-migrating juvenile anadromous salmonids were consumed annually by northern pikeminnow (*Ptychocheilus oregonensis*) in the Columbia and Snake Rivers prior to the Northern Pikeminnow Management Program for the lower Columbia and Snake Rivers and Northern Pikeminnow Removal Programs implemented collectively by Grant PUD, Public Utility District No. 1 of Chelan County, Washington, and Public Utility District No. 1 of Douglas County, Washington. When compared to the estimated 200 million juvenile anadromous salmonids produced in the combined Columbia–Snake River systems, northern pikeminnow are believed to consume approximately 8 percent of all downstream migrants, although 6.5 percent are believed to be consumed downstream of The Dalles Dam (Beamesderfer and others, 1996).

Extensive research on juvenile salmon predation has been conducted in the Columbia River downstream of its confluence with the Snake River. Fewer studies of predation on juvenile salmonids have been done in the Columbia River upstream of its confluence with the Snake River, the most comprehensive study was from the early 1990s (Burley and Poe, 1994). The Grant PUD initiated a northern pikeminnow removal program in 1995 in an attempt to reduce predation on juvenile salmonids (Garner and Keeler, 2008, 2009). However, no assessment has been made of the relative predation within the PRP since the removal program began. Furthermore, there is concern about the effects of fish predators other than northern pikeminnow, such as channel catfish (*Ictalurus punctatus)*, smallmouth bass (*Micropterus dolomieu*), and walleye (*Sander vitreus*, formerly *Stizostedion vitreum*). The Grant PUD and the Priest Rapids Coordinating Committee (PRCC) requested that the U.S. Geological Survey (USGS), in collaboration with the Washington Department of Fish and Wildlife (WDFW), assist them in their efforts to evaluate the effects of native and introduced predatory fish on migrating juvenile salmon. From 2009 to 2010, we developed and conducted research to increase our understanding of predator-prey interactions within the PRP.

Our objectives in this study were to assess the current status of predation on juvenile salmonids migrating through the Priest Rapids and Wanapum Reservoirs on the Columbia River, Washington. Specifically, we were to repeat the methods of a previous study (Burley and Poe, 1994) to assess the current status of predation on juvenile salmonids from the tailrace of Rock Island Dam to the tailrace of Priest Rapids Dam on the Columbia River. In addition, we were to implement alternate study design and sampling protocols that could be used for future studies of juvenile salmonid predation within the PRP.

Study Methods

We conducted field collections of fish predators and their diets in 2009–11. In 2009, we implemented design and sampling strategies to allow comparisons to a Mid-Columbia Predation Index Study from 1993 (Burley and Poe, 1994; hereafter referred to as Burley and Poe). We replicated this study, with the exception that we sampled from the tailrace of Rock Island Dam to the tailrace of Priest Rapids Dam and modified some data collection and laboratory analysis protocols to conform to current standards and regulatory requirements. We also explored alternate sampling strategies that incorporated habitat data and geographic information system (GIS) software to select sites and allocate samples. In 2010, we continued our sampling using modified methods in our study design and sample frame design that incorporated the results from 2009. In 2011, the PRCC redirected the original study objectives to specifically assess predation effects of juvenile steelhead migrating through the Priest Rapids Development only. The results of the 2011 work are described in a separate report (Hardiman and others, 2012). We used fish collected in 2011, however, to describe certain characteristics of the predator populations (such as fish ages) and to present the results in this report.

Study Area

The PRP study area included approximately 64 river miles, from the Rock Island Dam (RM 453) tailrace to about 8 mi downstream of the Priest Rapids Dam (RM 397) in the Columbia River (fig. 1). The PRP consists of two run-of-the-river hydroelectric developments owned and operated by Grant PUD. The Priest Rapids Reservoir is about 18 mi in length, with a shoreline of 56 mi and an approximate surface area of 7,580 acres (Pfeifer and others, 2001). The Wanapum Reservoir is 38 mi in length, with 91 mi of shoreline and a surface area of 14,590 acres (Pfeifer and others, 2001). Environmental conditions during the study periods were obtained for Priest Rapids, Wanapum, and Rock Island Dams from the University of Washington's Columbia River Data Access in Real Time (DART) Web site (*http://www.cbr.washington.edu/dart/*).

Field Data Collection

Site Selection

The study area was divided into strata based on the longitudinal position of reaches in each reservoir. The construction of hydroelectric projects on the Columbia River has formed a series of impoundments that have characteristics typical of lakes and streams. The consequences of impoundment are relatively predictable; the reservoirs are more like streams immediately downstream of the upstream dam and more like lakes near the downstream dam. As such, reservoirs typically can be divided into three zones (riverine, transitional, and lacustrine), corresponding to riverine conditions (tailrace area); transition to lake conditions (mid-reservoir); and lake-like conditions near the downstream dam (forebay area). Past predation studies have shown that predation of juvenile salmonids varies longitudinally in impoundments of the Columbia River (Petersen, 1994) and that areas near hydroelectric dams, that are typically restricted to boat use (Boat Restricted Zones; BRZ), are areas where predation of juvenile salmonids is relatively high (Ward and others, 1995). The work of Petersen (1994) demonstrated that failure to account for this spatial variability resulted in bias in predation estimates. Therefore, we structured our sampling strategy, in part, based on the development of longitudinal strata in the study area.

Sampling consisted of Burley and Poe's efforts in 2009 and additional predator indexing efforts using a modified sampling design in 2009 and 2010 that incorporated the use of a GIS containing habitat features. In 2009, the longitudinal strata (that is, forebay, mid-reservoir, and tailrace) replicated the Burley and Poe (1994) study, and were approximately 3.7 mi in length with the exception of the BRZ areas (fig. 1). For the Burley and Poe efforts each of the longitudinal strata were divided into transects that were approximately 1,640 ft in length and were randomly selected for shoreline (depths of less than 10 ft) electrofishing efforts. For the predator index sampling, a GIS was used to generate a systematic grid of points spaced every 50 ft with a depth criterion of less than 10 ft within each of the longitudinal strata. Points were then randomly selected for electrofishing sites each week. Because of the smaller sizes of the BRZ areas, the entire available shoreline was sampled whenever access was provided to these areas.

Modifications to the sample design were incorporated into the 2010 sample framework, based on assessment of the 2009 sampling efforts. One constraint was the limited access to sampling in the BRZ areas because of high flows and coordination needed to cease some dam operations to safely access these areas. Therefore, we added additional strata immediately upstream of the forebay and downstream of the tailrace BRZs in 2010 (fig. 2). By adding these reaches, we were able to sample the near-BRZ areas weekly without affecting dam operations. Another sample area modification was to expand the mid-reservoir reaches in both Wanapum and Priest Rapids Reservoirs from the approximate 3.7-mi reach used in 2009 to the entire river area that was not included in one of the other sampling reaches (fig. 2). This eliminated the possibility of missing potentially important areas not sampled in 2009.

Sample Allocation

The sample allocation for the Burley and Poe efforts was designed to replicate sampling periods to capture the spring and summer periods as achieved in the 1993 study (Burley and Poe, 1994). Efforts were allocated over a 10-day sampling period for the spring and summer, where each strata would be covered twice, consisting of six randomly selected transects, with the exception of the BRZs (only two transects). To determine when to initiate sampling, because there was no rationale for mimicking the actual dates sampled in 1993, we used water temperature as a criterion to begin sampling during the spring and summer periods. Sampling for the spring was initiated when water temperatures reached approximately 12°C, and for the summer, when water temperatures were approximately 19°C. Burley and Poe’s spring sampling occurred from May 27 to June 12, 2009, and summer sampling occurred from August 3 to 20, 2009.

For the 2009 and 2010 predator indexing efforts, we sampled continuously throughout the juvenile salmonid migration period, and then retrospectively determined the spring and summer periods based on Smolt Passage Indices presented on the Columbia River DART web site for Rock Island Dam. The sample design was such that the entire study area would be covered each week; and week days were randomly assigned to reaches by sample week throughout the study. Efforts allocated to the BRZ sampling were less than those allocated for the other strata because of the coordination and alteration of dam operations required to access BRZ areas. To determine the spring migration period, we summed the smolt index values for yearling Chinook, coho, and sockeye salmon, and steelhead trout, and then assumed the middle 90 percent of the run as the sampling period. In 2010, logistics prevented us from sampling until May 19, which was later than these criteria would dictate. We used the smolt passage index at Rock Island Dam for sub-yearling Chinook salmon to define the summer period so that the beginning of the summer period was the first day that the index values for Rock Island Dam exceeded and subsequently did not go below values for either yearling Chinook, coho, and sockeye salmon, and steelhead trout. In 2009, sampling occurred from May 1 to August 27, with the spring migration period defined as May 4–June 11, and the summer migration period defined as June 22–August 7. For 2010, sampling occurred from May 19 to September 3, with the spring migration period defined as May 19–June 9, and the summer period defined as June 27–August 11.

Boat Electrofishing

We used standardized operating procedures for electrofishing (available upon request) to collect predators in 2009 and 2010. Electrofishing efforts were conducted along the shoreline at preselected sites using two 18 ft-long (5.5 m-long), Smith Root® 5.0 Generator Powered Pulsator (GPP) electrofishing boats. Following the WDFW warm-water sampling protocol (Bonar and others, 2000), individual electrofishing boats were operated parallel to the shoreline at a rate of 0.6–0.9 m/h, maintained a distance from shore that allowed the inshore boom to fish entirely in the water, and avoided areas that exceeded 10 ft in depth. To facilitate fish galvanotaxis, we operated the GPP unit at approximately 1–2 amperes (amps) using a low power setting (50–500 volts) with a frequency between 30–120 Hz DC. To prevent unnecessary fish injury, we noted the behavior of fish within the electrical field and adjusted the power accordingly.

Time, personnel, and direction of travel associated with sampling also were standardized. The goal of each electrofishing boat was to electrofish each site for 600 s. The number of crew on an individual boat also was regulated to maintain a constant effort between times and boats. Each crew consisted of one boat operator and two dip netters stationed at the front of the vessel, and each crew member was outfitted with a personal flotation device. Electrofishing was always conducted downstream.

For the Burley and Poe efforts, electrofishing began 90 min before sunrise (determined using the Mattawa site from *http://www.usno.navy.mil/USNO/astronomical-applications/data-services/rs-one-year-us*) and continued until we attained a target catch of 15 northern pikeminnow from each section sampled. For the predator indexing efforts, electrofishing began no earlier than 30 min after sunset (determined using the Mattawa site from *http://www.usno.navy.mil/USNO/astronomical-applications/data-services/rs-one-year-us*) and continued until all sites were completed, weather permitting. The following information was recorded for each sample site: water temperature, specific conductance, time of day, transect start and end GPS coordinates, initials of crew, date, site designation, and power settings used to electrofish. During electrofishing, stunned fishes were placed immediately in one of the two onboard livewells equipped with a pump that continually added freshwater into the tank. After the completion of two 600-s electrofishing runs, the boat operator moored the electrofishing boat on shore where WDFW or USGS staff collected the required biological information from the captured fish. In the event that transit time between sites was extended as a result of distance or environmental conditions, crews collected the pertinent data from the captured fishes immediately after the completion of the first site.

Following standardized operating procedures (available upon request), biological information was collected for the following target species: northern pikeminnow, smallmouth and largemouth bass, channel catfish, and walleye. Because of the potential for the captured fishes to be consumed by anglers, we did not use the anesthetic commonly referred to as MS-222 per U.S. Food and Drug Administration guidelines. Therefore, all fish captured as non-lethal take were worked up in a non-anesthetized state. The collection of data from identified fish included the length, weight, and aging structures, such as scales for non-lethal-take fish and opercles for lethal-take fish. Hard structures for aging were collected from northern pikeminnow, smallmouth bass, and walleye for the duration of the fieldwork. The diets of walleye, smallmouth and largemouth bass (*Micropterus salmoides*), and walleye were collected using a lavage technique (non-lethal take), while northern pikeminnow and channel catfish (lethal take) stomachs were surgically removed. All diets were preserved (either frozen whole or contents soaked in 95-percent ethanol) and transported back to the laboratory to be analyzed for contents at a later date.

Laboratory Analyses

Aging Analysis

Scales and opercles collected in the field were transported to the Large Lakes Research Team Laboratory in Ellensburg, Washington, to be prepared for aging analysis according to standardized operating procedures (available upon request). Personnel at the WDFW aging laboratory read scales using a standard office microfiche that had the ability to alter magnifications levels. Initially, a magnification that permitted a view of the entire scale was used to examine circuli. The areas where circuli were concentrated indicated an annulus or year mark (Jearld, 1983). Each annulus from the focus or center of the scales was identified and counted to provide an estimate of a length at age for an individual fish, and data were sent to the Large Lakes Research Team Laboratory. Cleaned opercular bones were placed proximal side up in a petri dish containing 95-percent ethanol and viewed under a dissecting microscope between 60 and 120 magnification. Samples were viewed under reflected light and contrasted against a solid black background. Annuli were counted on the proximal surface in a plane from the center to the anterior opercle edge similar to Le Cren (1947). Annuli were distinguished as the band of transparent growth occurring during the slow growing season (assumed winter months) and soon after the opaque fast growth (assumed spring and summer months). Fish were assumed to have a birth date of January 1; therefore, annuli forming at the opercle edge in fall months were not counted unless there was opaque growth beyond the annuli, although for spring collections, annuli at the edge were counted (occurring after the universal birth date of January 1). Up to three readings on older, more difficult structures were made per sample until a consistent reading could be determined. The age estimation was recorded and the opercle was placed back in the sample envelope and sealed.

Mean length at age and the standard error (SE) were calculated for each age class for the three predators. Length-at-age data for northern pikeminnow, smallmouth bass, and walleye were combined for the 2009, 2010, and 2011 sampling seasons in order to increase our sample size and to reduce the amount of variation associated with aging fish. Aging data should yield a mean length-at-age trend that increases as a group of fish ages. This trend was not the case for all our predatory fish 10 years or older. Therefore, length-at-age frequencies for fish determined to be 10 years or older omitted data for fish that had a mean length of less than that of fish estimated to be 1 year younger. Decreasing confidence in age estimates for older fish when scales are used have been noted in other studies (Donabauer 2010, Erickson, 1983; Isermann and others, 2003; Hanchin, 2011).

Diet Analysis

Diet analysis was conducted in a laboratory setting using two different methodologies (SOPs available upon request), one for northern pikeminnow and another for bass and walleye. The methodology for processing northern pikeminnow stomachs involved pancreatin digestion or maceration. Pancreatin digestion of northern pikeminnow gut contents works because a northern pikeminnow’s stomach digests at a high pH, leaving the mineral content of bones untouched. Bass, walleye, and other piscivorous fish use acidic digestion, which demineralizes prey fish bones leaving flaccid wisps that are completely dissolved by pancreatin. Therefore, bass and walleye diets were preserved in ethanol and analyzed apart from northern pikeminnow diets.

A major difference in the two methodologies is that prey fish are identified by diagnostic bones post-pancreatin digestion for northern pikeminnow and, therefore, are not identifiable into more distinct categories (such as salmonid, non-salmonid) for pre-digestion prey weights. Northern pikeminnow diets were macerated with pancreatin and sodium sulfide nonahydrate between 40°C and 45°C. Pancreatin digests most tissue, but does not disintegrate or emulsify fat completely. A 1.5- to 2.0-molar solution of NaOH (lye) was, therefore, used to dissolve the remaining fat. Next, samples were rinsed through a 425-μm (#40) mesh sieve. The diagnostic bones we used to identify and to enumerate fishes (cleithra, dentaries, hyomandibular arches, pharyngeal arches, otoliths, and opercles) are paired structures on the left and right sides of the fish. Therefore, bones were counted in pairs so as not to inflate the number of fish counted. For example, if we counted three left and two right salmon or steelhead cleithra of the same size, the total number of fish was recorded as three. For each individual northern pikeminnow diet that contained fish, the proportion of each prey fish count post-maceration was averaged to represent the mean percent composition of all diets analyzed.

Diet contents were separated into five categories: fish, crayfish, mollusks, insects, and miscellaneous (unidentifiable material, and vegetation /inorganics) and weighed. The most common item in northern pikeminnow stomachs is the miscellaneous category, consisting primarily of a mucilaginous substance that presumably is digesta and sloughed intestinal intima. Each prey category was compiled and weighed for each northern pikeminnow pre-maceration; after weighing, all diet items were returned to the sample bag to be macerated. Prey items in smallmouth bass and walleye diets were identified to the lowest practical taxon and blotted wet weights were recorded.

For each individual predator diet, the proportion of each prey item weight was averaged to represent the mean percent composition of all diets analyzed. Prey items were further identified in each prey category, wherever possible. Prey fish categories included: Unknown fish species, Unknown salmonids, Unknown non-salmonids, Chinook, Whitefish spp., Salmon/Steelhead, Northern Pikeminnow, Peamouth, Chiselmouth, Redside Shiner, Dace spp., Cyprinid spp., *Cottus* spp., Threespine Stickleback, Sucker spp., Walleye, *Lampetra* spp., Sandroller, and *Lepomis* spp. The unknown salmonid group consists of fish that could not be further identified and could include salmon, trout, char, or whitefish. The salmon/steelhead group includes fish in the genus *Oncorhynchus*. Fish in that group cannot be identified beyond genus because their diagnostic bones are too similar. Chinook salmon were only identified as such because of the presence of coded wire tags or PIT tags. Zooplankton diet categories included: *Daphnia* spp., Bosminidae, Chydoridae, Copepoda, Ostracoda, and Sididae. Insect diet categories included: Insect parts, Diptera, Trichoptera, Lepidoptera, Ephemeroptera, Odonata, Orthoptera, Hemiptera, Hymenoptera, Coleoptera, Plecoptera, and unknown insects. Other diet items include: Amphipoda, Isopoda, Mollusca, Annelida, and Arachnida. For each individual predator diet that contained fish, the proportion of each prey fish was averaged to represent the mean percent composition of all diets analyzed.

Data Analyses

Analysis of the data was organized into study year, data collection methodology (that is, Burley and Poe or predator indexing), and sampling period (such as overall, spring, and summer), as defined in the section, “Sample Allocation.” Metrics for relative abundance, consumption, and predation were calculated for these periods using the methodology described below for northern pikeminnow and smallmouth bass. Because so few other predators (such as walleye, largemouth bass, and channel catfish) were captured during our efforts, and those that were captured were from a limited geographic area, we determined that developing consumption or predation indices for these species was of limited utility.

Relative Abundance Indices

To estimate the relative abundance indices of northern pikeminnow (> 250 mm) for the Burley and Poe efforts, the density index (DI_{BandP}) was estimated as the proportion of nonzero catches (Counihan and others, 1999*)*. To compare this index to the original values presented in Burley and Poe (1994), we calculated the proportion of nonzero catches from the density index they used:

$$1/\sqrt{proportion\ of\ \ effort\ with\ zero\ catch} \quad (1)$$

For all other efforts, we estimated the relative abundance of predatory fish by estimating the *CPUE* (number captured per 10 min of electrofishing) of northern pikeminnow (> 170 mm), smallmouth bass (> 150 mm), and walleye (> 180 mm) as the DI_{CPUE} (Ward and others, 1995).
The abundance index (*AI*) for each species was then estimated to be:

$$AI_i = DI_i \times S_i \qquad (2)$$

where:

AI_i = Index of predator abundance in sampling area *i*,
DI_i = Index of predator density in the sampling area *i*, and
S_i = Surface area (ha) for sampling area *i*, adjusted to include shoreline areas less than 3 m in depth.

To compare our results with those of Burley and Poe, we recalculated the abundance indices they presented based on current estimates of S_i. Estimates of S_i were derived using the GIS of the study area to estimate the area within each of the strata sampled in 2009–10 that are less than 3 m in depth (table 1).

Consumption Indices

Previous studies have demonstrated the analytical techniques we used to develop consumption indices for northern pikeminnow (CI_{NPM}) and smallmouth bass CI_{SBM} (Ward and others, 1995; Ward and Zimmerman, 1999). Ward and others (1995) based their consumption index on the concept of meal turnover-time (Windell, 1978; Rieman and others, 1991). We adopted the methods of Ward and others (1995) to estimate consumption of juvenile salmonids by northern pikeminnow, using the following consumption index:

$$CI_{NPM} = 0.0209 \cdot T^{1.60} \cdot W^{0.27} \cdot (n \cdot GW^{-0.61}) \qquad (3)$$

where:

T = water temperature (°C),
W = predator weight (g),
GW = mean total gut weight (g), and
n = mean number of salmonids per northern pikeminnow.

We used the consumption index developed by Ward and Zimmerman (1999), who modified the relations developed by Rogers and Burley (1991) to describe smallmouth bass evacuation time as the consumption index for smallmouth bass as:

$$CI_{SMB} = 0.0407 \left(e^{0.15T} \cdot W^{0.23} \cdot \left(n \cdot GW^{-0.29} \right) \right) \qquad (4)$$

where:

T = water temperature (°C),
W = predator weight (g),
GW = mean total gut weight (g), and
n = mean number of salmonids per smallmouth bass.

Predation Indices

We then combined the consumption indices with the abundance indices to calculate the predation index (Ward and others, 1995) as:

$$PI_i = AI_i \cdot CI_i \tag{5}$$

where:

PI_i = predation index for sample *i*,
AI_i = abundance index for area *i*, and
CI_i = consumption index for sample *i*.

For the comparisons to Burley and Poe, the PI_i was estimated according to the procedures in their report (Burley and Poe, 1994). The predation index values for the predator index sampling in 2009 and 2010 were estimated for each electrofishing effort and then averaged by strata. Reservoir-wide estimates were summed across strata as done by Burley and Poe (1994) and as a mean for a stratified random sample as done by Cochran (1977) for the predator index sampling in 2009 and 2010.

Bioenergetics

The advent of bioenergetics modeling has enabled researchers to estimate the impacts of predators on biota within a system (Hanson and others, 1997). Using data from standard food habit studies that examine instantaneous diets, bioenergetics modeling allows a researcher to estimate energetic requirements of individual or predator cohorts (Brandt and Hartman, 1993). We used the Fish Bioenergetics 3.0 model (Hanson and others, 1997) to estimate prey consumption for northern pikeminnow and smallmouth bass of different ages during spring and summer periods. The bioenergetics model uses the following input parameters: water temperature, predator diet, prey energy density, predator size (weight), predator abundance, and predator age distribution, and works on the generalized formula:

Energy consumed = Respiration + Waste + Growth.

This can be further divided into a more specific mass balance equation (Hanson and others, 1997): Consumption = (respiration + active metabolism + specific dynamic action) + (egestion + excretion) + (somatic growth + gonad production).

The Fish Bioenergetics software (Hanson and others, 1997) contains many parameter sets for different fishes, but lacks the parameters necessary to model the bioenergetics of northern pikeminnow. Petersen and Ward (1999) compiled the physiological parameters necessary to model the energetic requirement of northern pikeminnow for various situations. Using the available parameters, we constructed model simulations in the Fish Bioenergetics software for northern pikeminnow in the PRP. The model output is based on total weight of prey items consumed by each predator cohort. For our modeling simulations, a cohort is a group of fish of the same age class and species, and the modeled population output is the sum of all individual cohort model runs for each species.

Temporal, biological, and environmental parameters are required to fully populate the bioenergetics model. To estimate the energetic requirement of the fish species evaluated during our study period, water temperature data were obtained from the Grant County Public Utility District Natural Resource link (*http://www.gcpud.org/naturalResources/fishWaterWildlife/waterqualityMonitoring.html*). The diet composition of individual predators throughout the study period was obtained from our field collections. The proportion of a diet for an individual was calculated by dividing the sum of each individual prey item by the total weight of the diet contents for that individual. Diet data from field collections were compiled by day, species, and age class, and were averaged for each model day. Diet contents were then assigned constant energy densities using various literature sources (Cummins and Wuycheck, 1971; Stewart and others, 1983). For model simulations, we estimated the Bioenergetics software p-value (proportion of maximum consumption) based on hypothetical consumption rates that would likely have been experienced in the field. We used a p-value of 0.5 for both smallmouth bass and northern pikeminnow in the PRP and conducted model runs assuming fish consumed 50 percent of their maximum consumption rate. Values commonly range between 0.2 and 0.6 estimated from observed growth of fishes in the field for bioenergetics modeling (Dieterman and others, 2004; Mateo, 2007; McCarthy and others, 2009).

We used our estimated ages of the fish collected to partition the proportion of the modeled population into age classes (table 2) or individual cohorts for the bioenergetics modeling. The age data was further used to determine mean length at age, and the mean weight of each age class for both smallmouth bass and northern pikeminnow. Because we did not have an accurate population estimate for the species of interest, we used our field data to estimate a hypothetical population for modeling purposes. The total numbers of predators captured were used for the population estimate. Modeling was further partitioned into spring and summer periods for the 2009 and 2010 study years, relative to our study periods based on juvenile salmonid migration times.

Results

River Conditions

River discharge and water temperatures in 2009 were lower than the 10-year average from mid-June to early-July, and remained lower than the 10-year average for the remainder of the field season (fig. 3). Conversely, in 2010, river discharge generally was higher from mid-June to early-July, and consistently higher than the 10-year average. Water temperatures in 2009–10 were similar to the 10-year average.

Catch Data

Northern Pikeminnow

Northern pikeminnow were captured during 2009 Burley and Poe sampling efforts, and also during 2009 and 2010 predator index sampling efforts. During the Burley and Poe sampling, we captured and measured 1,225 northern pikeminnow ranging from 43 to 580 mm in total length in Priest Rapids and Wanapum Reservoirs (fig. 4). Similar overall numbers of fish were captured between the spring (n=601) and summer (n=624) periods. The fish captured during the spring period, ranging from 43 to 531 mm in total length, were slightly smaller than fish captured during the summer efforts, ranging from 50 to 580 mm in total length. The *CPUE* of northern pikeminnow greater than 250 mm in total length during the 2009 Burley and Poe sampling was highest in the Rock Island tailrace and generally was higher in Wanapum reservoir than in Priest Rapids reservoir for both spring and summer periods (table 3).

The predator index sampling during 2009 covered a longer time period (overall, May 1–August 27) than during Burley and Poe, but fewer fish were captured (n=1,025). The northern pikeminnow captured ranged from 40 to 567 mm in total length (fig. 5); smaller than those captured during Burley and Poe efforts. During the spring, we captured 392 northern pikeminnow ranging from 45 to 520 mm in total length. Fewer fish were captured during the summer (n=361), but the overall total lengths were larger, as seen during the Burley and Poe sampling (ranging from 61 to 539 mm in total length) (fig. 5). The *CPUE* of northern pikeminnow greater than 170 mm during 2009 predator index sampling was highest in Rock Island tailrace during the spring, and generally was higher in the Wanapum reservoir than in the Priest Rapids reservoir during the spring and summer periods (table 3).

Sampling started and ended later in 2010 than in 2009. However, we captured and measured the greatest number of northern pikeminnow in 2010 compared to all other sampling efforts (n=2,581). The northern pikeminnow captured ranged from 33 to 581 mm in total length (fig. 6). During the spring period, we captured 544 northern pikeminnow ranging from 42 to 510 mm in total length; in the summer period, we captured almost double that number with 990 northern pikeminnow ranging from 42 to 581 mm in total length (fig. 6). The *CPUE* of northern pikeminnow greater than 170 mm in total length during the 2010 spring period was highest in the Priest Rapids tailrace near-BRZ reach, followed by the Wanapum mid-reservoir (table 4). For the summer period, the *CPUE* was highest in the Wanapum mid-reservoir followed by the Priest Rapids tailrace near-BRZ reach.

The mean lengths of northern pikeminnow captured during sampling efforts varied by strata in the PRP (figs. 7–9). Generally, we found that larger northern pikeminnow were more prevalent near the dams than in the mid-reservoir reaches. During the Burley and Poe sampling, the largest mean northern pikeminnow lengths were from fish in the forebay of Wanapum Dam and the tailrace of Priest Rapids Dam (fig. 7). This trend was evident in both the spring and summer periods. For the 2009 and 2010 predator indexing efforts, the largest mean northern pikeminnow lengths were from fish in the tailrace and forebay of Wanapum Dam and in the tailrace of Priest Rapids Dam (figs. 8 and 9).

Aging analysis was completed for all northern pikeminnow (fig. 10) captured in 2009, 2010, and 2011 in the PRP. The analysis indicated that ages of the captured fish ranged from 1 to 24 years (median age = 3 years). The mean length at age was estimated for all age classes (fig. 11). For all northern pikeminnow captured in the Priest Rapids reservoir, the relationship between length and weight is described by the equation:

$$\log_{10}(\text{weight}) = 2.9974(\log_{10}\text{length}) - 5.1203;\ r^2 = 0.9625;$$

For Wanapum Reservoir the relation is described by:

$$\log_{10}(\text{weight}) = 3.0422(\log_{10}\text{length}) - 5.2224;\ r^2 = 0.9813.$$

Smallmouth bass

We captured smallmouth bass in the PRP during the Burley and Poe efforts in 2009 and during the predator indexing efforts in 2009 and 2010. We generally captured fewer smallmouth bass than northern pikeminnow for all sampling efforts. We captured and measured 272 smallmouth bass during the Burley and Poe sampling in the PRP ranging from 35 to 518 mm in total length (fig. 12). In the spring, we captured 168 smallmouth bass ranging from 51 to 517 mm in total length and in the summer, we captured 104 smallmouth bass ranging from 35 to 518 mm in total length. The *CPUE* of smallmouth bass greater 150 mm in length in the spring and summer Burley and Poe sampling was highest in the forebay of Priest Rapids Dam and in the mid-reservoir section of Priest Rapids Reservoir (table 3).

Fewer smallmouth bass were captured in the 2009 predator indexing sampling than during the Burley and Poe sampling. During predator index sampling, we captured 232 smallmouth bass in Priest Rapids and Wanapum Reservoirs that ranged from 21 to 479 mm in total length (fig. 13). In the spring, we captured 48 bass that ranged from 105 to 467 mm in total length. The capture number more than doubled for the summer period (n=112), with smallmouth bass that ranged from 112 to 450 mm in total length (fig. 13). The *CPUE* for predator indexing was highest in the forebay BRZs of Priest Rapids and Wanapum Dams in the spring and summer periods (table 3).

The 2010 sampling resulted in the highest number of smallmouth bass being captured out of all the sampling efforts; this followed the same trend as the northern pikeminnow capture results. We captured and measured 687 smallmouth bass ranging from 46 to 515 mm in total length in Priest Rapids and Wanapum Reservoirs (fig. 14). In the spring sampling, we captured 149 bass ranging from 71 to 469 mm in total length; in the summer sampling, we captured 294 bass ranging from 73 to 515 mm in total length (fig. 14). The *CPUE* of smallmouth bass greater than 150 mm in length in the spring and summer periods was highest in the forebay areas of Priest Rapids and Wanapum Dams (table 4).

We also observed spatial trends in the mean length of smallmouth bass captured across the strata sampled in 2009 and 2010 (figs. 15–17). During Burley and Poe spring 2009 sampling, the largest mean smallmouth bass lengths were from the tailrace and forebay of Wanapum Dam and the tailrace of Priest Rapids Dam (fig. 15). A similar trend was evident in the Burley and Poe summer sampling with the exception that only one bass was captured in the Priest Rapids tailrace. For the 2009 and 2010 predator index sampling, the largest mean smallmouth bass lengths were from the Priest Rapids mid-reservoir and tailrace reaches, and the Wanapum forebay and mid-reservoir reaches (figs. 16 and 17).

Our aging analyses of smallmouth bass (fig. 18) captured in 2009, 2010, and 2011, in the Priest Rapids Project indicate that the ages ranged from 1 to 14 years (median age = 3 years). The mean length at age was estimated for smallmouth bass and is presented in figure 19. For all smallmouth bass captured in Priest Rapids Reservoir, the relation between length and weight is described by the equation:

$$\log_{10}(\text{weight}) = 3.1151(\log_{10}\text{length}) - 5.1566;\ r^2 = 0.9864;$$

for Wanapum Reservoir, the relation is described by:

$$\log_{10}(\text{weight}) = 3.1417(\log_{10}\text{length}) - 5.2164;\ r^2 = 0.9829.$$

Walleye

Very few walleye were captured across all sampling efforts and study years. During the Burley and Poe sampling, we captured 13 walleye in Priest Rapids and Wanapum Reservoirs, ranging from 100 to 775 mm in total length (fig. 20). In the spring, we captured seven walleye that ranged from 425 to 775 mm in total length; in the summer, we captured six walleye that ranged from 100 to 481 mm in total length. During the 2009 predator index sampling, we captured 18 walleye in Priest Rapids and Wanapum Reservoirs that ranged from 165 to 685 mm in total length (fig. 21). Of these only 3 walleye were captured in the spring period, while 15 walleye were captured in the summer, ranging from 165 to 685 mm in total length (fig. 21). We captured more than three times as many walleye in 2010 (n=59), ranging from 184 to 786 mm in total length (fig. 22). In the spring 2010 predator index sampling, we captured 15 walleye ranging from 200 to 771 mm in total length, and in the summer, we captured 21 walleye ranging from 194 to 693 mm in total length (fig. 22). The *CPUE* for walleye was low in both the spring and summer for all sampling periods (< 0.005) in 2009 and 2010, with the highest values from the Priest Rapids BRZ (*CPUE* = 0.01) in both the spring and summer.

Our aging analyses of walleye (fig. 23) captured in 2009, 2010, and 2011 in the Priest Rapids Project indicate that walleye ages range from 1 to 16 years (median age = 3 years; *n*=34). The mean length at age relation for walleye is described in figure 24**.** We did not develop a relationship between length and weight or examine the spatial variability in mean lengths because so few walleye were captured.

Diet Analyses

Northern Pikeminnow

When we evaluated the diets of northern pikeminnow, we found the highest proportion of the diet was consistently the miscellaneous prey category. That is, the highest proportion by weight could not be identified into any of the other prey categories during the pre-maceration process. Of the diets collected as part of the Burley and Poe spring sampling, the miscellaneous prey category constituted on average 59 percent, with insects as the next dominant item at 31 percent, followed by fish (6 percent), mollusks, and crayfish (fig. 25). The diets from the Priest Rapids tailrace reach had the highest percentage of fish (18 percent) in the spring sampling, followed by the Priest Rapids forebay (10 percent), and Rock Island tailrace (6 percent). For the summer sampling, the diet proportions were similar to the spring with 61 percent as miscellaneous, 30 percent insects, and 6 percent mollusks, followed by fish (1.5 percent) and crayfish (fig. 25). The proportion of fish (6.5 percent) was highest in the tailrace of Rock Island Dam in the summer (fig. 25). Of the diets with fish prey items captured during Burley and Poe sampling, northern pikeminnow containing salmon occurred in four strata in the spring (Priest Rapids tailrace, Wanapum tailrace, Wanapum forebay, and Wanapum mid-reservoir), and no salmon were observed in the diets in the summer.

In the 2009 predator index sampling, we observed similar trends with fish constituting a relatively minor component of the diets of northern pikeminnow captured, but being more prevalent near the dams (fig. 26). Sampling fish comprised on average 2 percent of the diet in the spring and 3 percent in the summer. Percentages of fish prey items were highest in the Wanapum forebay BRZ (11 percent) in the spring, and in the tailraces of Priest Rapids (13 percent) and Wanapum (13 percent) dams (fig. 26) in the summer. Of the northern pikeminnow with fish in their diets, salmon were present in low proportions in the Priest Rapids tailrace only in spring (0.44) and summer (0.25).

Although fish were a relatively minor component of the northern pikeminnow diet in the 2010 predator index sampling, they were again most prevalent in the diets of northern pikeminnow captured in the reaches nearest to Priest Rapids, Wanapum, and Rock Island Dams (fig. 27). In the spring sampling, the average proportion of the diet consisting of fish (16 percent) was higher than in all of the 2009 sampling efforts. However, the most dominant prey items were still in the miscellaneous category (61 percent), followed by insects (19 percent), and then fish, mollusks, and crayfish. In the summer, the average proportion of diet consisting of fish was much lower (1.1 percent), with most reaches sampled having no northern pikeminnow captured with fish in their diets (fig. 27). The proportion of the fish prey that was salmon in northern pikeminnow was variable among strata, and was highest in the tailrace of Wanapum Dam (fig. 28). The occurrence of salmon within the fish prey items generally was higher in the tailrace areas than in the forebay and mid-reservoir areas, and was higher in the spring than in the summer (fig. 28).

Smallmouth Bass

The diets of smallmouth bass generally had a much higher proportion of fish prey items than northern pikeminnow diets. For smallmouth bass collected during the spring Burley and Poe sampling, fish constituted the highest percentage (84 percent) on average of the diet. The same result was seen for the summer sampling, with fish constituting an average of 67 percent of the smallmouth bass diet. This trend was consistent across most of the reaches sampled in the spring and summer periods, with the exception of the Priest Rapids forebay (fig. 29). Of the smallmouth bass diets with fish, salmon were documented only in the Priest Rapids mid-reservoir reach in the spring.

During the 2009 predator index sampling, fish generally were generally the most prevalent diet item in smallmouth bass. On average, fish were 55 percent of the spring smallmouth bass diet, and 76 percent of their summer diet. Fish were the most prevalent smallmouth bass diet item in all reaches where diets were collected, with the exception of the Priest Rapids tailrace BRZ (fig. 30). Juvenile salmonids were found in the diets of bass collected in the forebay of Priest Rapids Dam and in the Priest Rapids mid-reservoir reach in the spring. In the summer, salmon were found in the diets of bass collected in four reaches: Priest Rapids tailrace, Priest Rapids forebay, Priest Rapids mid-reservoir, and Wanapum mid-reservoir. In all cases, the proportion of fish in the diets that were salmon never exceeded 0.25.

As in the 2009 sampling, fish generally were the dominant prey item for smallmouth bass captured in 2010 (fig. 31). On average, fish were 83 percent of the diet in the spring and 57 percent of the diet in the summer. This trend was consistent across all reaches with the exception of crayfish that were the dominant prey item in the summer in the forebay BRZs for both Priest Rapids and Wanapum Dams. fig. 31). Salmonids were observed in the diets of smallmouth bass captured in eight reaches concentrated in the forebays and mid-reservoir reaches of Priest Rapids and Wanapum Dams in 2010.

Walleye

The diets of walleye, collected during the Burley and Poe sampling and the 2009 and 2010 predator index sampling, consisted primarily of fish. The proportion of fish in the diets was mostly near 1, with the exception of a fish collected in the Rock Island tailrace reach in 2009 that had no fish in its stomach. Otherwise, the proportion of walleye diets that were fish was never less than 0.89. The proportion of fish in the diets of walleye that were salmon was concentrated in the tailrace of Priest Rapids Dam, and ranged from 0.5 to -1. In 2010, the distribution of walleye collected that had salmon was higher (fig. 32). The proportion of salmon in the diets of walleye captured in 2010 was highest in the tailrace of Priest Rapids Dam in the spring and in the tailrace of Wanapum Dam in the summer (fig. 32).

Predation Indices

Northern Pikeminnow

Northern pikeminnow predation indices estimated for the Burley and Poe sampling were very low, and were much lower than those estimated in 1993 (Burley and Poe, 1994). Predation index values for 2009 ranged from 0 to 31 in the spring, and no predation was evident in samples from the summer (table 5). The predation index estimates we calculated based on the data from Burley and Poe (1994) ranged from 0 to 71 in the spring and 0 to 120 in the summer. For the 2009 predator index sampling, the estimated predation indices that used *CPUE* as the density index also indicated very low predation in the study area in the spring and summer with only the Priest Rapids tailrace being greater than zero (table 6). The northern pikeminnow predation indices for 2010 were higher and more widely distributed throughout the study area than in 2009, ranging from 0 to 1.918 (table 7). Northern pikeminnow predation in 2010 was highest in the Wanapum mid-reservoir (1.918, SE=1.211) and Wanapum tailrace (1.018, SE=1.018) reaches in the spring, and were less than 0.196 in the summer with evidence of predation occurring only in the Rock Island tailrace and the Priest Rapids mid-reservoir reaches.

Smallmouth Bass

The predation indices for smallmouth bass during the 2009 predator index sampling indicated that predation of salmonids in the study area was low in all areas in the spring and summer (table 6). In the spring, predation indices were less than 0.240 for all reaches, and predation of salmonids was documented in the Priest Rapids mid-reservoir and the Priest Rapids forebay reaches (PF1 and PF0) only. For the summer, predation of salmonids was documented in the Priest Rapids tailrace near-BRZ, the Priest Rapids mid-reservoir, the Priest Rapids forebay BRZ, and the Wanapum mid-reservoir, with the highest index value from the Priest Rapids tailrace (1.073, SE=1.073). In 2010, our results suggest that predation of juvenile salmonids by smallmouth bass was more widespread than in 2009 (table 7). In the spring of 2010, predation was highest in the Priest Rapids mid-reservoir reach (5.940, SE 2.731), followed by the Wanapum forebay BRZ (0.90, SE=0.90) and the Priest Rapids forebay near-BRZ reach (0.114, SE=0.114). In the summer, predation was again highest in the Priest Rapids mid-reservoir (1.760, SE=1.152), the Priest Rapids forebay reach (1.055, SE=0.776), and the Wanapum forebay BRZ and near-BRZ reaches. In the spring and summer, predation was higher in the forebay and mid-reservoir reaches than in the tailraces.

Bioenergetics

We observed seasonal differences in total and fish consumption by northern pikeminnow and smallmouth bass in 2009 and 2010. The output from the bioenergetics model results indicated that the northern pikeminnow modeled population (*n*=928) consumed 6,447 g of fish in the spring 2009 (fig. 33), which was approximately 15 percent of their diet by weight (fig. 34). In the summer, the weight of fish consumed (5,002 g) was 3 percent less than in the spring sampling period. In 2010, the modeled population (*n*=1,118) consumed 11,865 g of fish in the spring (9 percent of their diet) (fig. 34) and 20,995 g in the summer (fig. 33). Even though the proportion of the modeled population diet that was composed of fish was only 3 percent, the total grams of fish consumed by northern pikeminnow in the summer, was much higher (fig. 34).

A higher proportion of the diets of smallmouth bass were composed of fish than northern pikeminnow. We estimated smallmouth bass (*n*=165) consumed 1,124 g of fish in spring 2009 and 4,192 g in summer 2009 (fig. 35). This comprised approximately 60 and 40 percent of their total diet (fig. 36). We further estimated that 168 g (9 percent of diet) of salmonids were consumed in the spring and 801 g (8 percent of diet) in the summer. In 2010, the modeled population of smallmouth bass (*n*=372) consumed 1,582 grams (55 percent of diet) of fish in the spring and 12,448 g (48 percent of diet) in the summer. The salmonid consumption was estimated to be 354 g (12 percent of diet) in the spring and 2,667 g (11 percent of diet) in the summer.

Discussion

The predation indices estimated from the Burley and Poe sampling in 2009 were much lower than those we calculated from the 1993 data of Burley and Poe (1994). This may be a result of efforts to reduce the abundance of northern pikeminnow in the Priest Rapids project by physically capturing and removing them (Garner and Keeler, 2008). The reduced predation may be, in part, a result of changes in the northern pikeminnow population characteristics brought about by the northern pikeminnow removal program. The mean total lengths we observed in the study reaches were much lower than those reported in Burley and Poe (1994). For instance, Burley and Poe (1994) reported a mean fork length of 436 mm for northern pikeminnow captured in the Wanapum Dam tailrace; the mean total length of northern pikeminnow we captured in this reach was less than 150 mm in both the spring and summer periods. Grant PUD also has noted a decrease in the average size of northern pikeminnow captured in 2011 compared to previous years but note that the reduction may be due to gear bias (Curt Dotson, Grant County Public Utility District, written communication 2011). However, our results summarizing data from northern pikeminnow captured using a different gear, electrofishing, corroborate Grant PUD's observations.

Reductions in the size of northern pikeminnow may be resulting in a decrease in predation because consumption of juvenile salmonids increases with the size of northern pikeminnow (Vigg and others, 1991). Rieman and Beamesderfer (1991) suggest that continuous exploitation of northern pikeminnow greater than 250 mm in fork length would result in a 50 percent or greater reduction in predation. When evaluating the effects of the pikeminnow removal program, Zimmerman and Ward (1999) documented post-removal program predation index values that were 44–91 percent lower than mean values prior to the implementation of the removal program throughout the lower Columbia River basin. Zimmerman and Ward (1999) note that the observed declines in relative predation were consistent with changes in the size and age structure of northern pikeminnow populations associated with the Northern Pikeminnow Management Program; that is, there was a shift towards smaller, younger individuals (Knutsen and Ward, 1999). Although the overall mean size of northern pikeminnow captured as part of our electrofishing efforts has decreased compared to 1993, we observed similar trends in mean length in the longitudinal reaches. Specifically, we observed a trend of larger fish in reaches nearest the dams, as did Burley and Poe (1994), suggesting that larger fish within the population still are found near dams. Our analysis of the diets of northern pikeminnow also suggests that the fish captured near Wanapum and Priest Rapids Dams were more likely to have fish as a component of their diets, and that salmon were found in their diets.

Very low northern pikeminnow predation indices were observed in 2009 for both the Burley and Poe and the predator index sampling, despite differences in the diel timing of these efforts. The electrofishing efforts conducted during the predator indexing began no earlier than 30 min after sunset, while the Burley and Poe electrofishing began 90 min before sunrise and continued sampling until a target catch of 15 northern pikeminnow were captured from each section sampled. That a similar result was attained for the different approaches suggests that the low levels of predation observed during the 2009 Burley and Poe efforts were not a function of the timing of the sampling. Although conducting electrofishing at night during the 2009 and 2010 predator index sampling versus early-morning resulted in a higher *CPUE* in most reaches and seasons for both northern pikeminnow and smallmouth bass, the increased collections did not result in higher predation index values. Furthermore, the timing of the summer 2009 Burley and Poe efforts were conducted past the peak migration period for sub-yearling Chinook salmon. Another factor that may have affected our results was that we were tagging and releasing northern pikeminnow with the intent of recapturing them; which occurred infrequently enough that we discontinued the efforts in 2010. Because there were so few northern pikeminnow captured in 2009 that were in the larger size categories, releasing the few we did capture likely resulted in us releasing predators that were the most likely to contain salmonids in their diets. The release of predators as part of our tagging effort could have contributed to the lack of documented predation in the summer 2009. However, there was little evidence of predation from our sampling efforts in the summer 2010 in many of the reaches.

We observed a shift in the diet composition of northern pikeminnow collected in the PRP from 1993 to the present (2011). Burley and Poe (1994) reported that the average proportion of northern pikeminnow diet that was fish was 0.66 in the spring and 0.35 in the summer; the largest proportion we observed was less than 0.2. The shift towards insects and food items other than fish may be a reflection of the reduction in the average size of northern pikeminnow captured; the shift is not likely the result of a reduced prey base because of the constant supply of hatchery juvenile salmonids migrating through the PRP. The ecological implications of the shift to a greater portion of northern pikeminnow being smaller are unclear and beyond the scope of this report. However, if our observations are indicative of the diets of most of the northern pikeminnow population in the study area, than it seems reasonable to assume that there would be consequences of a shift away from piscivory.

The results of our study suggest that there are areas within the PRP that can be targeted to mitigate the predation of smallmouth bass on juvenile salmonids. However, our results do not suggest that juvenile salmonids were a major constituent in the diet of smallmouth bass. Despite the higher proportion of fish observed in the diets of smallmouth bass, the predation indices during the 2009 predator index sampling supplied little evidence to suggest that juvenile salmonid predation by bass was very prevalent in the study area. The fact that juvenile salmon do not constitute a significant portion of the diet of smallmouth bass also has been observed in other studies. For instance, Naughton and others (2004) observed that juvenile salmonids constituted a maximum of 11 percent of the diets of smallmouth bass captured in the forebay of the Lower Granite Dam, Snake River, and only 5 percent in other areas of the Snake and Clearwater Rivers. Similar to our results for northern pikeminnow, predation indices were higher and more widespread throughout the study area for smallmouth bass in spring 2010 than in 2009. However, dissimilar to what we observed for northern pikeminnow, predation was high and more widespread in summer 2010 suggesting that smallmouth bass predation of sub-yearling Chinook salmon may be higher than predation of northern pikeminnow. In 2010, predation by smallmouth bass was highest in the Priest Rapids mid-reservoir reach and concentrated in the forebay areas of Priest Rapids and Wanapum Dams. Similarly, Naughton and others (2004) observed that the highest monthly consumption rates of juvenile salmonids by smallmouth bass were in the forebay areas in April 1996 and in the forebay BRZ in July 1997 at Lower Granite Dam, Snake River. Our findings also agree with those of Vigg and others (1991), who found that in the John Day Reservoir, Columbia River, consumption of juvenile salmonids by smallmouth bass was highest in the forebay. Ward and Zimmerman (1999), who found smallmouth bass consumption of juvenile salmonids usually was highest in the summer in the forebay of John Day Reservoir, and also was evident downstream of Bonneville Dam (rkm 190–197). Ward and Zimmerman (1999) also observed that consumption of juvenile salmonids by smallmouth bass was highly variable across reservoir reaches (for example forebay, mid-reservoir, and tailrace areas) and seasons and generally was low.

The results of our diet analyses for smallmouth bass suggest that fish were a more significant constituent in the diets of smallmouth bass compared to northern pikeminnow. Our diet analysis results are consistent with those previously reported for the study area. Burley and Poe (1994) reported that the diets of smallmouth bass collected in their survey of the mid-Columbia River consisted of 87 percent fish, 12 percent crustaceans, and 1 percent other items. The diet composition of smallmouth bass collected in the study area, however, seems to differ from the observed diets of smallmouth bass collected in other reaches of the Columbia and Snake Rivers, where smallmouth bass are relatively more abundant. Specifically, smallmouth bass in other reaches of the Columbia and Snake Rivers have been shown to contain a higher percentage of crustaceans. For instance, Naughton and others (2004) reported that crustaceans comprised the highest percentage of the diet (by weight) of smallmouth bass 175–249 mm in total length at all locations they sampled in the Snake River in 1996 and 1997, except for the Clearwater River arm, where non-salmonid fishes were the primary prey item. For smallmouth bass 250–389 mm in total length, Naughton and others (2004) observed that crustaceans were the primary diet item in 1997. Burley and Poe (1994) reported that crustaceans constituted 42 percent of the dietary totals for smallmouth bass collected in the John Day Reservoir. Zimmerman (1999) also found that in spring and summer, the proportional weight of crayfish was highest in the impounded reaches of the Columbia (50 percent) and Snake (52 percent) Rivers. From the results reported from other areas of the Columbia and Snake Rivers, crustaceans appear to be an important diet item of smallmouth bass. If the diets of smallmouth bass we collected are reflective of the availability of crustaceans as prey items in the study area, perhaps the lack of crustaceans available as prey may be limiting smallmouth bass numbers in the study area. Low densities of crayfish, for instance, could be due to a lack of suitable habitat in the study area or predation by another fish species, such as the northern pikeminnow.

Low numbers of walleye have been reported by other researchers sampling fishes in the Priest Rapids Project. Despite sampling the study area for approximately 4 months during each of 2009 and 2010 with electrofishing gear, we captured very few walleye. Burley and Poe (1994) captured only 16 walleye in the study area during their sampling efforts in 1993. Electrofishing may be inefficient at capturing walleye. Schoenebeck and Hansen (2005) suggest that the relationship between electrofishing catch rates and population size may depend on habitat and may vary seasonally. However, Rogers and others (2003) found that the electrofishing catch rate of adult walleye was positively related to adult walleye density, and that the electrofishing catch rate of the total walleye population was positively related to total walleye density. In a study that examined the fish population structure in the Priest Rapids Project, only 35 walleye were captured despite their efforts to capture fish with various gear in addition to electrofishing gear (Pfeifer and others, 2001). Our catches suggest little walleye recruitment is occurring in the study area. Pfeifer and others (2001) collected some smaller individuals in the backwaters of the Wanapum reservoir and hypothesized that walleye may have spawned successfully in the reservoir or recruited from upstream sources, principally Lake Roosevelt; our catch data lead us to concur with this assessment.

Our bioenergetics modeling provided additional insight into the interactions of predators and juvenile salmonids in the study area. The bioenergetics modeling output indicates that fish (in general) and salmon (in particular) consumed by weight were greater in the summer than in the spring sampling periods, with the exception of the 2009 northern pikeminnow data; despite the results that the proportion of fish in the diets of northern pikeminnow and smallmouth bass were slightly less in the summer. We used daily diets and temperatures based on field-data collections, but held the proportion of maximum consumption constant across the study period as inputs into the bioenergetics model. Given that water temperatures increased in the summer migration period, we expect a concomitant increase in the energetic requirements of northern pikeminnow and smallmouth bass. Increased energetic demands can either be manifested as a loss in weight or an increase in either total consumption or increase in consumption of higher energy density prey items, such as fish to compensate for the higher energy demands. Our results show that northern pikeminnow and smallmouth bass total consumption and fish consumption by weight were higher in the summer periods, suggesting that predation effects from northern pikeminnow and smallmouth bass may be higher for juvenile salmon (namely, sub-yearling Chinook salmon) migrating in the summer sampling period. Our efforts to characterize the diets of northern pikeminnow and smallmouth bass in the study area and couple that information to a bioenergetics framework also could provide a way to assess the effects of existing removal programs, such as the Grant PUD northern pikeminnow removal program or the potential effects of new removal programs, such as those for smallmouth bass. For instance, one could model the predicted reductions in salmon eaten that would occur if a certain number of smallmouth bass were removed. Converting the reductions in the salmon eaten by weight to numbers of salmon would require assumptions regarding the relative proportions of various salmon species in the diet and the size distributions of the species. However, such a modeling exercise would provide context to the relative benefits expected in light of the cost of implementing such a program.

In 2009, our fish collection efforts resulted in the capture of few northern pikeminnow that were large fish (> 250 mm) with salmon in their stomachs. Thus, a result of using this data for bioenergetics modeling is that very few salmonids were consumed relative to other prey items in the modeling scenarios. However, this result is consistent with diet results from the northern pikeminnow removal program studies, where the proportion of northern pikeminnow diets that were smolts ranged from 0.8 to 1.8 percent for study years 2008 and 2009 (Garner and Keeler, 2008, 2009). In 2010, fish and salmon consumption was higher than in 2009, and likely was a result of the collection of more large predators with salmon in their stomachs in 2010. The estimated weight of fish consumed by northern pikeminnow may be underestimated as a result of the differences in their morphology and physiology and the processing of their stomach contents. Much of the material in a northern pikeminnow's stomach often consisted of miscellaneous material, some of which may have been salmonid prey items, but was not discernible during the pre-maceration as fish. Thus, even though salmonids and other fish can be detected in the diets post-maceration, a weight was not assigned to this prey item to be incorporated into the diet by weight analysis. Thus, the fish prey weights are underrepresented in the diet proportions for northern pikeminnow. We chose not to estimate a weight associated with bones found post-maceration, as we did not have a method to consistently assign a weight to these fish such that it would be represented properly with the other items found in the stomach at that time. Smallmouth bass have a true stomach and partitioned digestive tract, making the collection and identification of prey items considerably easier. Furthermore, the focus of this study was on predation indices, which use the counts of salmon found in stomachs to estimate predation and not a proportion of weights of salmon in the diet. In theory, diagnostic bones can be measured and used to estimate the size of a fish prey item at the time of consumption; however, this would then overestimate the weight of fish in the diet relative to the other items in which pre-consumption weights could not be estimated.

Our inability to access the BRZ areas of Priest Rapids and Wanapum Dams during the 2009 Burley and Poe sampling confounds comparisons to the results of the study conducted in 1993. Burley and Poe (1994) observed relatively high consumption index values in the BRZs. Ward and others (1995) and others have observed that predation is disproportionately large near dams, with 33 percent of the overall predation occurring in the BRZs. To attain access to the BRZs, it was necessary to coordinate with the dam operators so that discharge through the spillway could be discontinued to allow our electrofishing crews safe access to these areas. Despite our efforts at coordination, we encountered issues that precluded us from completing scheduled sampling events. In addition to coordination (miscommunication) and logistical issues (river flows that precluded the cessation of spill), during the 2009 and 2010 sampling seasons, we also encountered environmental conditions (such as high winds and river flows) that kept us from sampling the BRZ areas. Although we were unable to access the BRZs as part of the 2009 Burley and Poe sampling, we did have limited success as part of our other sampling efforts in 2009 and 2010.

We recommend that future predation studies in the Priest Rapids Project include a design scheme to allocate sample efforts to areas immediately adjacent to the BRZ areas, such as was done in 2010. The addition of a reach as close to the dam as possible but not in the BRZ allowed us to allocate efforts to areas thought to have higher consumption rates. We recommend retaining these reaches in future studies of predation in the PRP. The logistical constraint and safety issues we encountered trying to sample the BRZ areas biased estimates of these areas and, therefore, our assessment of predation in the study area. Studies examining predation in other reaches of the Columbia River have shown these areas can have high densities of predators (Ward and others, 1995). Evaluations of diets of northern pikeminnow collected off the transformer deck of the Wanapum Dam suggest these fish were more likely to contain salmonids than fish captured in other areas (Hardiman and others, 2012). That the predation indices for smallmouth bass were as high as they were for the forebay areas, especially for Wanapum Dam in the summer 2010 sampling, suggest relatively high levels of predation given the small area contained within that reach. Therefore, although the data we present suggest that predation is lower now (2010) than in 1993, our results suggest areas where control efforts for smallmouth bass could be focused if managers chose this as an action to mitigate the predation losses caused by smallmouth bass. Although our catch data for walleye suggest that this species is not abundant in the study area, our *CPUE* and diet analyses suggest areas where efforts to reduce the numbers of this species could be focused; the tailraces of Priest Rapids and Wanapum Dams are the areas where salmon were documented as being consumed by walleye.

Future predation indexing should either be conducted throughout the migration season, or the migration run timing variability because of environmental conditions or hatchery practices, and whether monitoring for predation of multiple species or of one particular species is desired need to be incorporated into the sampling design. Our efforts to repeat the timing of the 1993 study were confounded by the lack of reported criteria used to time the 1993 fieldwork. We surmised from the Burley and Poe (1994) report that the logistics of conducting such an effort over a large geographical area, much larger than the PRP, dictated to some extent when sampling was conducted in a particular river reach. In the absence of specific criteria, we chose to use water temperature as a criterion to begin sampling. Water temperature was selected as a criterion because of the bioenergetic implications of predator activity associated with changing temperatures (Cech and others, 1994) and our desire to sample under conditions similar to those of the original work. This decision resulted in our Burley and Poe summer sampling period occurring towards the end of the summer migration. Conversely, the 2009 and 2010 predator index sampling was structured so that sampling efforts mostly encompassed both the spring and summer migration periods. Sampling continuously throughout the juvenile salmonid migration in 2009 and 2010 allowed us to use juvenile salmonid passage information to place the predation sampling in the context of the migration of multiple juvenile salmonid species. How to strategize the timing of efforts to characterize predation in a particular area potentially is problematic for future efforts to examine predation in the PRP, especially for the purposes of determining trends over time.

Progress towards the development of a comprehensive long-term monitoring strategy was confounded by the redirect of the original objectives and tasks for the third and final year of this study to address predation of steelhead in 2011 (Hardiman and others, 2012). However, the PRCC has expressed continued interest in establishing a predation monitoring program in the Priest Rapids Project. Toward this end, we provide recommendations on how to proceed with the development of such a program. Monitoring programs that address a diverse set of objectives and information should occur nationwide and provide information on: regulation compliance, the status of aquatic resource conditions, effectiveness of management and regulatory programs, and policy planning and decision-making processes. Considerable expenditures have been made on such programs, often with mixed results and information provided. The U.S. Environmental Protection Agency (EPA) initiated the Environmental Monitoring and Assessment Program (EMAP) to advance the science of natural resource monitoring at regional and national scales. A significant task in the development of EMAP has been the statistical design and analysis methodologies to support meeting the goal of "with known confidence" in the design of monitoring studies. This effort has drawn heavily on existing survey design literature and applications in other areas.

The EPA reviewed past and current aquatic monitoring programs and identified some common characteristics of the design and analyses for such programs that fail—that is, do not meet the expectations for producing information regarding the status and trends of aquatic resources—and generally categorized them into four broad classes.

- The objectives for monitoring are not clearly, precisely stated and understood.
- Monitoring measurement protocols, survey design, and statistical analysis become scientifically out-of-date.
- Monitoring results are not directly tied to management decision-making.
- Results are not timely nor communicated to key audiences in terms they can understand.

Organizations such as EPA that conduct national and regional monitoring, and regional groups such as the Pacific Northwest Aquatic Monitoring Partnership (http://www.pnamp.org/) have identified key aquatic resource survey design components necessary for the formulation of a long-term monitoring effort. For instance, the EPA suggests that the following are necessary components for a monitoring program:

- Objectives stated precisely and quantitatively.
- Target population explicitly, precisely defined.
- Sample frame constructed that represents the target population.
- Decision on which survey design will best provide information to meet objectives.
- Selection of sampling sites using survey design.
- Implementation of consistent measurement protocols at sampled sites.
- Statistical analysis that matches survey design.

We suggest that the completion and inclusion of these components are necessary to enact a long-term monitoring activity for predation in the Priest Rapids Project. We strongly recommend that the PRCC pursue the completion of these key elements as they make progress towards the development of long-term monitoring programs.

We further recommend that the PRCC convene an expert panel that can work through the completion of these components. Participation in regional monitoring groups, such as the Pacific Northwest Aquatic Monitoring Partnership, can help to facilitate the process. Specifically, with respect to predation monitoring, decisions need to be made as to what metrics are necessary to assess status and trends in predation. We present a variety of metrics that are dependent on collecting predators and examining their diets. The metrics we present have been used before, but are labor-intensive and, therefore, costly (Petersen and Ward, 1999). Furthermore, the results of these types of studies are not always easily interpreted by key audiences; a characteristic listed above as being problematic for the success of a monitoring program. Metrics other than those used in this study may be as good or better at communicating the status and trends of the underlying driver behind assessing predation: the mortality of juvenile salmonids from fish predators in the Priest Rapids Project. For instance, survival goals have been established for the study area; perhaps survival metrics could serve as a metric to assess mitigation efforts to reduce predators in the study area. Increases in survival should be an indication of reduced mortality from fish predators. Alternately, various other methods have been used to justify and evaluate efforts to mitigate the effects of predators, including monitoring the movements of tagged predators and prey, measuring growth and fecundity of predators, and modeling how juvenile salmonid mortality varies with predator density, river flow, and other variables (Petersen and Ward, 1999). The formulation of an expert panel can help the PRCC work through the development and justification of metrics used to assess predation of juvenile salmon in the study area. However, valuable information can be derived from assessing the diets of fish predators that can help to directly assess predation of juvenile salmonids and the effects of fish predators on other components of the ecosystem in addition to juvenile salmon.

With respect to the development of a sample frame, the USGS has formulated a sample frame for the PRP using a Generalized Random Tessellation Stratified algorithm (Larsen and others, 2007). This sample frame encompasses both the river channel and upland areas. The sample frame was developed as part of efforts to facilitate the development of a long-term monitoring program for aquatic invasive species and as part of efforts to initiate an integrated status and trends monitoring program for aquatic resources in the Columbia River basin (U.S. Geological Survey; unpub. Data, 2011). The sample frame is available upon request and is slated to be made available through a tool being developed by the Pacific Northwest Aquatic Monitoring Partnership (*http://www.pnamp.org/project/3263*).

Acknowledgments

We thank Conrad Frost and Amy Puls of the USGS and Curt Nelson, Fritz Wichterman, Klint Caillier, and seasonal and permanent staff of the WDFW for their assistance in the field and laboratory. We thank Lucinda Morrow and Lance Campbell of the WDFW aging laboratory. In addition, we want to thank Curt Dotson for contract administration and the members of the Priest Rapids Coordinating Committee for their comments and thoughts on this project. We would also acknowledge John Beeman and Matt Mesa, USGS, and Jeffrey Korth, WDFW, for their input and reviews of this report.

References Cited

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

Beamesderfer, R.C., Ward, D.L., and Nigro, A.A., 1996, Evaluation of the biological basis for a predator control program on northern squawfish (*Ptychocheilus oregonensis*) in the Columbia and Snake rivers: Canadian Journal of Fisheries and Aquatic Sciences, v. 53, p. 2,898–2,908.

Bickford, S.A. and Skalski, J.R, 2000, Reanalysis and interpretation of 25 years of Snake–Columbia River juvenile salmonid survival studies: North American Journal of Fisheries Management, v. 20, p. 53–68.

Bonar, S.A., Bolding, B.D., and Divens, M., 2000, Standard fish sampling guidelines for Washington State ponds and lakes: Olympia, Wash., Washington Department of Fish and Wildlife, Report No. FPT 00-28.

Brandt, S.B., and Hartman, K.J., 1993, Innovative approaches with bioenergetics models—Future applications to fish ecology and management: Transactions of the American Fisheries Society, v. 122, p. 731–735.

Burley C.C., and Poe, T.P, 1994, Significance of predation in the Columbia River from Priest Rapids Dam to Chief Joseph Dam: Prepared for Chelan, Douglas, and Grant County Public Utility Districts, Washington, by Washington Department of Wildlife and National Biological Survey, Olympia, Wash.

Cech, J.J., Jr., Castleberry, D.T., Hopkins, T.E., and Petersen, J.H., 1994, Northern squawfish, *Ptychocheilus oregonensis*, Ch consumption rate and respiration model—Effects of temperature and body size: Canadian Journal of Fisheries and Aquatic Sciences, v. 51, p. 8–12.

Cochran, W.G., 1977, Sampling techniques (3d ed.): New York, Wiley.

Counihan, T.D., Miller, A.I., and Parsley, M.J., 1999: Indexing the relative abundance of age–0 white sturgeons in an impoundment of the lower Columbia River from highly skewed trawling data: North American Journal of Fisheries Management, v. 19, p. 520–529.

Coutant, C.C., and Whitney, R.R., 2000: Fish behavior in relation to passage through hydropower turbines—A review: Transactions of the American Fisheries Society, v. 129, p. 351–380.

Cummins, K.W., and Wuycheck, J.C., 1971, Caloric equivalents for investigations in ecological energetics: Mitteilungen International Vereinigung für Theoretische und Angewandte Limnologie, v. 18, p. 1–151.

Dieterman, D.J., Thorn, W.C., and Anderson, C.S., 2004: Application of a bioenergetics model for brown trout to evaluate growth in southeast Minnesota streams: Minnesota Department of Natural Resources Policy Section, Fisheries and Wildlife Investigational Report 513.

Donabauer, S.B., 2010, Comparing otoliths, dorsal spines and scales to estimate age, growth, and mortality between male and female walleye from Brookville reservoir, Indiana: Final Report, Fisheries Section, Indiana Department of Natural Resources, Indiana Division of Fish and Wildlife.

Erickson, C.M., 1983: Age determination of Manitoban walleye using otoliths, dorsal spines, and scales: North American Journal of Fisheries Management, v. 3, p. 176–181.

Federal Energy Regulatory Commission, 2008, Priest Rapids Project license agreement: Federal Energy Regulatory Commission, accessed June 5, 2012, at *http://www.gcpud.org/pudDocuments/naturalResourcesDocs/h1.pdf*.

Garner, K., and Keeler, C., 2008, Northern Pikeminnow (*Ptychocheilus oregonensis*) removal efforts for the Priest Rapids Project, mid-Columbia River, 2008: Priest Rapids Hydroelectric Project (FERC No. 2114) Public Utility District No. 2 of Grant County, P.O. Box 878, Ephrata, Wash.

Garner, K., and Keeler, C., 2009: Northern Pikeminnow (*Ptychocheilus oregonensis*) removal efforts for the Priest Rapids Project, mid-Columbia River, 2009: Priest Rapids Hydroelectric Project (FERC No. 2114) Public Utility District No .2 of Grant County, P.O. Box 878, Ephrata, Wash.

Hanchin, P.A., 2011, The fish community and fishery of Lake Gogebic, Gogebic and Ontonagon Counties, Michigan in 2005–06 with emphasis on Walleye, Northern Pike, and Smallmouth Bass: Michigan Department of Natural Resources, Fisheries Division, Fisheries Special Report 58.

Hanson, P.C., Johnson, T.B., Schindler, D.E., and Kitchell, J.F., 1997, Bioenergetics Model 3.0 for Windows: Madison, Wis., University of Wisconsin Sea Grant Institute, Technical Report WISCUT-T-97-001.

Hardiman, J.M., Counihan, T.D., Burgess, D.S., Simmons, K.E., Holmberg, G., Rogala, J.A., and Polacek, R.R., 2012, Assessing fish predation on migrating juvenile steelhead and a retrospective comparison to steelhead survival through the Priest Rapids Hydroelectric Project, Columbia River, Washington, 2009–11: U.S. Geological Survey Open-File Report 2012–1129, 36 p.

Harmon, J.R., and Parks D.L., 1980, Evaluation of a bypass system for juvenile salmonids at Little Goose Dam: Marine Fisheries Review, v. 42, p. 25–28.

Isermann, D.A., Meerbeek, J. R., Scholten, G.D., and Willis, D.W., 2003. Evaluation of three different structures used for walleye age estimation with emphasis on removal and processing times. North American Journal of Fisheries Management 23:625–631.

Iwamato, R.N., Muir, W.D., Sandford, McIntyre, Frost, D.A., Williams, J.G., Smith, S.G., and Skalski, J.R., 1994, Survival estimates for the passage of juvenile Chinook salmon through Snake River dams and reservoirs, 1993:. Report prepared for the U.S. Department of Energy, Bonneville Power Administration Division of Fish and Wildlife, Contract DE-A179-93BP10891, Project 93-29, 139 p.

Jearld, A., Jr. 1983, Age determination, *in* Nielsen, L.A., and Johnson, D.L., eds, Fisheries techniques: Bethesda, Md., American Fisheries Society.

Johnson, G.E., Anglea, S.M., Adams, N.S., and Wik, T.O., 2005, Evaluation of a prototype surface flow bypass for juvenile salmon and steelhead at the powerhouse of Lower Granite Dam, Snake River, Washington, 1996–2000: North American Journal of Fisheries Management, v. 25, p. 138–151.

Larsen, D.P., Olsen, A.R., and Stevens, D.L., 2007, Using a master sample to integrate stream monitoring programs: Journal of Agricultural, Biological, and Environmental Statistics, v. 13, no. 3, p. 243–254, doi:10.1198/108571108X336593.

Knutsen, C.J., and Ward, D.L., 1999, Biological characteristics of northern pikeminnow in the lower Columbia and Snake Rivers before and after sustained exploitation: Transactions of the American Fisheries Society, v. 128, p. 1,008–1,019.

Larsen, D.P., Olsen, A.R., Lanigan, S.H., Moyer, C., Jones, K.K., and Kincaid, T.M., 2007, Sound survey designs can facilitate integrating stream monitoring data across multiple programs: Journal of the American Water Resources Association, v. 43, p. 384–397.

Le Cren, E.D., 1947, The determination of the age and growth of the perch (*Perca fluviatilis*) from the opercular bone: The Journal of Animal Ecology, v. 16, p. 188–204.

Mateo, I., 2007, A bioenergetics based comparison of growth conversion efficiency of Atlantic cod on Georges Bank and in the Gulf of Main: Journal of Northwest Atlantic Fisheries Science, v. 38, p. 23–35.

McCarthy, S.G., Duda, J.J., Emlen, J.M., Hodgson, G.R., and Beauchamp., D.A., 2009, Linking habitat quality with trophic performance of steelhead along forest gradients in the south fork Trinity River watershed, California: Transactions of the American Fisheries Society, v. 138 p. 506–521.

Muir, W.D., Smith, S.G., Iwamoto, R.N., Kamikawa, D.J., McIntyre, K.W., Hockersmith, E.E., Sandford, B.P., Ocker, P.A., Ruehle, T.E., and Williams, J.G., 1995, Survival estimates for the passage of juvenile salmonids through Snake River Dams and reservoirs, 1994: Annual report prepared for the Bonneville Power Administration, Portland, Oreg., and U.S. Army Corps of Engineers, Walla Walla, Wash., Contract DE93-29A179-93B101891, Project 93-29, 187 p.

National Marine Fisheries Service, 2004, Biological Opinion and Magnuson-Steven Fishery Conservation and Management Act Interim Protection Plan for Operation of the Priest Rapids Hydroelectric Project, May 3, 2004: National Marine Fisheries Service, 115 p..

National Marine Fisheries Service, 2008, Biological Opinion and Magnuson-Steven Fishery Conservation and Management Act New License for the Priest Rapids Hydroelectric Projec, February 1, 2008: National Marine Fisheries Service, 74 p..

Naughton,G.P., Bennett, D.H., and Newman, B., 2004, Predation on juvenile salmonids by smallmouth bass in the Lower Granite reservoir system, Snake River: North American Journal of Fisheries Management, v. 24, no. 2, p. 534–544.

Petersen, J.H., and Ward, D.L. 1999, Development and corroboration of a bioenergetics model for northern pikeminnow (*Ptychocheilus oregonensis*) feeding on juvenile salmonids in the Columbia River: Transactions of the American Fisheries Society, v. 128, p. 784–801.

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

Petersen, J.H., 2002, Compensatory feeding following a predator removal program—Detection and mechanisms: Reports to Bonneville Power Administration, Contract No. 0003395, Project No. 199007800, BPA report DOE/BP-00003395-1, 92 electronic p..

Pfeifer, B., Hagen, J.E., Weitkamp, D., Bennett, D.H., Lukas, J., and Dresser, T., 2001, Evaluation of fish species present in the Priest Rapids Project area, mid-Columbia River, Washington, USA: Prepared for Public Utility District No. 2 of Grant County, Ephrata, Wash.

Ransom, B.H., and Steig, T.W., 1995, Comparison of the effectiveness of surface flow and deep spill for bypassing Pacific salmon smolts (*Onhorhynchus spp.)* at Columbia River Basin hydropower dams: San Francisco, Calif., Proceedings of the International Conference on Hydropower, Waterpower 1995, July 25–28.

Raymond, H.L., 1979, Effects of dams and impoundments on migrations of juvenile Chinook salmon and steelhead from the Snake River, 1966 to 1975: Transactions of the American Fisheries Society, v. 108, p. 505–529.

Rieman B., Beamesderfer, R., Vigg, S., and Poe, T, 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, v. 120, p. 448–458.

Robichaud, D., Nass, B., Timko, M.A., English, K.K., and Ransom, B., 2005: Analysis of Chinook smolt behavior and relative survival at Wanapum Dam using three-dimensional acoustic telemetry, 2004: Report for Public Utility District No. 2 of Grant County, Ephrata, Wash.

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

Rogers, M.W., Hansen, M.J., and Beard, T.D., 2003, Catchability of walleyes to fyke netting and electrofishing in northern Wisconsin lakes: North American Journal of Fisheries Management, v. 23, issue 4, p. 1,193–1,206.

Schoenebeck, C.W., and Hansen, M.J., 2005, Electrofishing catchability of walleyes, largemouth bass, smallmouth bass, northern pike, and muskellunge in Wisconsin lakes: North American Journal of Fisheries Management, v. 25, issue 4, p. 1,341–1,352.

Stewart, D.J., Weininger, D., Rottiers, D.V., and Edsall, T.A., 1983, An energetics model for lake trout, *Salvelinus namaycush*—Application to the Lake Michigan population: Canadian Journal of Fisheries and Aquatic Sciences, v. 40, p. 681–698.

Stier, D.J., and Kynard, B., 1986, Use of radio telemetry to determine the mortality of Atlantic salmon smolts passed through a 17-MW Kaplan turbine at a low-head hydroelectric dam: Transactions of the American Fisheries Society, v. 115, p. 771–775.

Sullivan, B.E., Prahl, F.G., Small, L.F., and Covert, P.A., 2001, Seasonality of phytoplankton production in the Columbia River—A natural or anthropogenic pattern?: Geochimica et Cosmochimica Acta, v. 65, no. 7, p. 1,125–1,139.

Timko, M.A., Brown, L.S., Wright, C.D., O'Connor, R.R., Fitzgerald, C.A., Meager, M.L., Rizor, S.E., Nealson, P.A., and Johnston, S.V., 2007a, Analysis of juvenile Chinook, steelhead, and sockeye salmon behavior using acoustic tags at Wanapum and Priest Rapids Dams, 2006: Draft report by HTI, Seattle, Wash., for Public Utility District No. 2 of Grant County, Ephrata, Wash.

Timko, M.A., Sullivan, L.S., Wright, C.D., Rizor, S.E., Fitzgerald, C.A., O'Connor, R.R., and Meager, M.L., 2007b, Analysis of juvenile Chinook, steelhead and sockeye salmon behavior using acoustic tags at Wanapum and Priest Rapids dams, 2007: Draft report by HTI, Seattle, Wash., for Public Utility District No. 2 of Grant County, Ephrata, Wash.

University of Washington, 2012, Columbia River data access in real time (DART): Seattle, Wash., University of Washington School of Aquatic and Fishery Science Web site, accessed June 1, 2012, at *http://www.cbr.washington.edu/dart/*.

U.S. Fish and Wildlife Service, National Marine Fisheries Service, Washington Department of Fish and Wildlife, Confederated Tribes of the Colville Reservation, and Yakama Nation, 2006, Settlement Agreement entered into by Public Utility District No. 2 of Grant County, Wash.: U.S. Fish and Wildlife Service, National Marine Fisheries Service, Washington Department of Fish and Wildlife, Confederated Tribes of the Colville Reservation, and Yakama Nation.

Vigg S., Poe, T.P., Prendergast, L.A., and Hansel, H.C., 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, v. 120, p. 421438.

Ward D.L., Petersen, J.H., and Loch, J.J., 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, v. 124, p. 321–334.

Ward, D.L., and Zimmerman, M.P., 1999, Response of smallmouth bass to sustained removals of northern pikeminnow in the lower Columbia and Snake Rivers: Transactions of the American Fisheries Society, v. 128 p. 1,020–1,035.

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

Zimmerman, M.P., 1999, Food habits of smallmouth bass, walleyes, and northern pikeminnow in the lower Columbia River basin during outmigration of juvenile anadromous salmonids: Transactions of the American Fisheries Society, v. 128, p. 1,036–1,054.

Zimmerman, M.P., and Ward, D.L., 1999, Index of predation on juvenile salmonids by northern pikeminnow in the lower Columbia River Basin, 1994–1996: Transactions of the American Fisheries Society, v. 128, no. 6, p. 995–1,007.

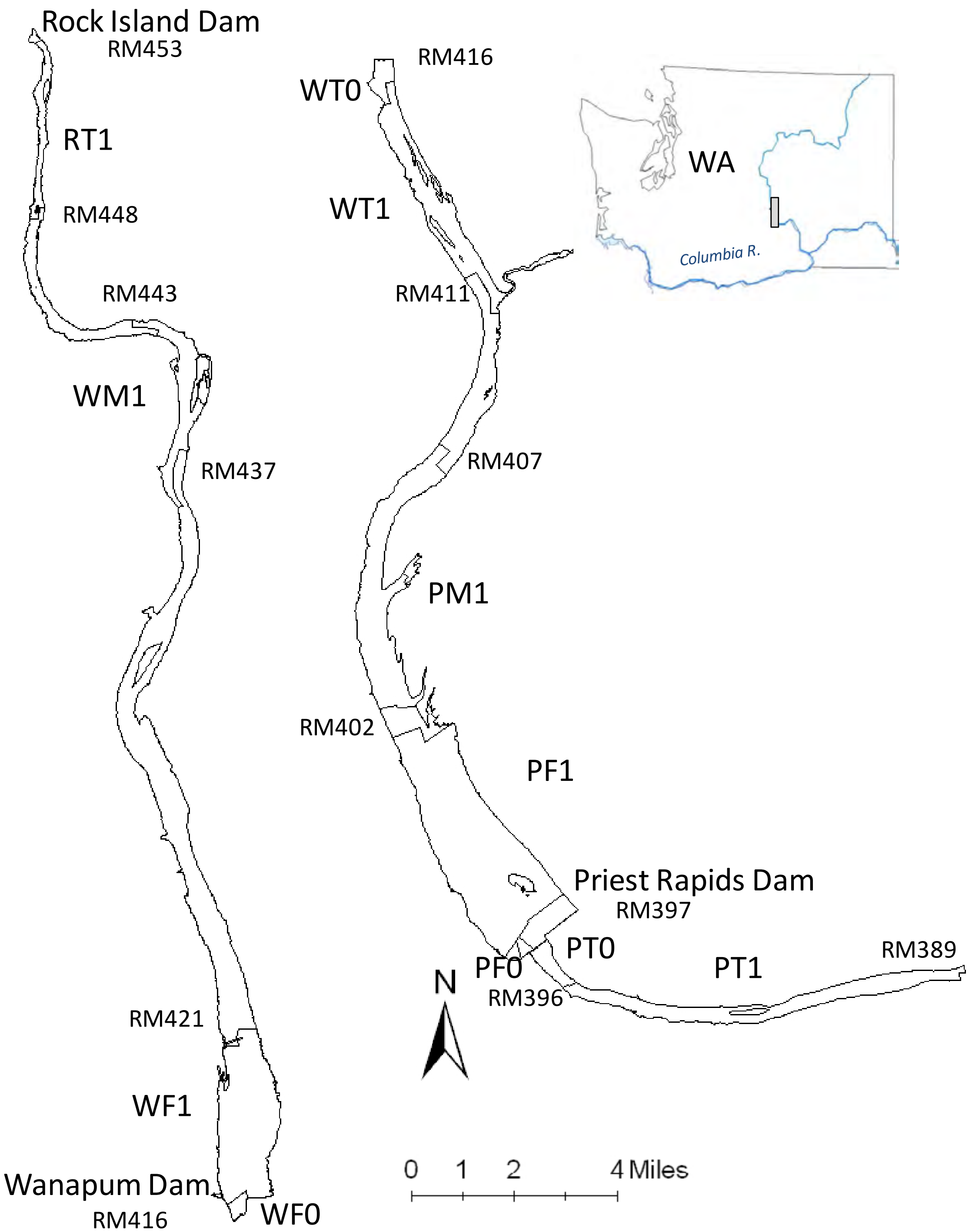


Figure 1. Study area sampled in the Columbia River, Washington, 2009. Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace. RM, river mile.

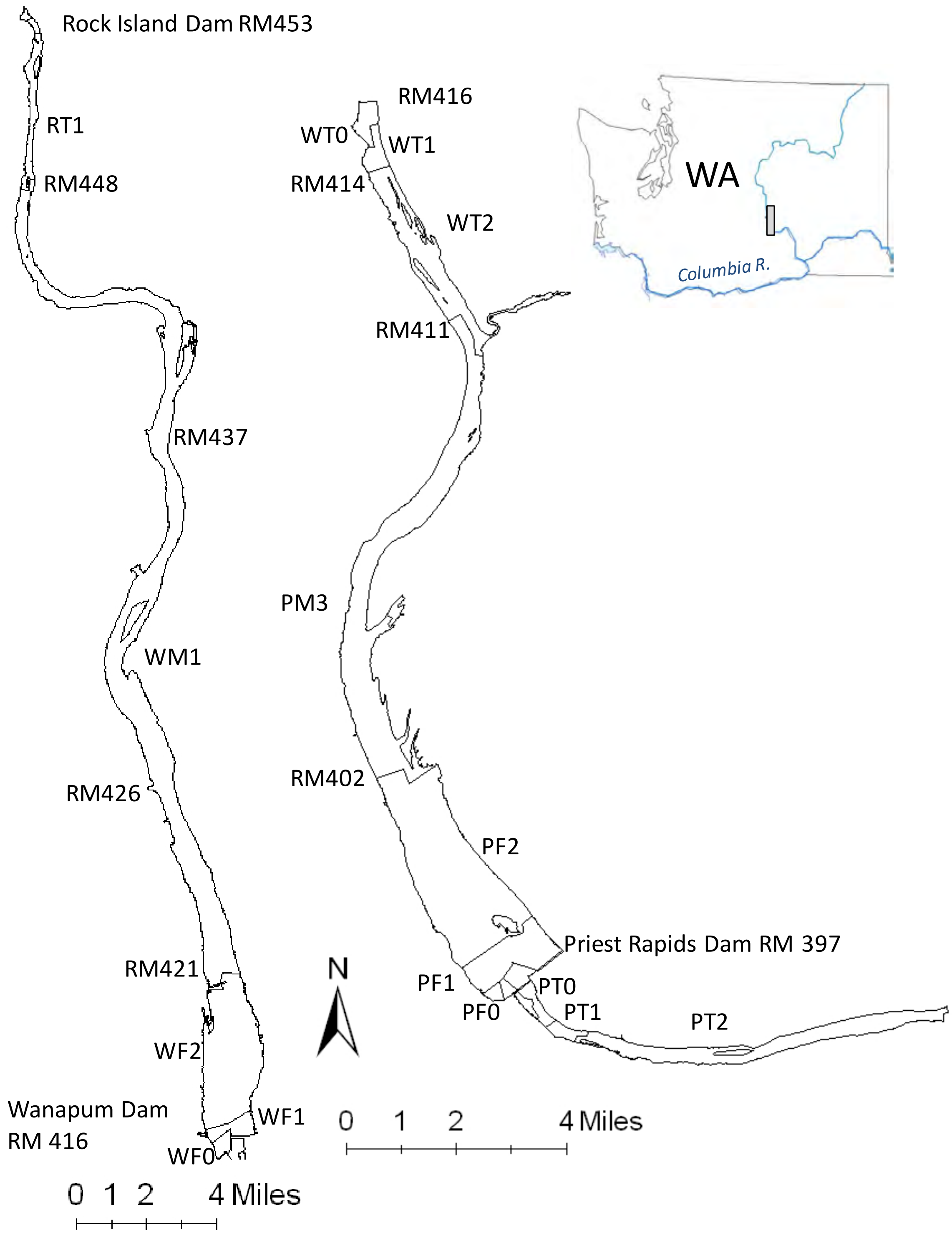


Figure 2. Study area sampled in the Columbia River, Washington, 2010. Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace. RM, river mile.

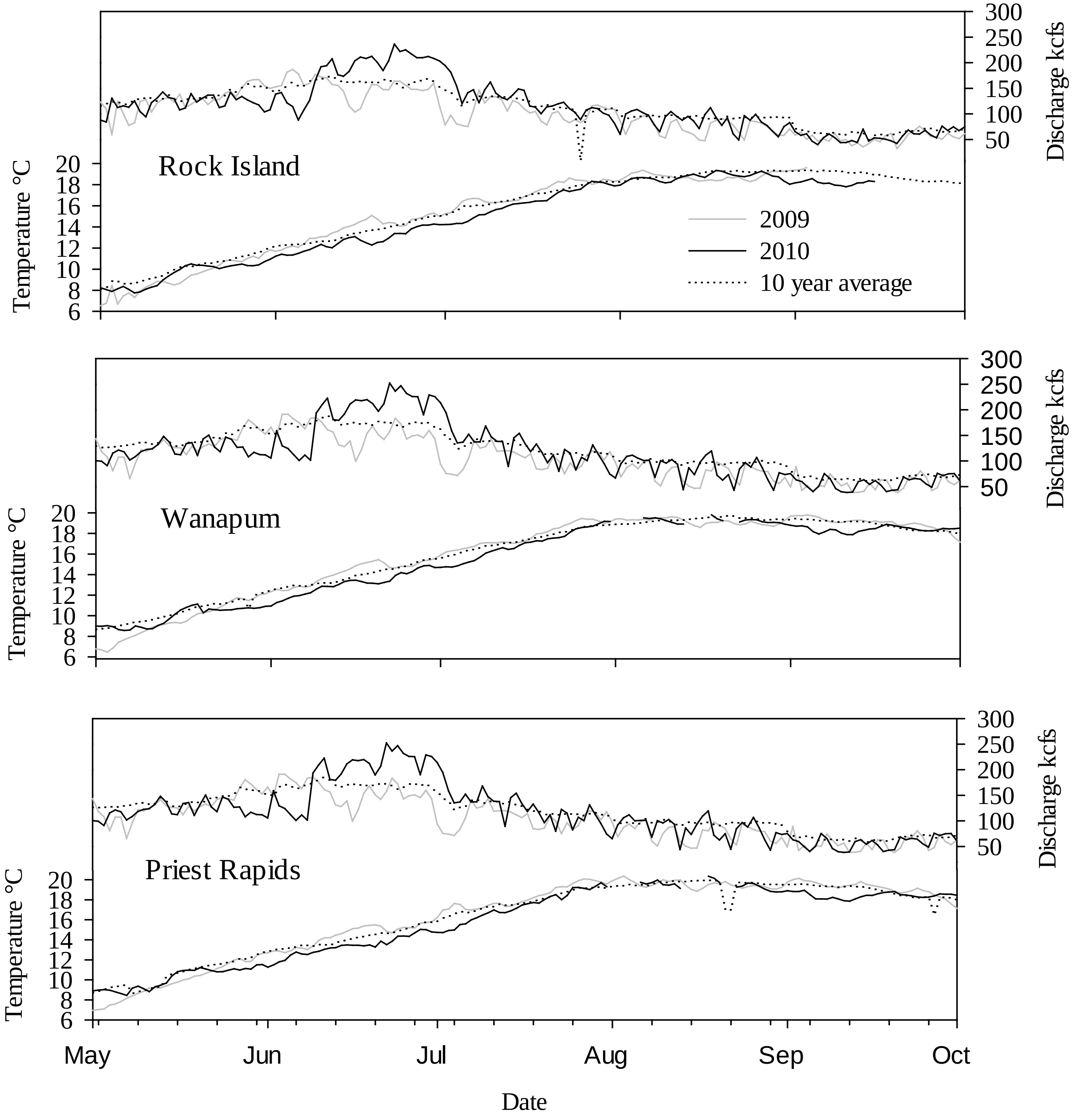


Figure 3. River discharge (1,000 cubic feet second) and water temperature as measured in the tailrace of Priest Rapids, Wanapum, and Rock Island Dams, Columbia River, Washington, from May to October. Discharge data from tailrace outflow. Temperature data from the Water Quality Meter station, downloaded from the University of Washington Columbia River Data access in real time Web site.

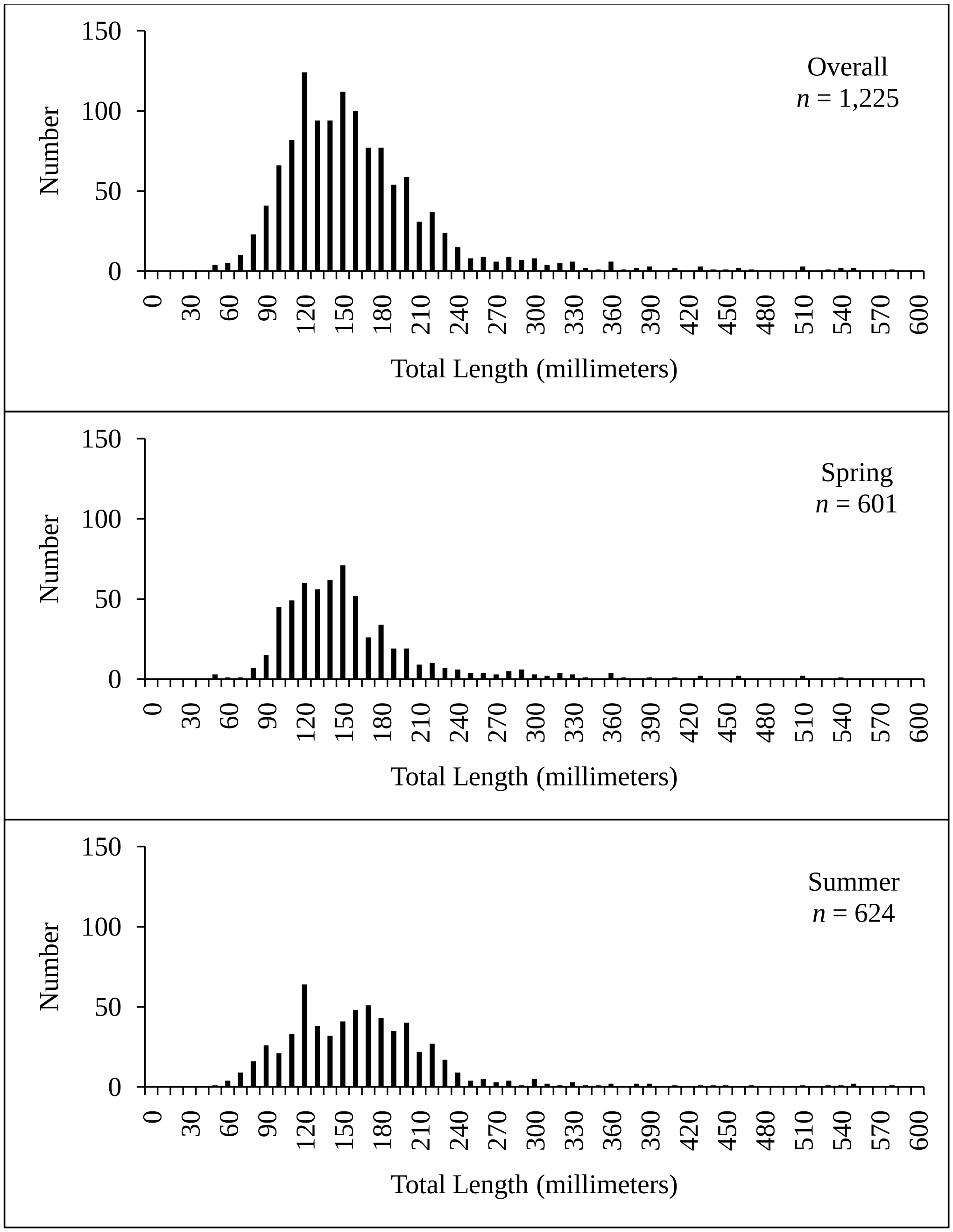


Figure 4. Length frequency histograms for northern pikeminnow during Burley and Poe sampling overall in 2009 (May 27–June 12 and August 3–20), in spring 2009 (May 27–June 12), and in summer 2009 (August 3–20), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

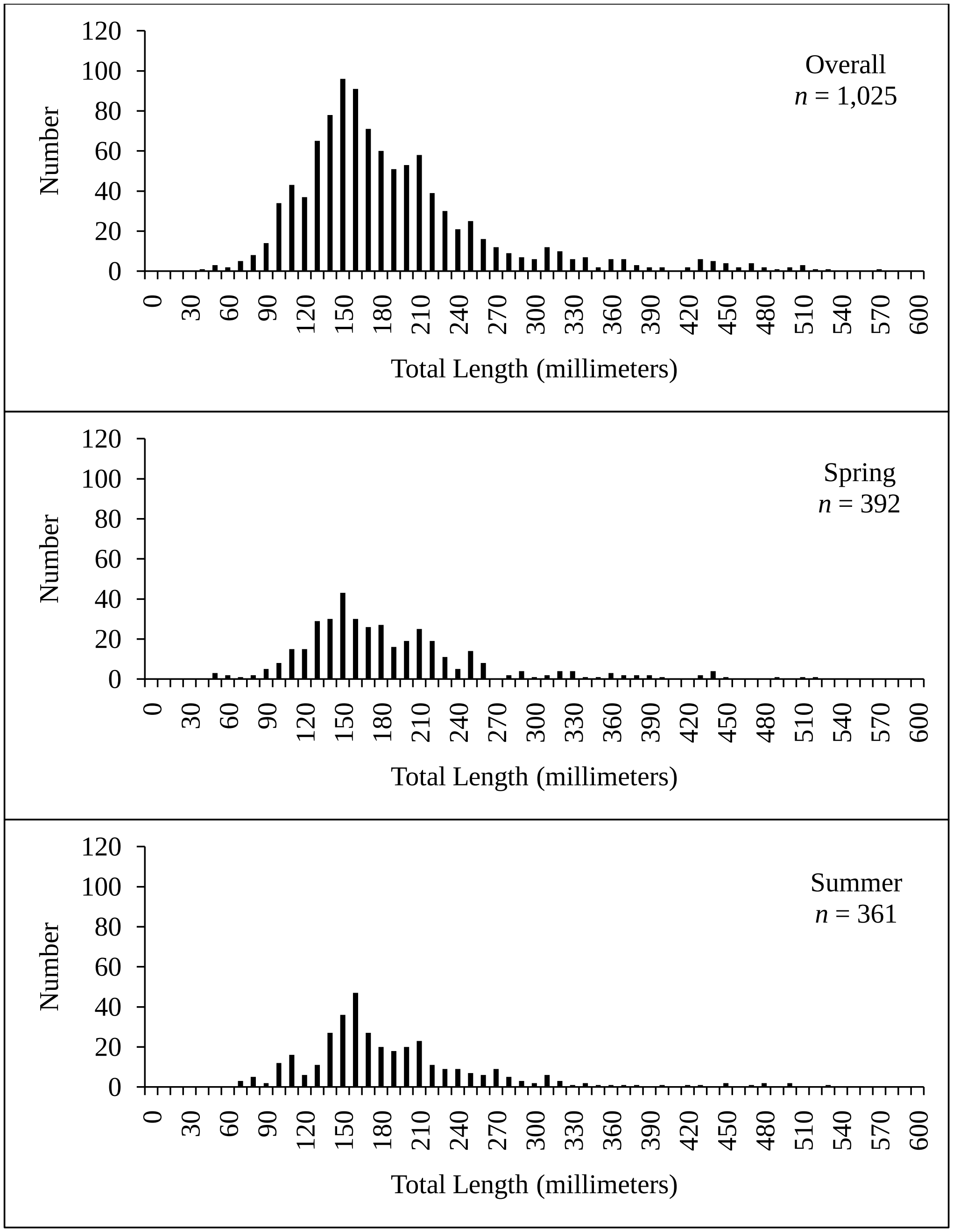


Figure 5. Length frequency histograms for northern pikeminnow during predator index sampling overall in 2009 (May 1–August 27), in spring 2009 (May 7–June 11), and in summer 2009 (June 23–August 5), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

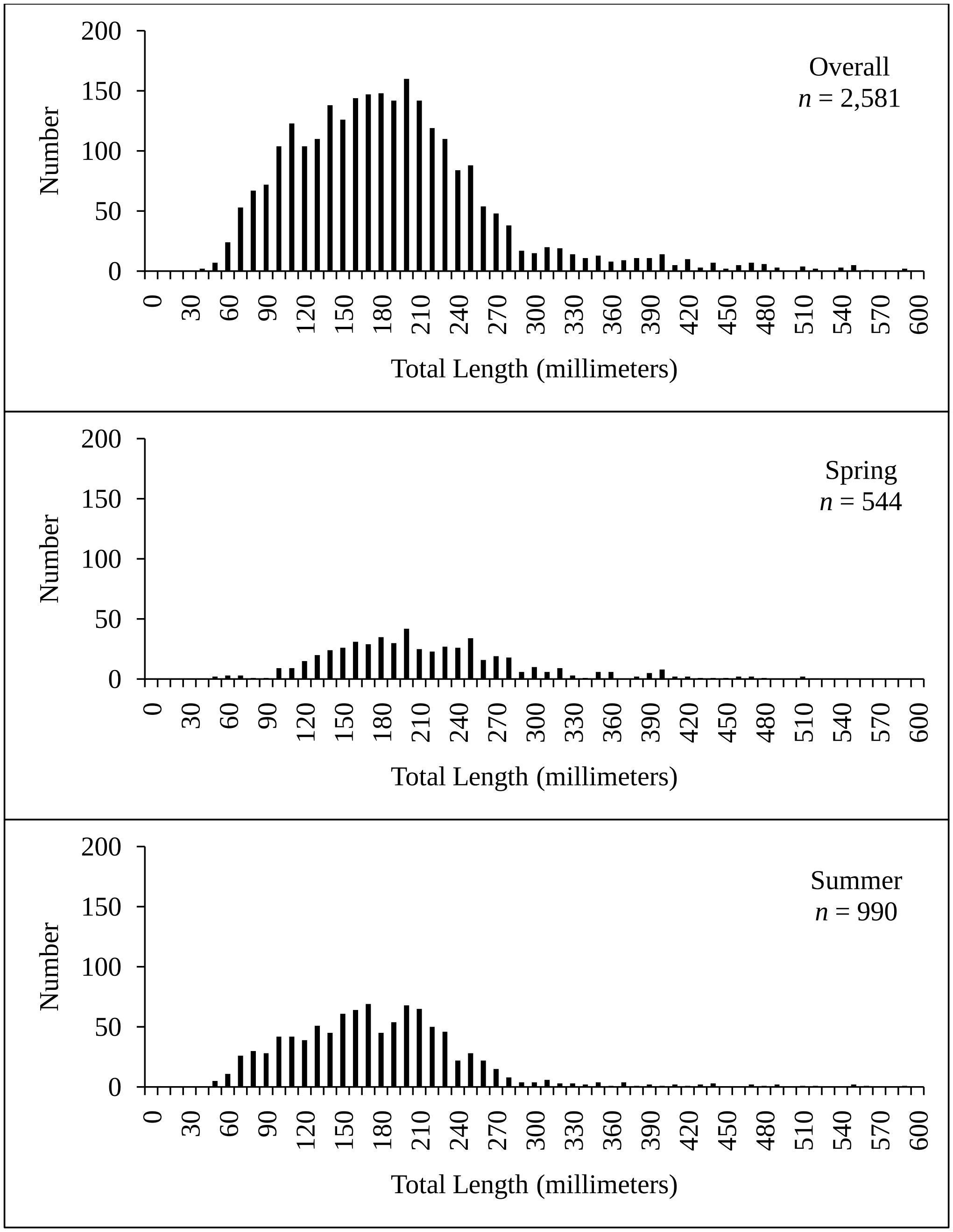


Figure 6. Length frequency histograms for northern pikeminnow during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 19–June 8), and in summer 2010 (June 28–August 11), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

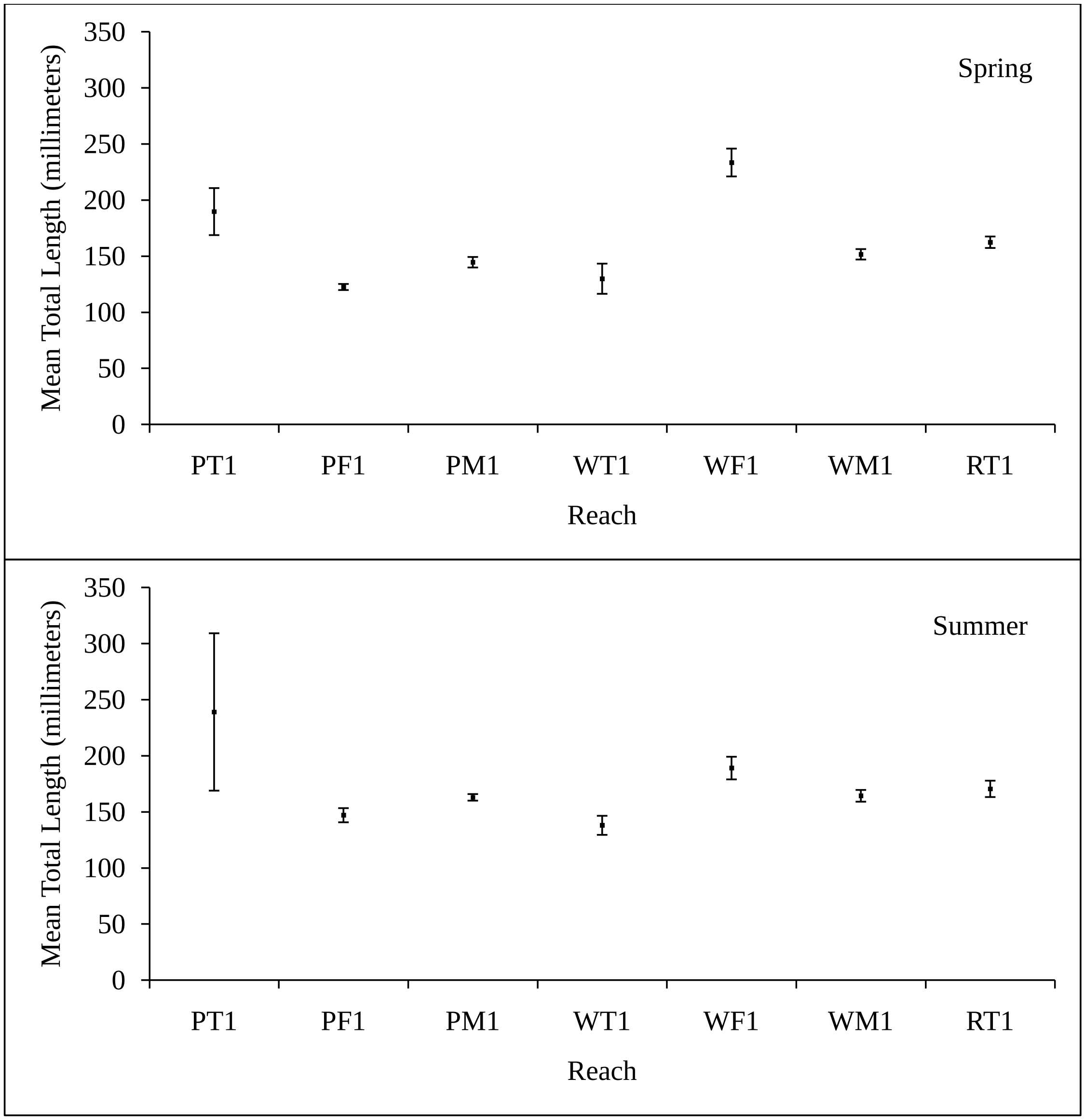


Figure 7. Mean length and one standard error for northern pikeminnow during Burley and Poe sampling in spring 2009 (May 27–June 12) and summer 2009 (August 3–20), by reaches, Priest Rapids Project, Columbia River, Washington. Reach locations: PT1, Priest Rapids Tailrace; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

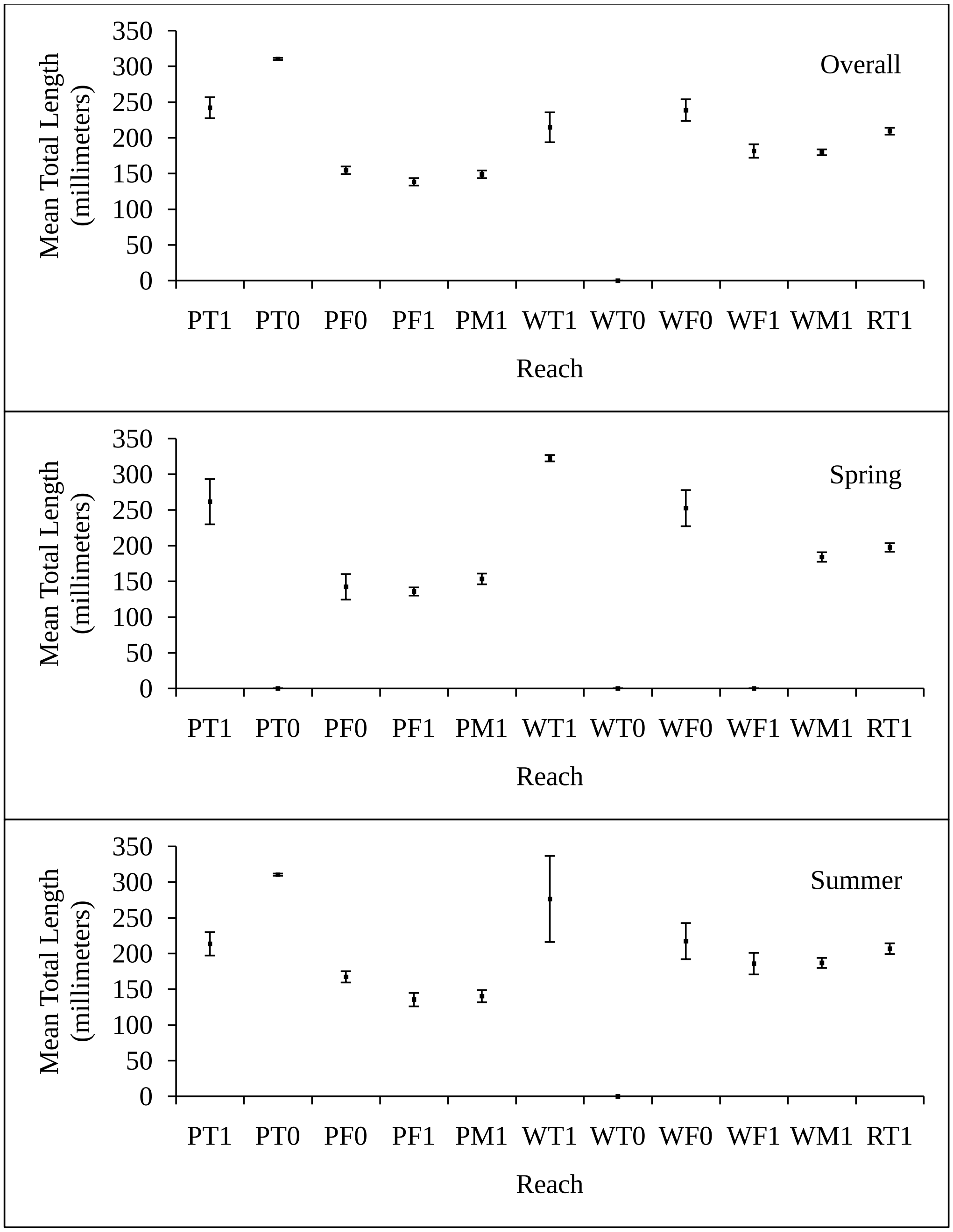


Figure 8. Mean length and one standard error for northern pikeminnow during predator index sampling overall in 2009 (May 1–August 27), in spring 2009 (May 7–June 11), and in summer 2009 (June 23–August 5), by reaches, Priest Rapids Project, Columbia River, Washington. Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

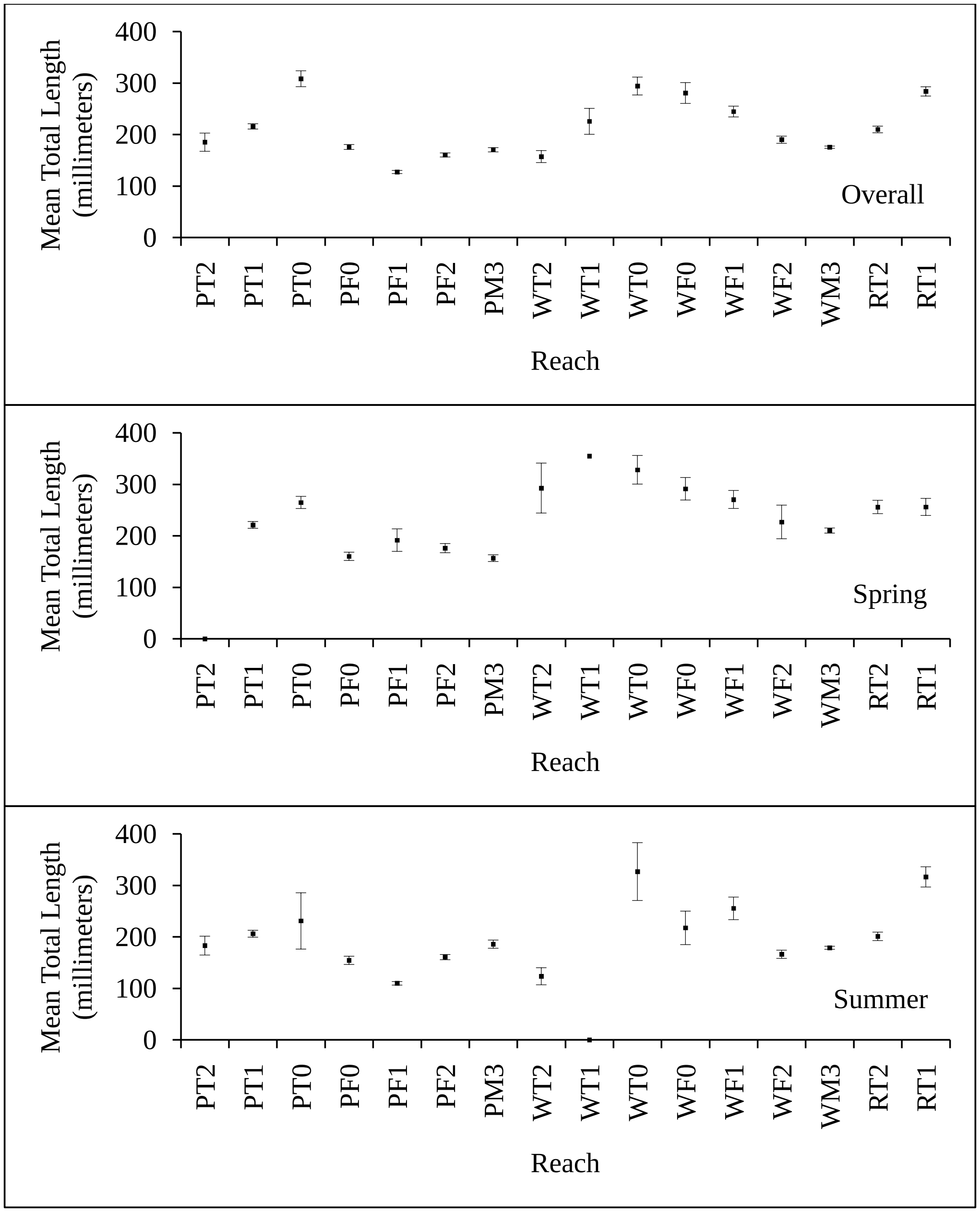


Figure 9. Mean length and one standard error for northern pikeminnow during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 19–June 8), and in summer 2010 (June 28–August 11), by reaches, Priest Rapids Project, Columbia River, Washington. Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.

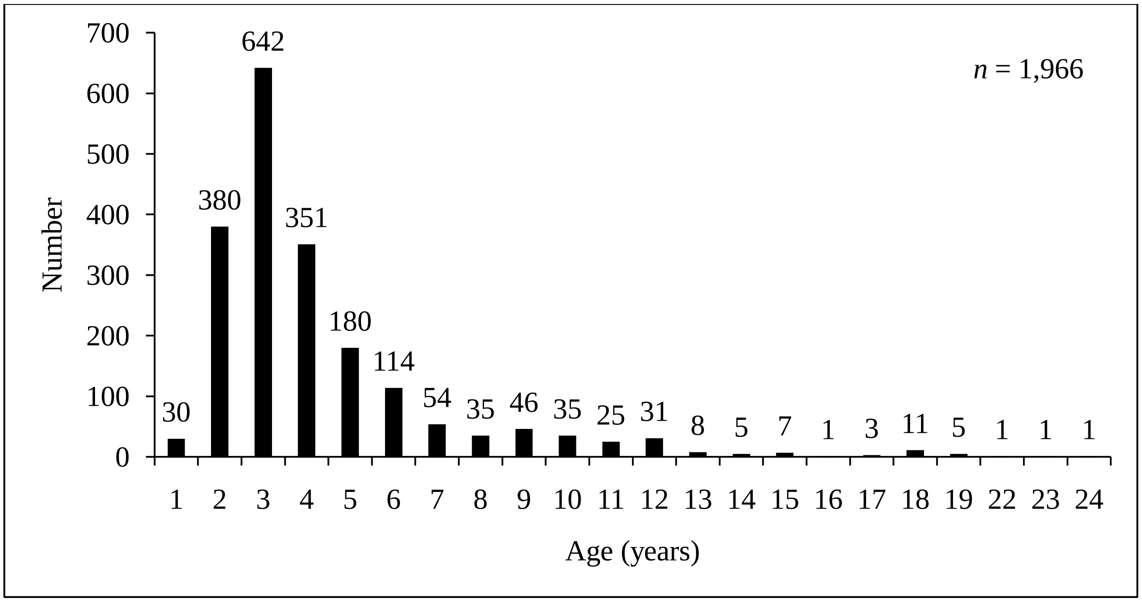


Figure 10. Age frequency (number) of northern pikeminnow captured, Priest Rapids Project, Columbia River, Washington, 2009–11. *n*, total number of fish.

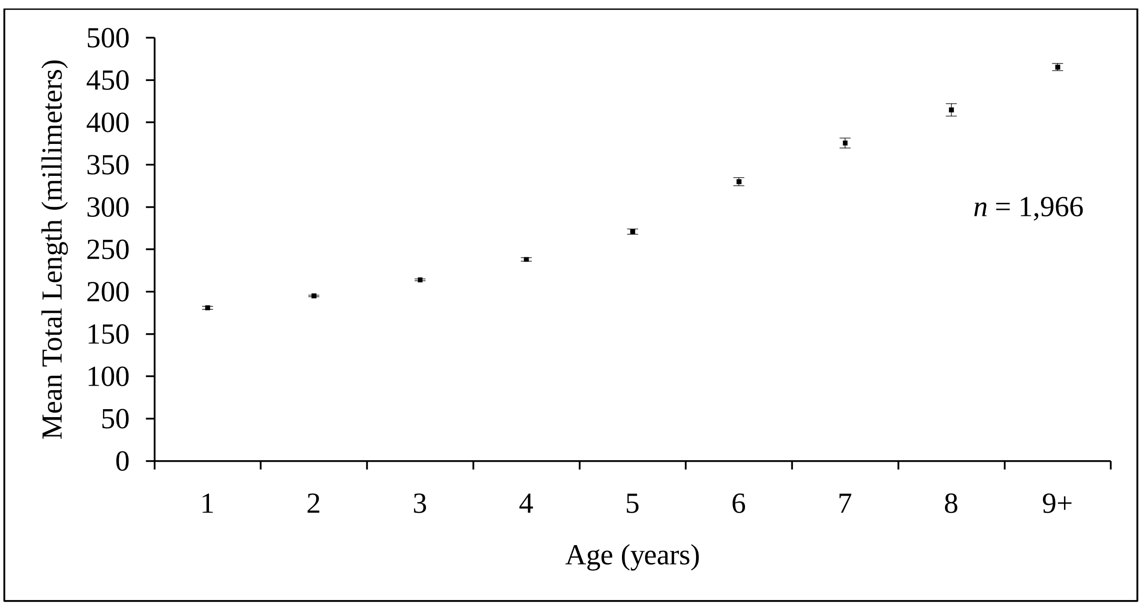


Figure 11. Mean length at age and one standard error for northern pikeminnow captured, Priest Rapids Project, Columbia River, Washington, 2009–11. Fish 9 years old and older are combined. *n*, total number of fish.

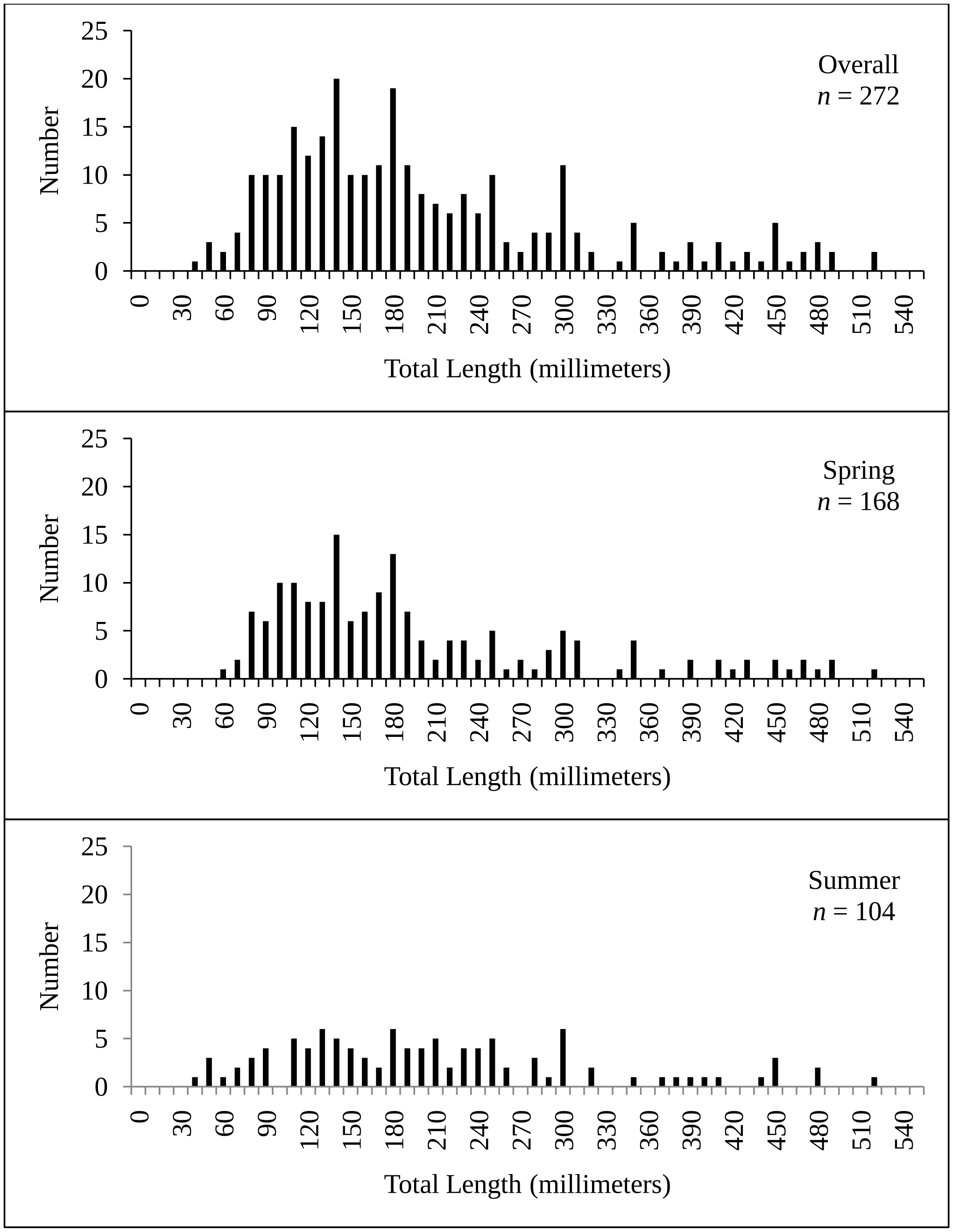


Figure 12. Length frequency histograms for smallmouth bass during Burley and Poe sampling overall in 2009 (May 27–June 12 and August 3–20), in spring 2009 (May 27–June 12), and in summer 2009 (August 3–20), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

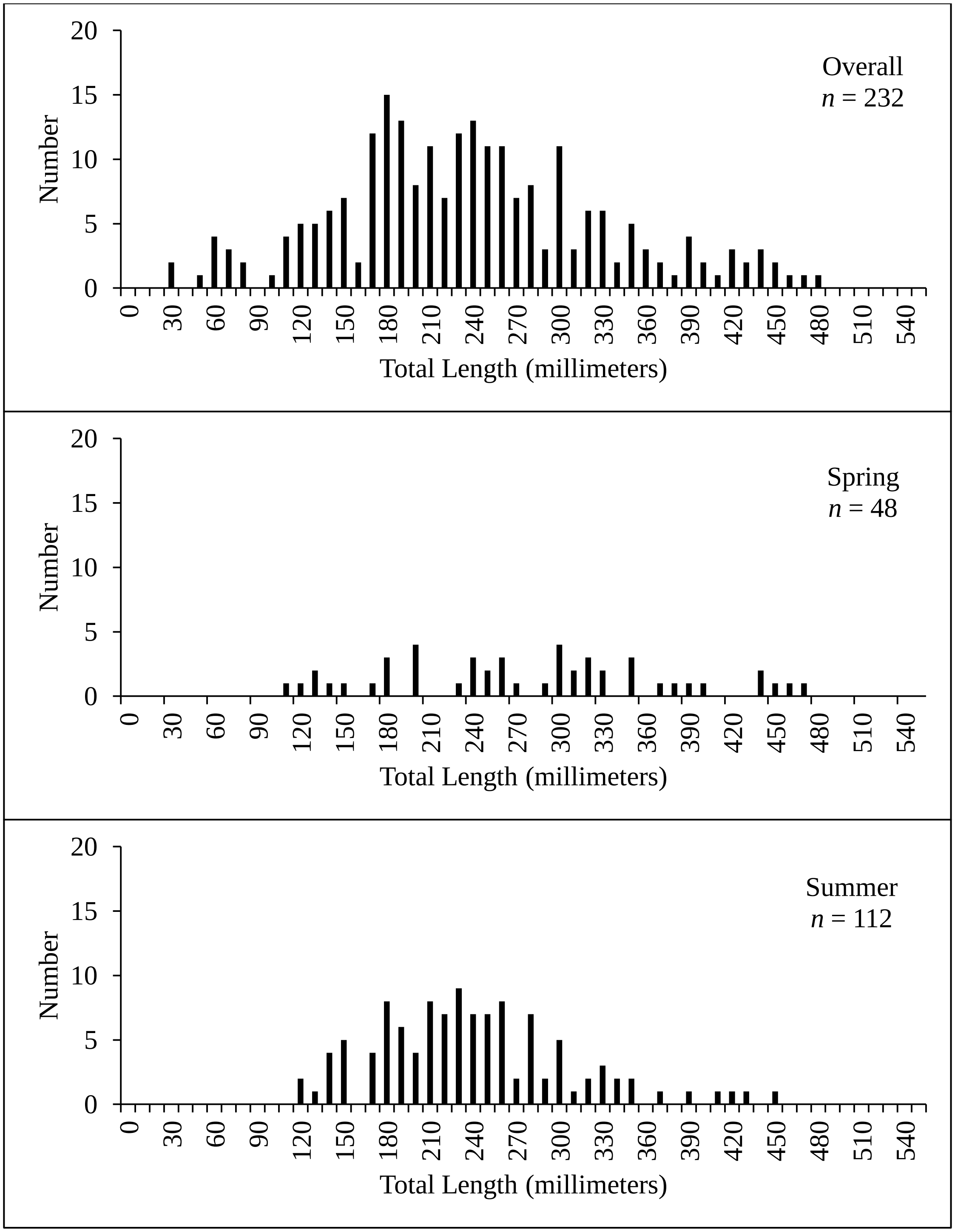


Figure 13. Length frequency histograms for smallmouth bass during predator index sampling overall in 2009 (May 1–August 27), in spring 2009 (May 7–June 11) and in summer 2009 (June 23–August 5), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

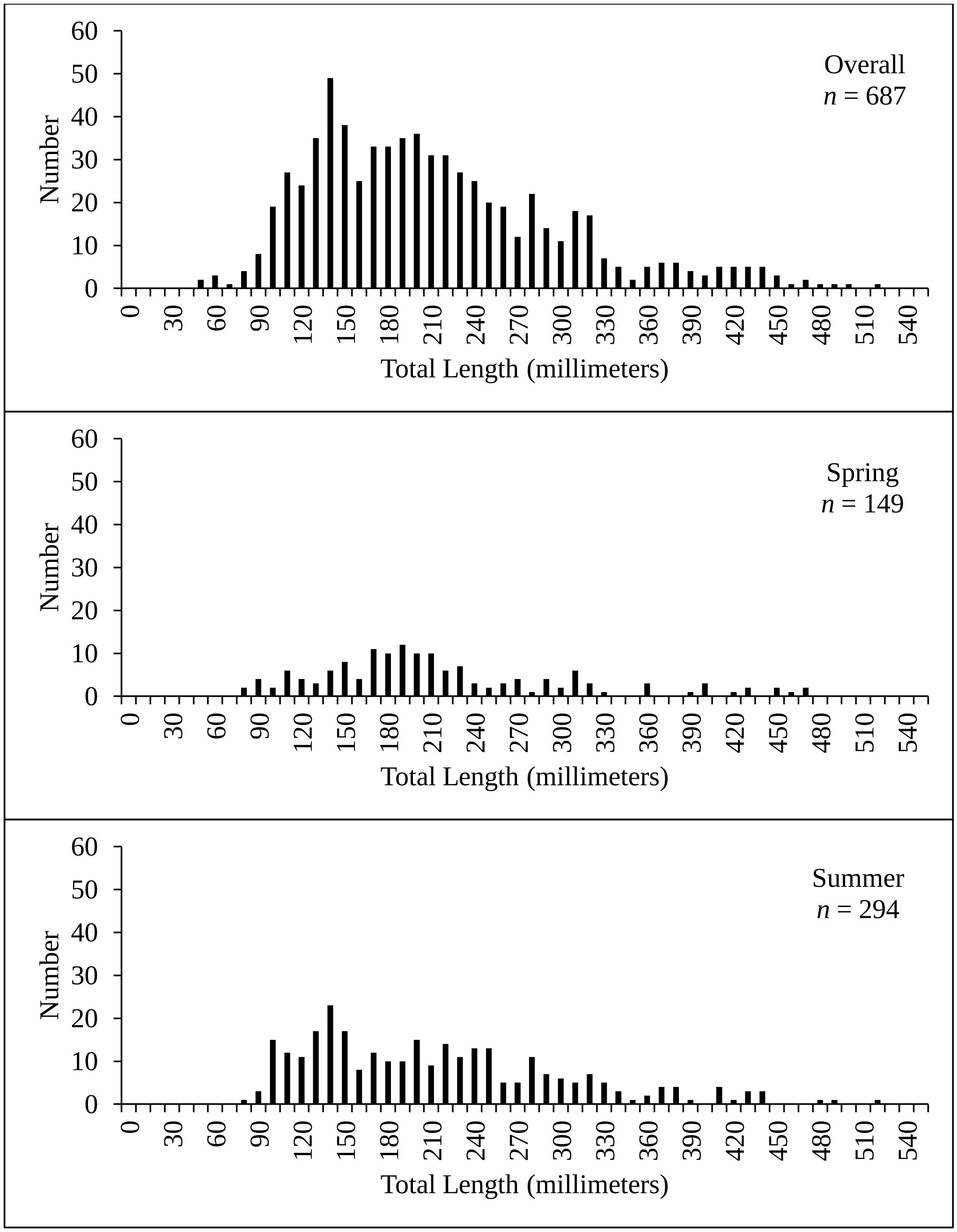


Figure 14. Length frequency histograms for smallmouth bass during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 19–June 8), and in summer 2010 (June 28–August 11), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

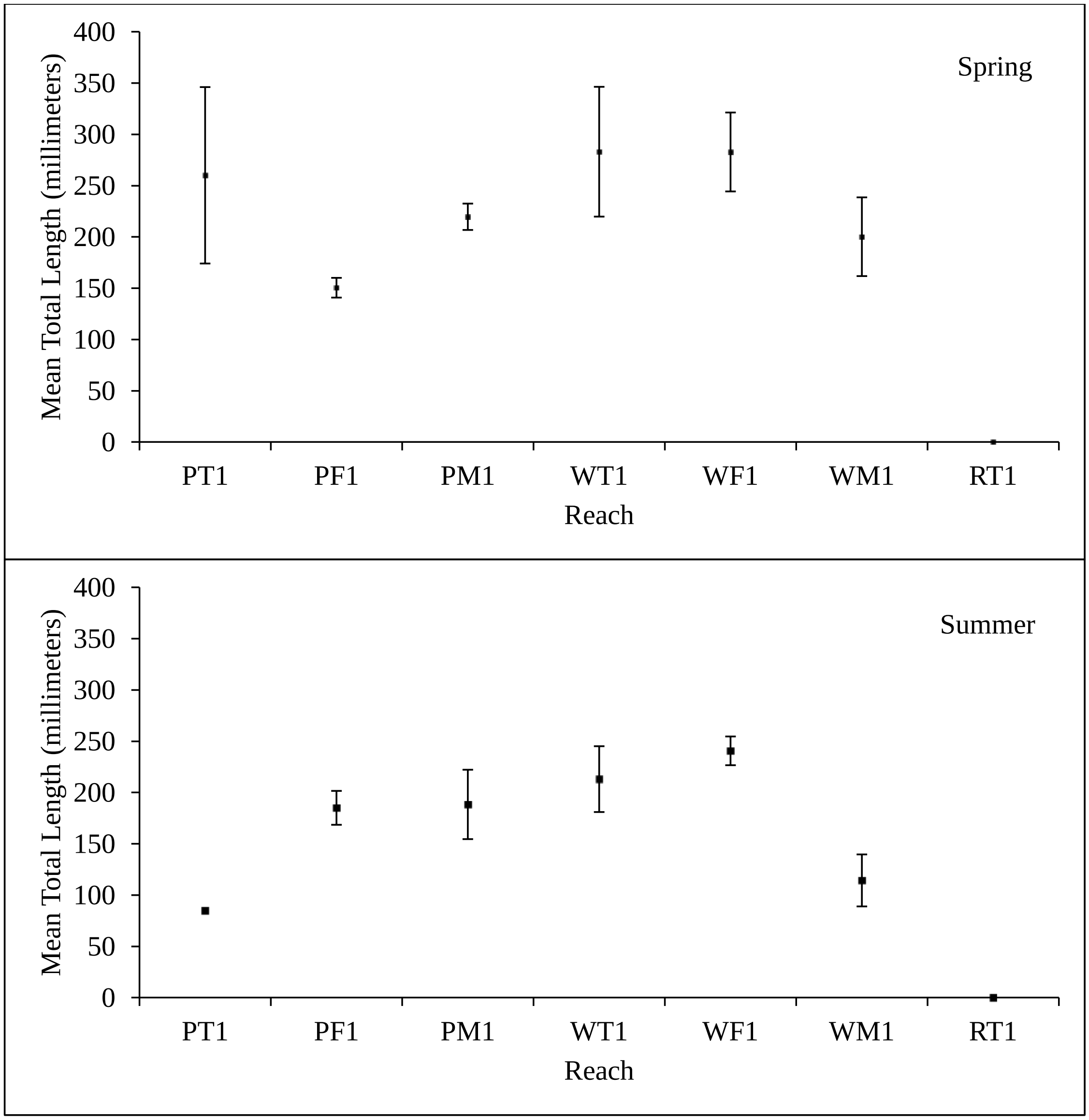


Figure 15. Mean length and one standard error for smallmouth bass during Burley and Poe sampling in spring 2009 (May 27–June 12) and summer 2009 (August 3–20), by reaches, Priest Rapids Project, Columbia River, Washington. Reach locations: PT1, Priest Rapids Tailrace; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

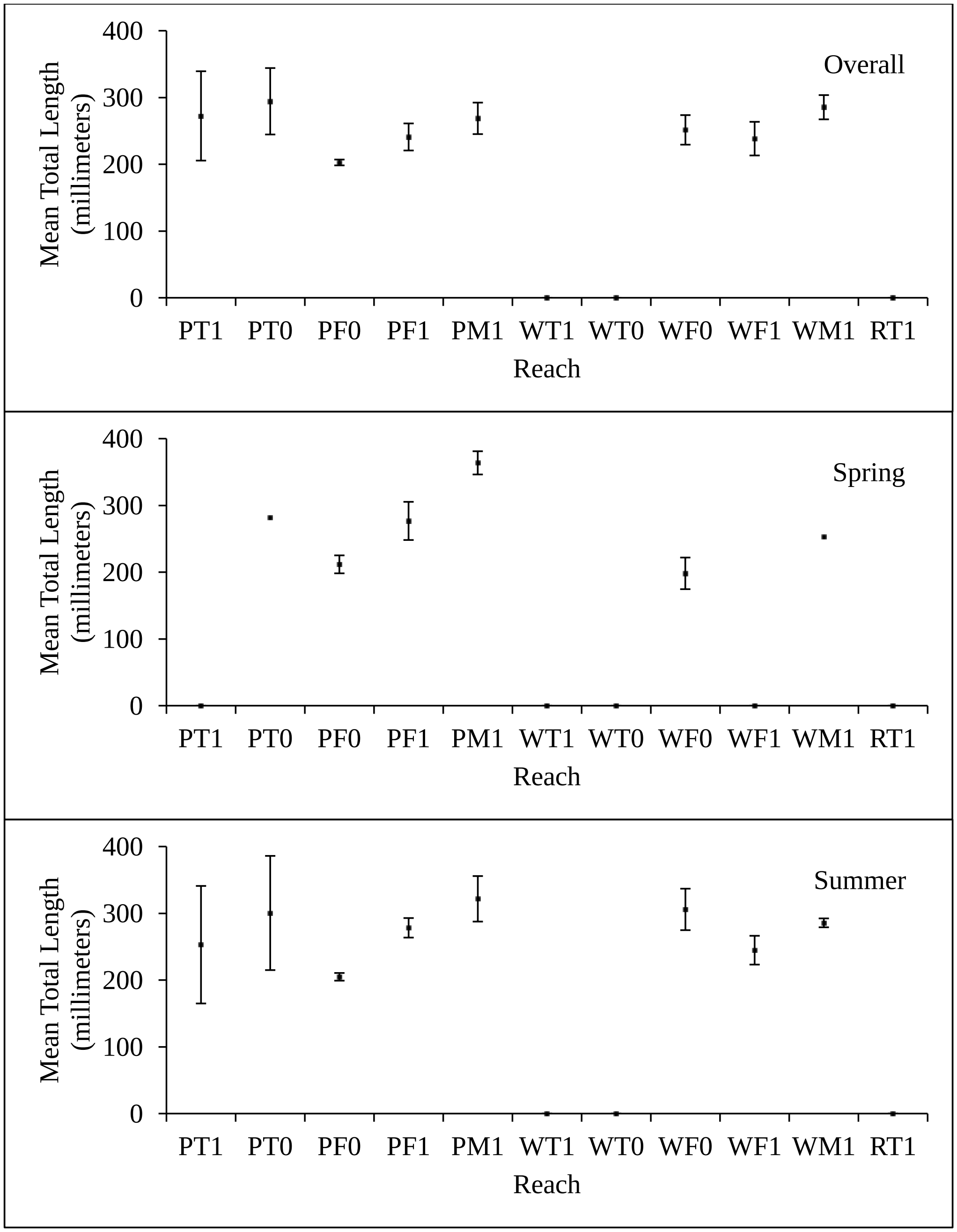


Figure 16. Mean length and one standard error for smallmouth bass during predator index sampling overall in 2009 (May 1–August 27), in spring 2009 (May 7–June 11), and in summer 2009 (June 23–August 5), by reaches, Priest Rapids Project, Columbia River, Washington. Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

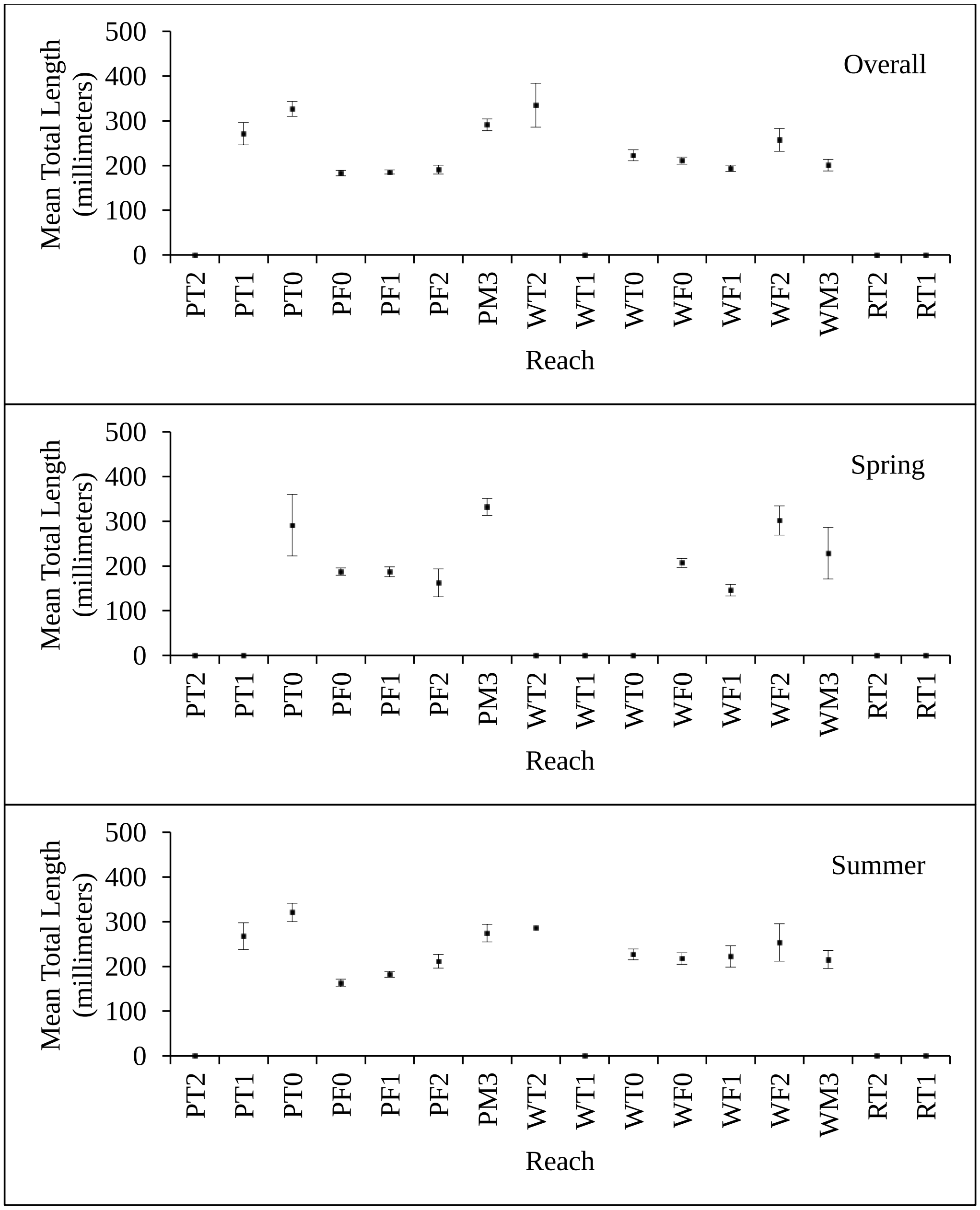


Figure 17. Mean length and one standard error for smallmouth bass during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 19–June 8), and in summer 2010 (June 28–August 11), by reaches, Priest Rapids Project, Columbia River, Washington. Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.

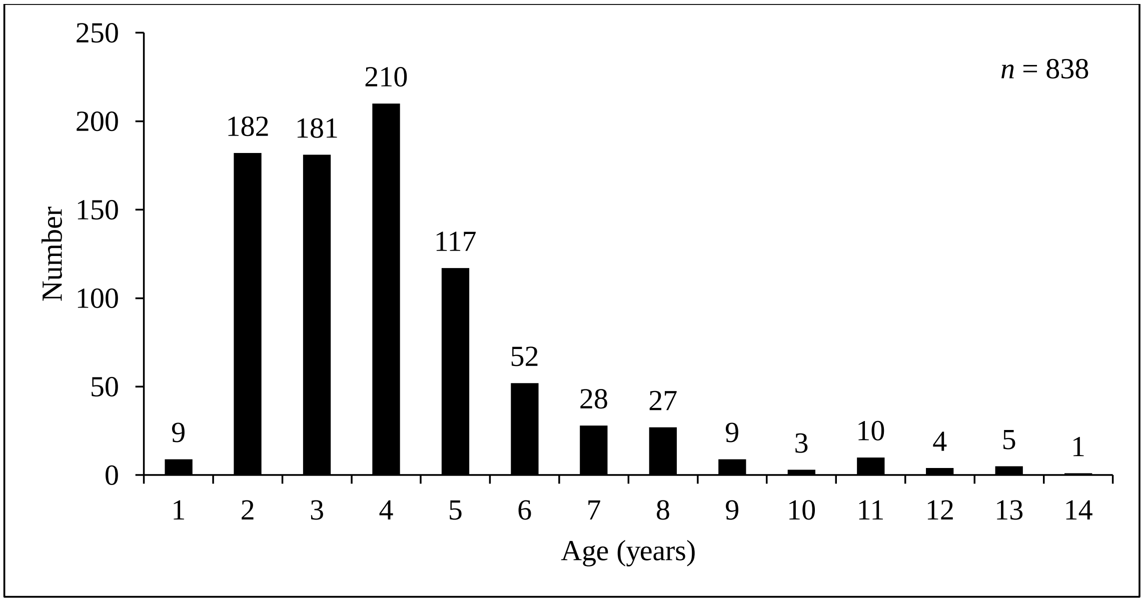


Figure 18. Age frequency (number) of smallmouth bass captured, Priest Rapids Project, Columbia River, Washington, 2009–11. *n*, total number of fish.

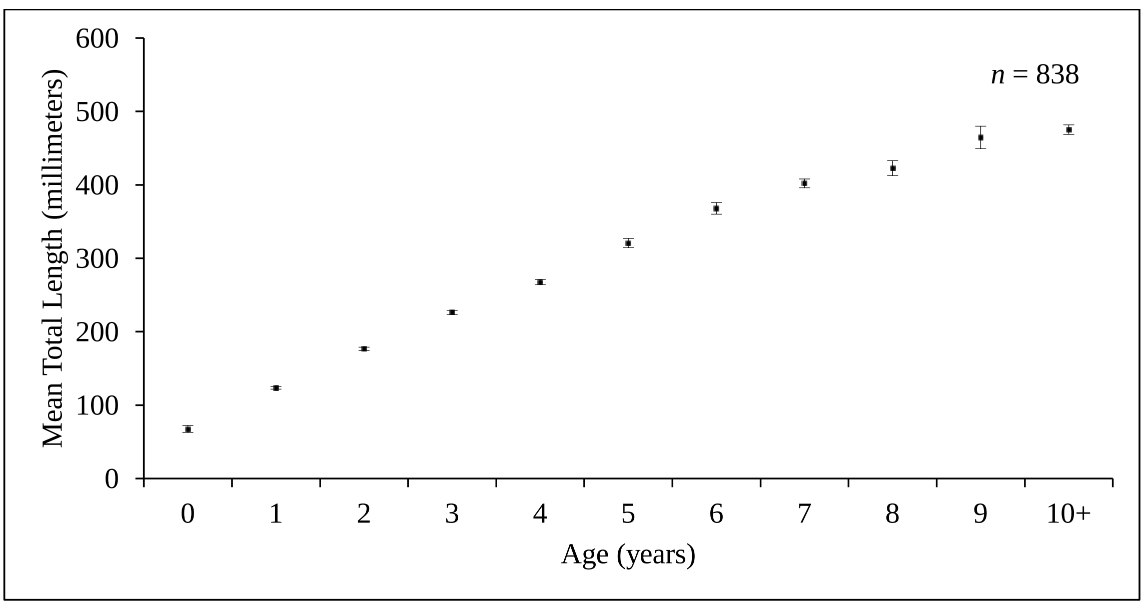


Figure 19. Mean length at age and one standard error for smallmouth bass captured Priest Rapids Project, Columbia River, Washington, 2009–11. Fish 10 years old and older are combined. *n*, total number of fish.

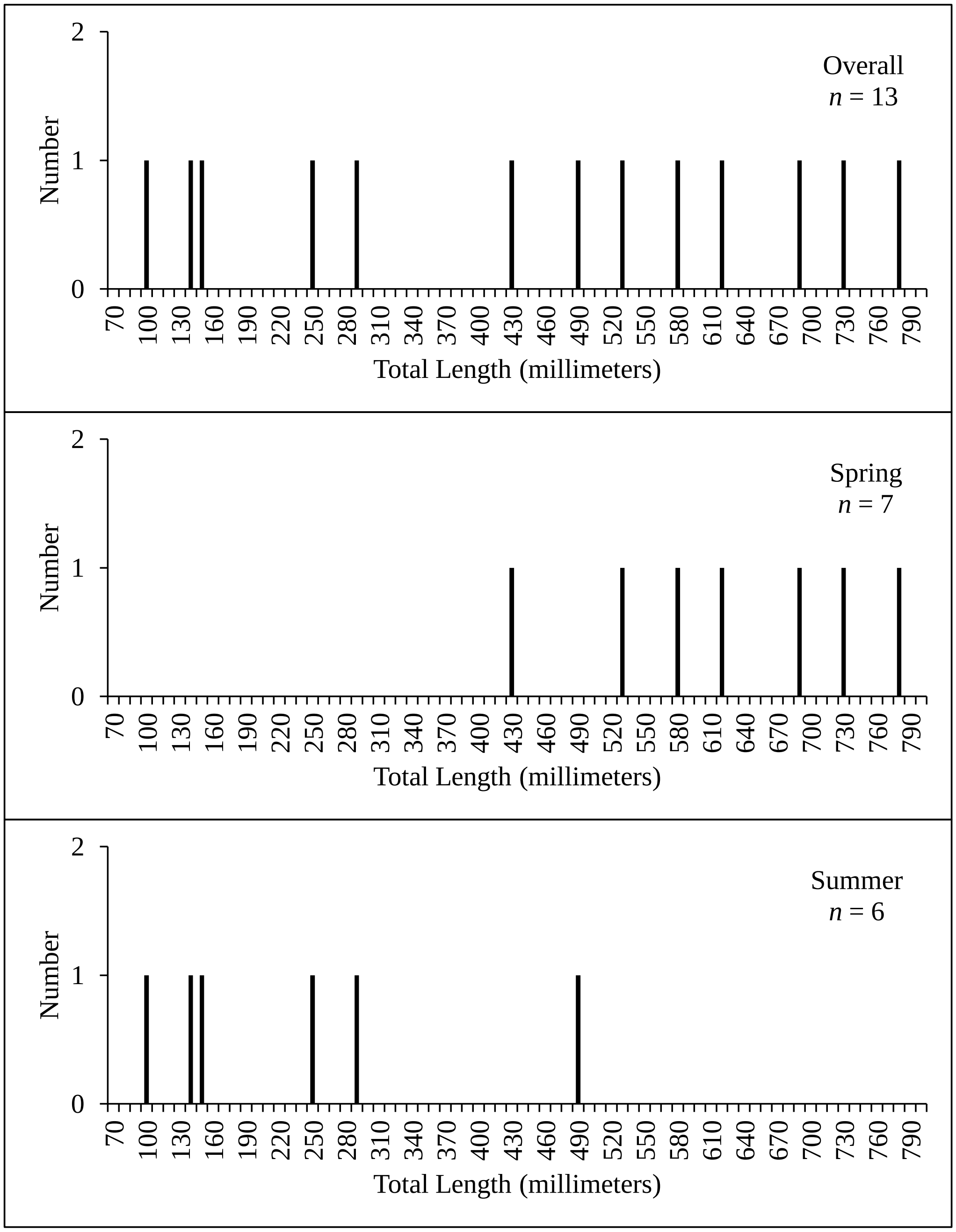


Figure 20. Length frequency histograms for walleye during Burley and Poe sampling overall in 2009 (May 27–June 12 and August 3–20), in spring 2009 (May 27–June 12), and in summer 2009 (August 3–20), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

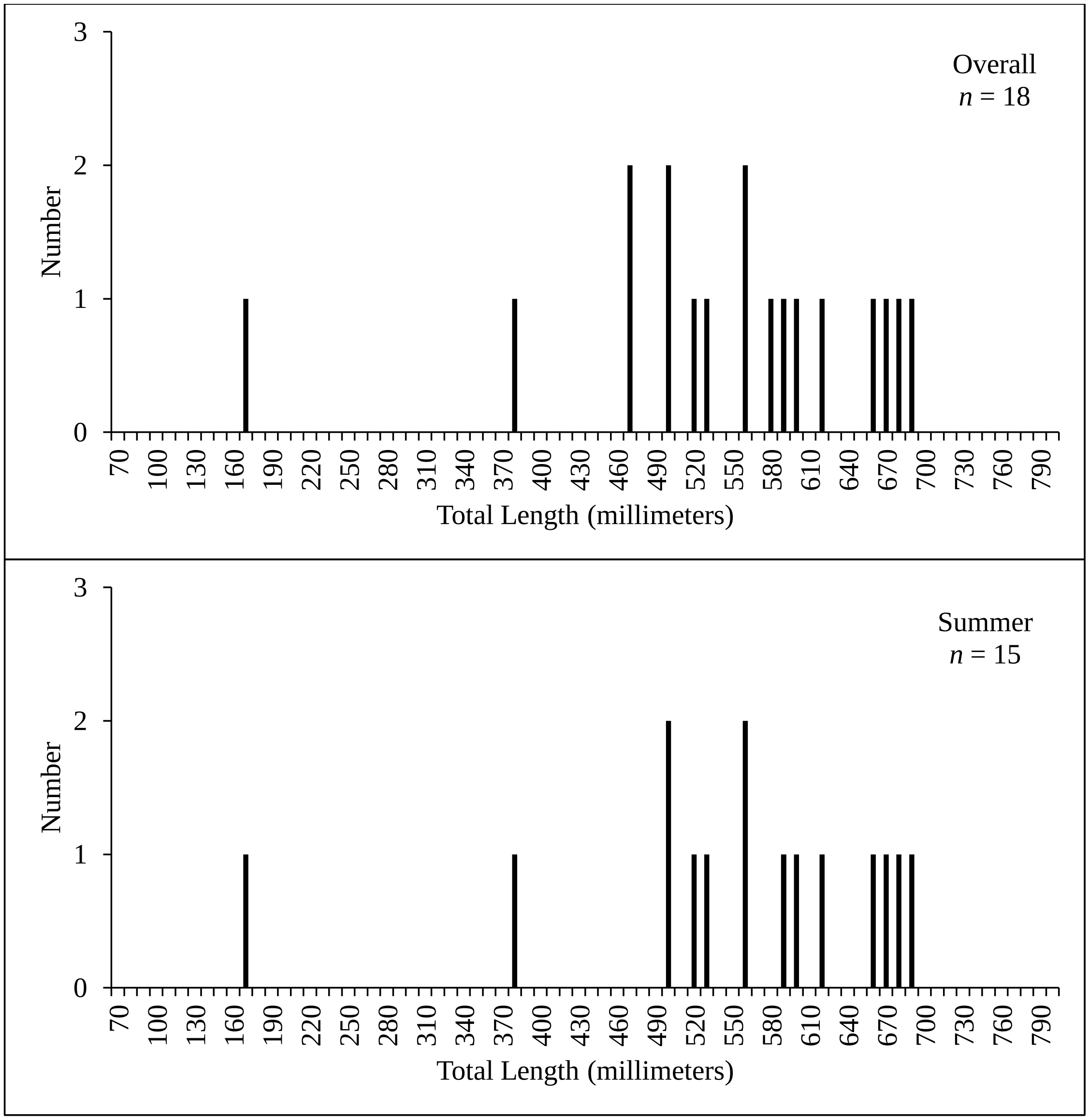


Figure 21. Length frequency histogram for walleye during predator index sampling overall in 2009 (May 1–August 27), and in summer 2009 (August 3–20), Priest Rapids Project, Columbia River, Washington. There were not enough fish captured in 2009 during night electrofishing sampling to generate length frequency histograms for spring or by reservoir. *n*, total number of fish.

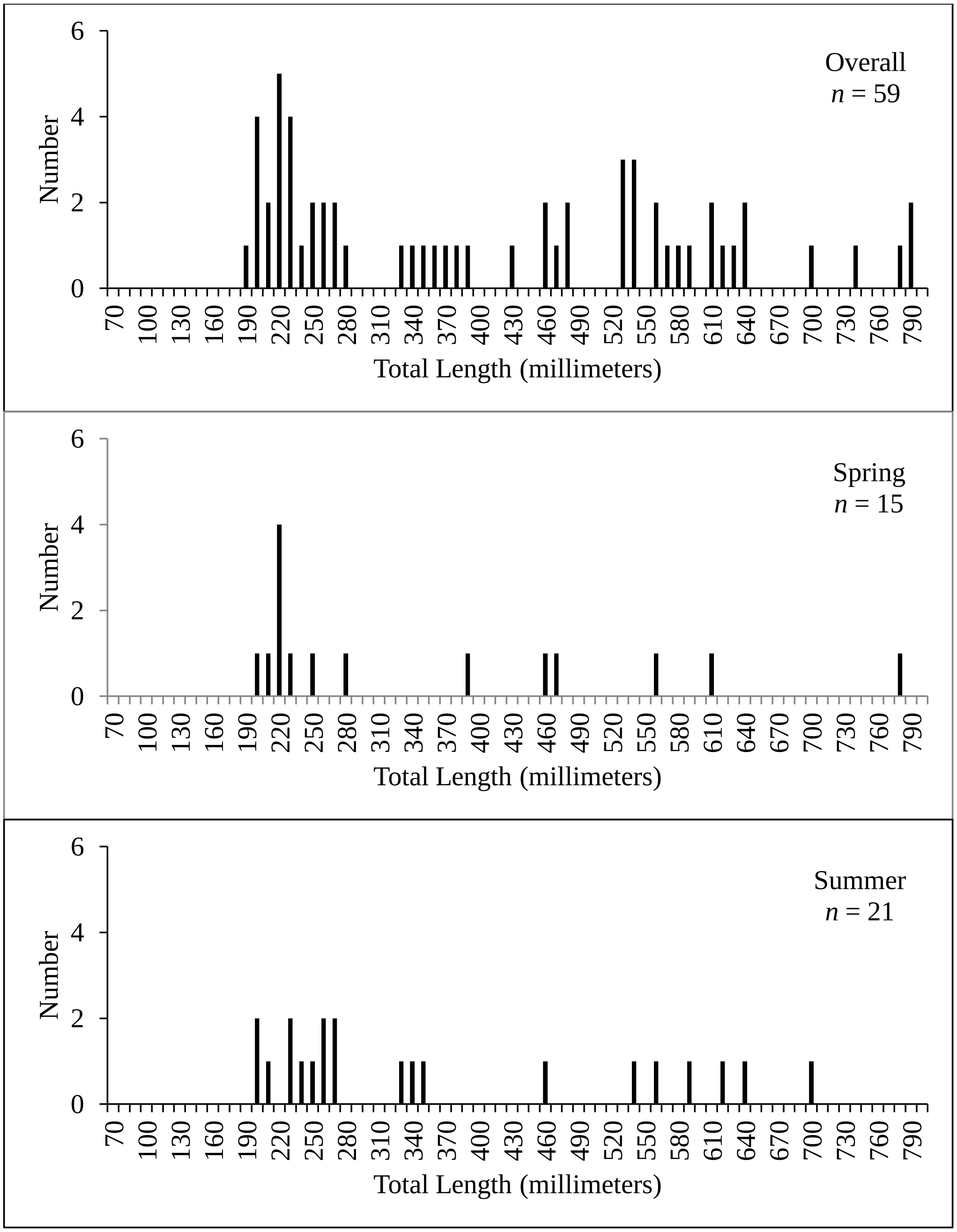


Figure 22. Length frequency histograms for walleye during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 19–June 8), and in summer 2010 (June 28–August 11), Priest Rapids Project, Columbia River, Washington. *n*, total number of fish.

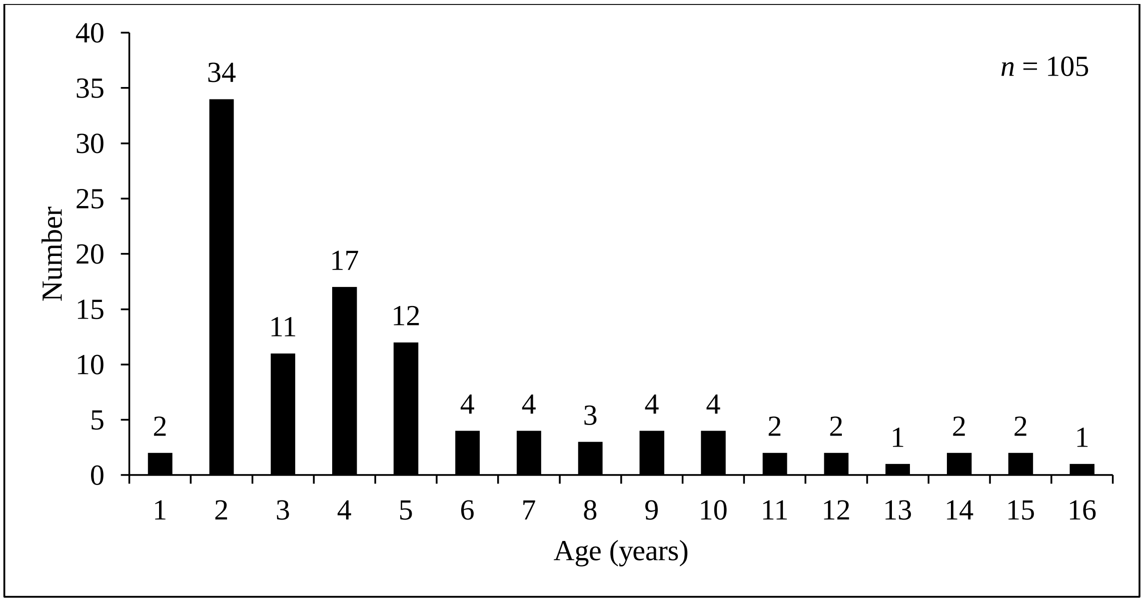


Figure 23. Age frequency (number) of walleye captured, Priest Rapids Project, Columbia River, Washington, 2009–11. *n*, total number of fish.

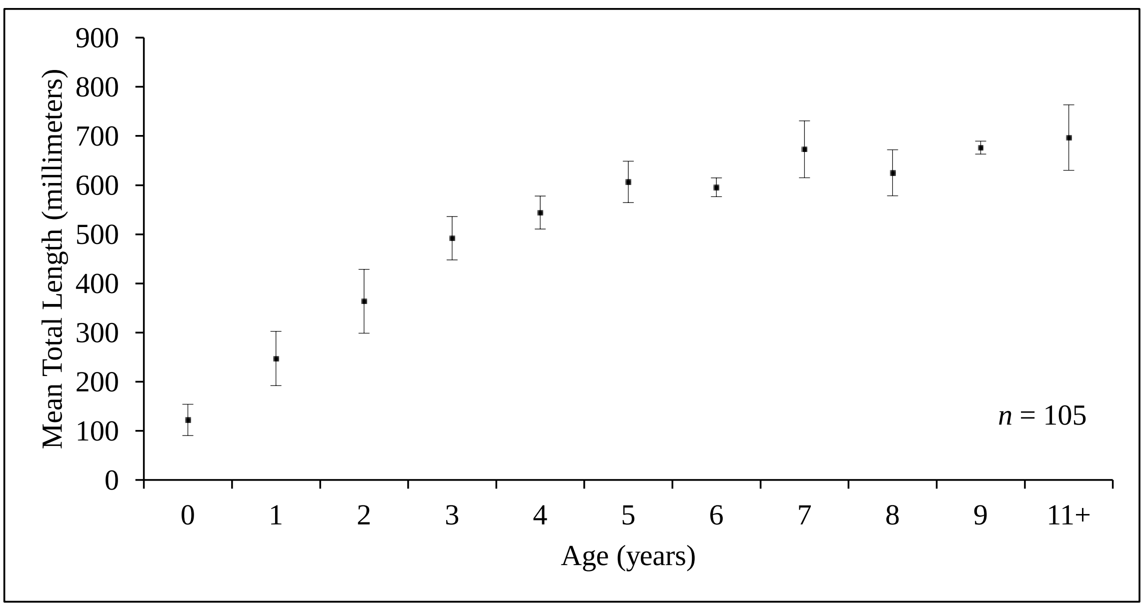


Figure 24. Mean length at age and one standard error for walleye captured, Priest Rapids Project, Columbia River, Washington, 2009–11. Fish 11 years old and older are combined. *n*, total number of fish.

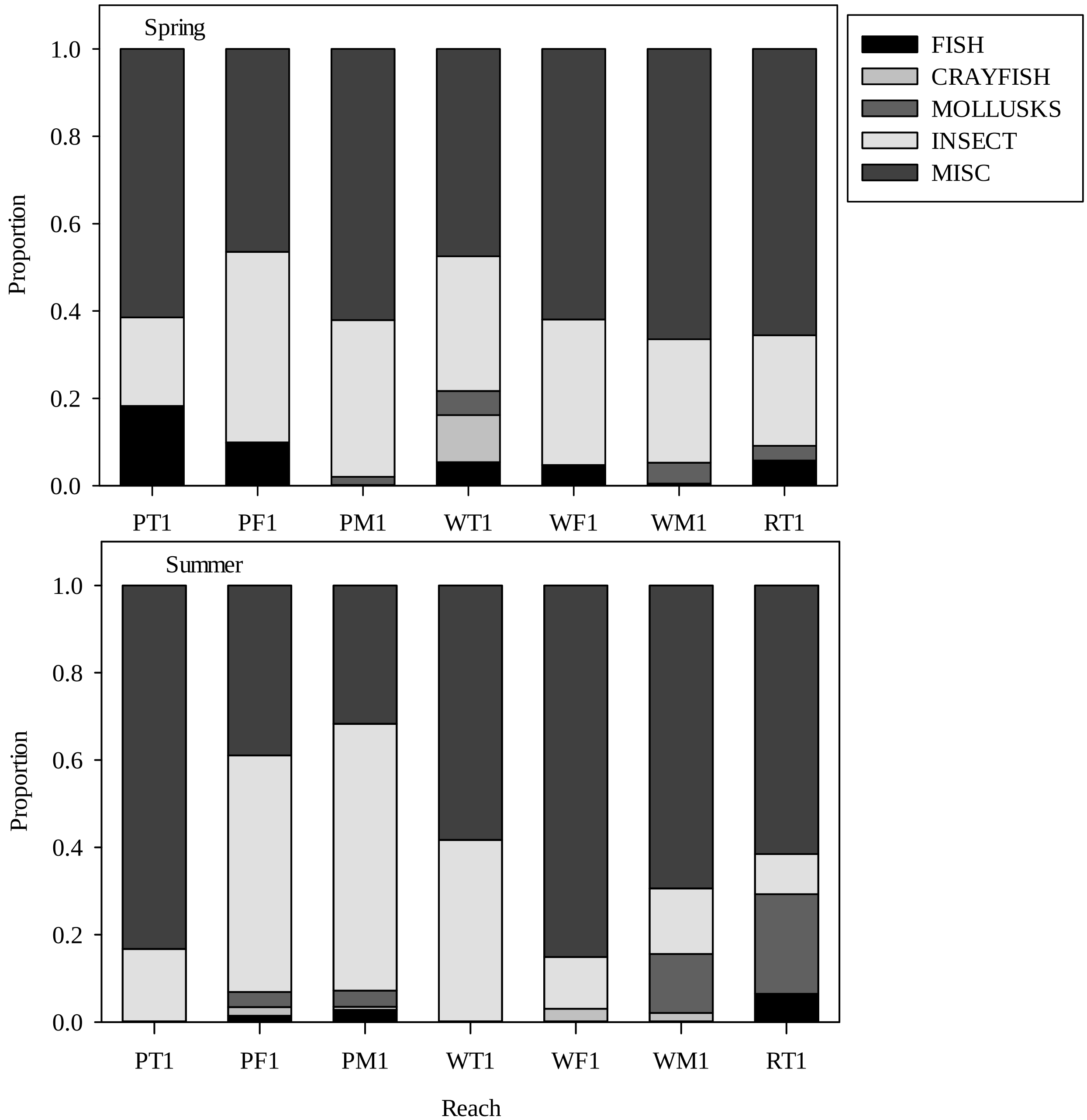


Figure 25. Proportion of diet for northern pikeminnow during Burley and Poe sampling in spring 2009 (May 27–June 12) and summer 2009 (August 3–20), by reaches, Priest Rapids Project, Columbia River, Washington. Reaches with no column indicate no diet sample. Reach locations: PT1, Priest Rapids Tailrace; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

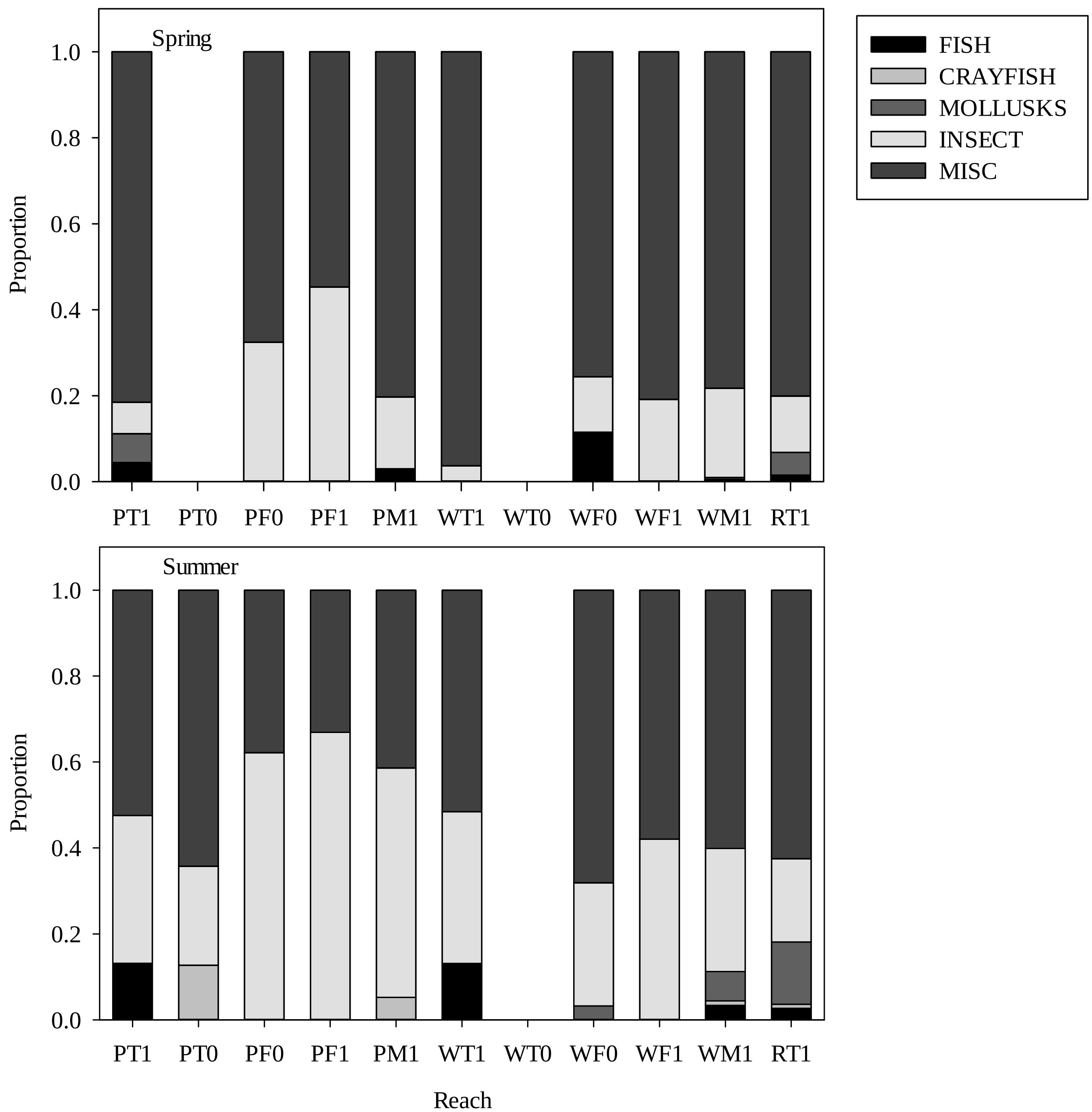


Figure 26. Proportion of diet for northern pikeminnow during Predator index sampling in spring 2009 (May 7–June 11) and summer 2009 (June 23 - August 5), by reaches, Priest Rapids Project, Columbia River, Washington. Reaches with no column indicate no diet sample. Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

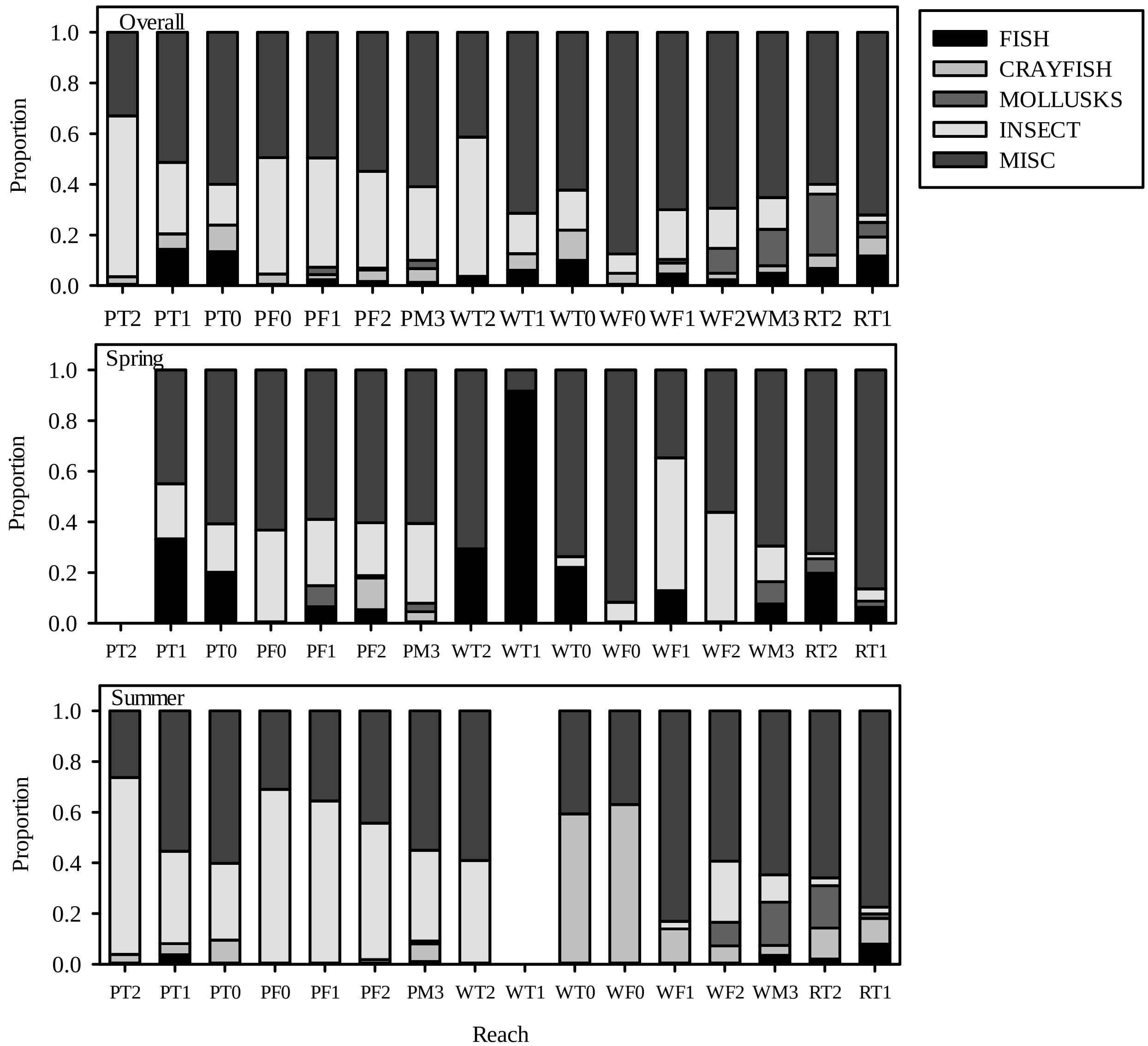


Figure 27. Proportion of diet of northern pikeminnow collected during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 2–June 9), and in summer 2010 (June 27–August 11), by reaches, Priest Rapids Project, Columbia River, Washington. Reaches with no column indicate no diet sample. Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.

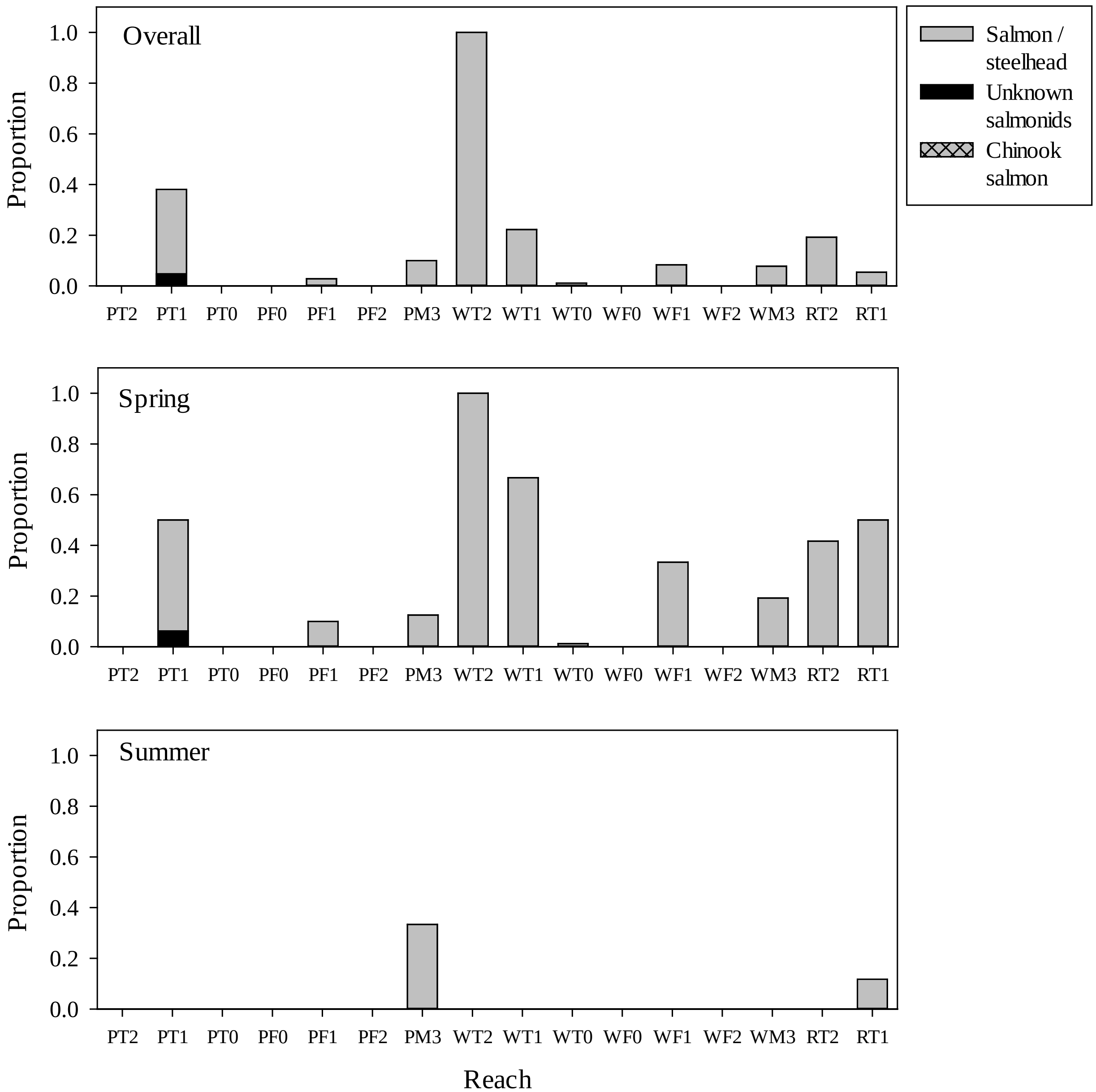


Figure 28. Proportion of fish that are salmon in the diets of northern pikeminnow during predator index sampling in 2010 overall (May 19–September 3), in spring 2010 (May 2–June 9), and summer 2010 (June 27 - August 11), by reach, Priest Rapids Project, Columbia River, Washington. Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.

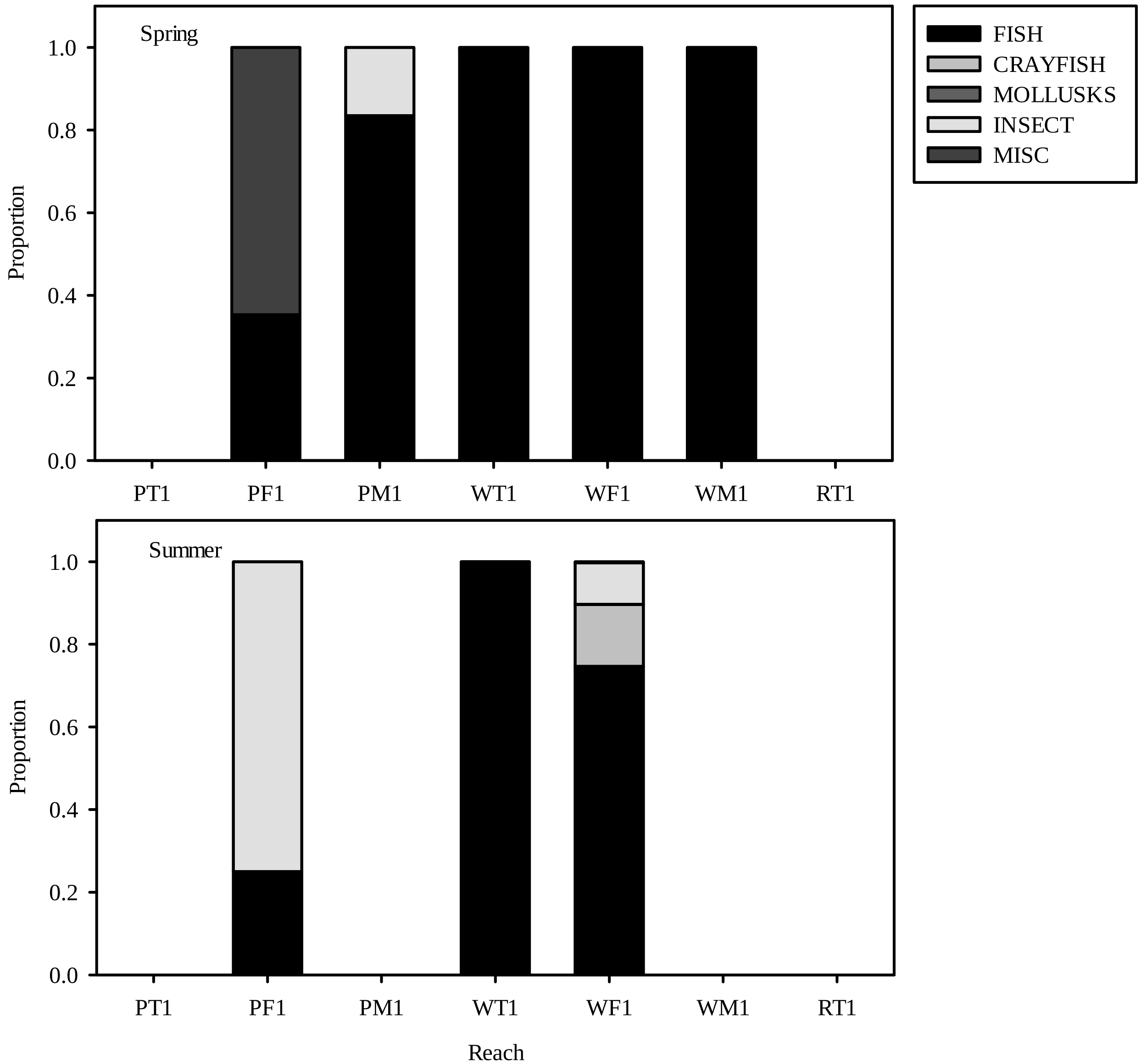


Figure 29. Proportion of diet for smallmouth bass during Burley and Poe sampling in spring 2009 (May 27–June 12) and in summer 2009 (August 3–20), by reaches, Priest Rapids Project, Columbia River, Washington. Reaches with no column indicate no diet sample. Reach locations: PT1, Priest Rapids Tailrace; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

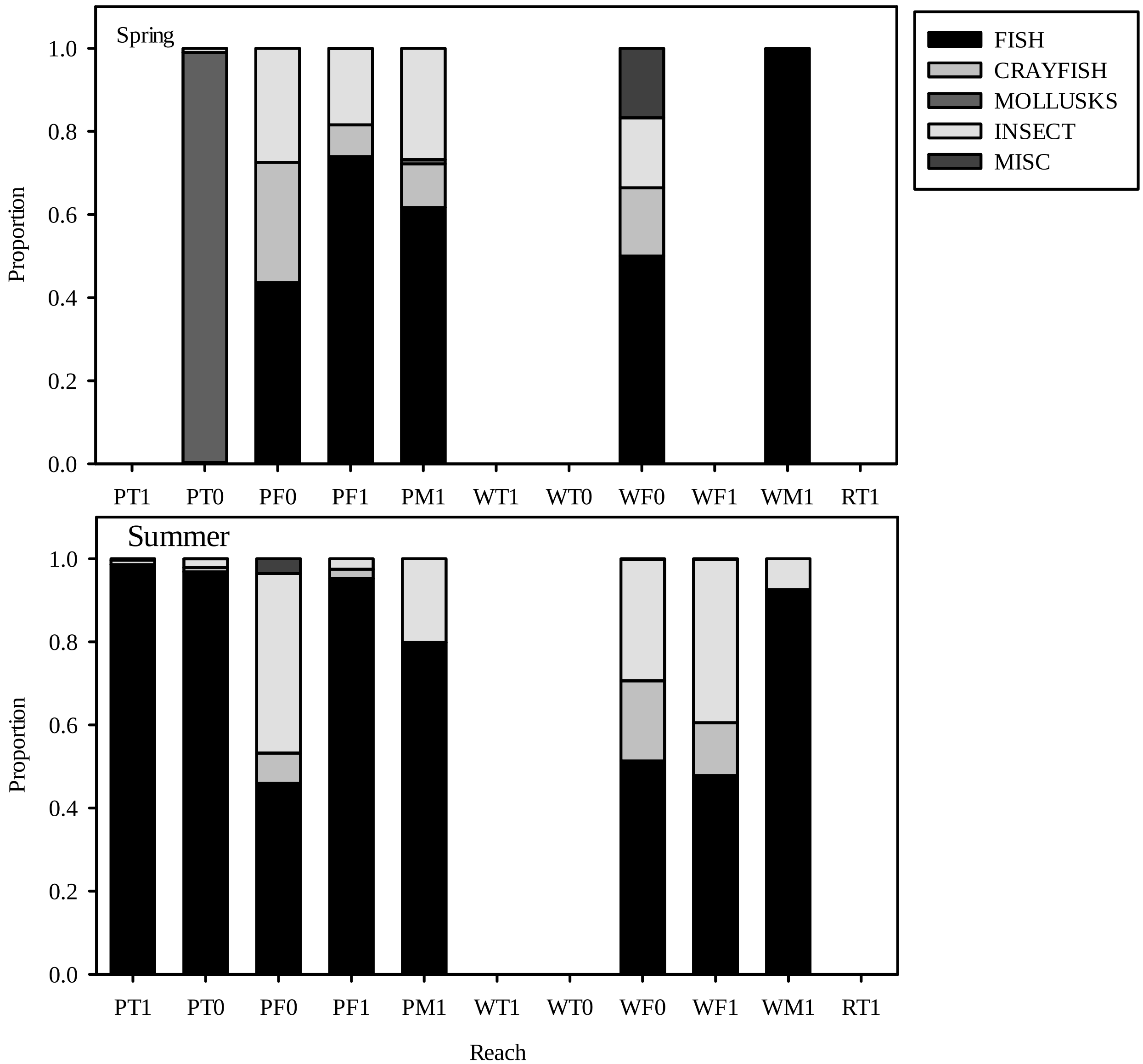


Figure 30. Proportion of diet for smallmouth bass during predator index sampling in spring 2009 (May 7–June 11) and summer 2009 (June 23 - August 5), by reaches, Priest Rapids Project, Columbia River, Washington. Reaches with no column indicate no diet sample. Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM1, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace.

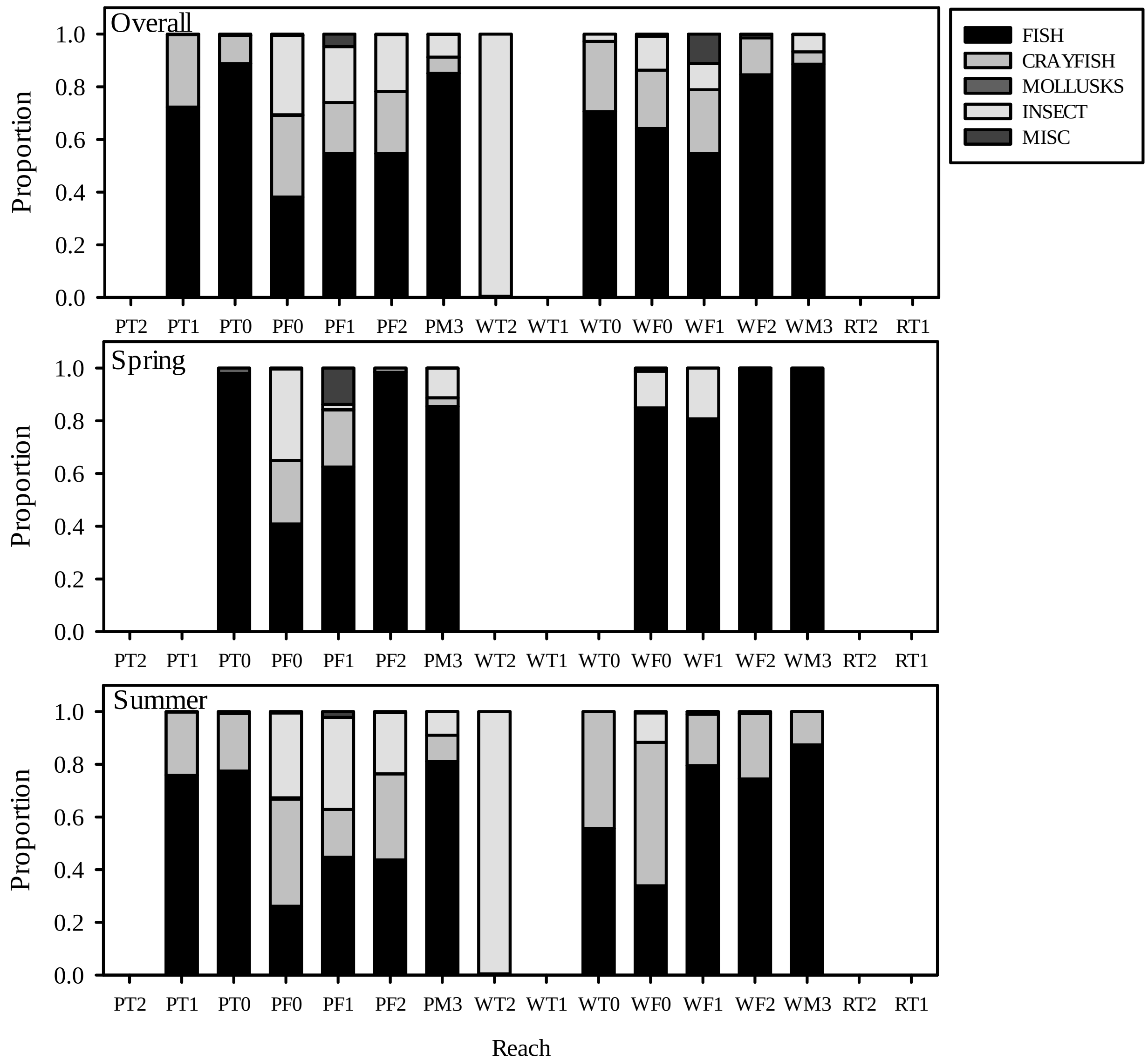


Figure 31. Diet composition of smallmouth bass captured during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 2–June 9), and in summer 2010 (June 27–August 11), by reaches, Priest Rapids Project, Columbia River, Washington. Reaches with no column indicate no diet sample. Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.

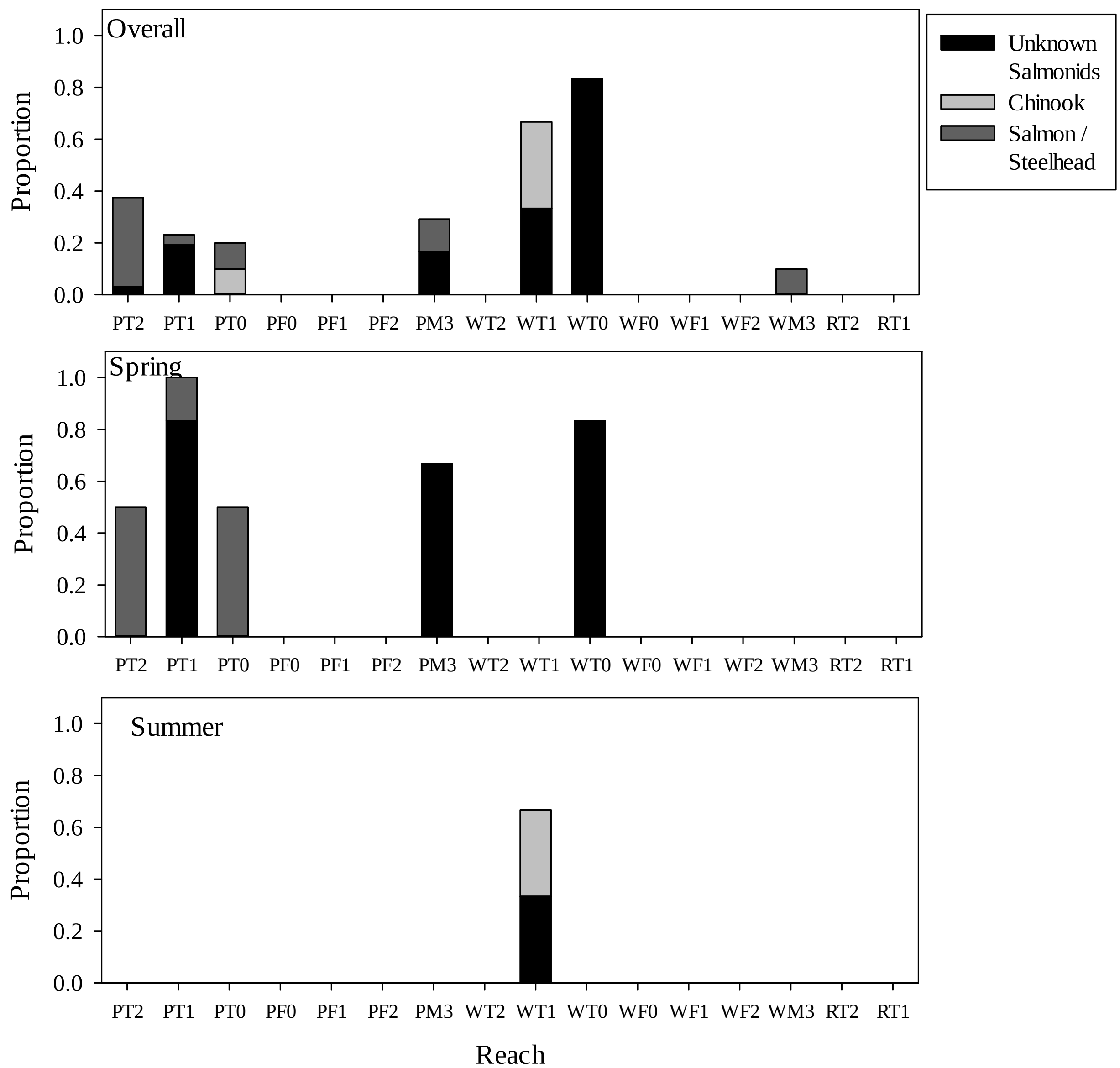


Figure 32. Proportion of fish in diet of walleye that are salmon during predator index sampling overall in 2010 (May 19–September 3), in spring 2010 (May 19– June 8), and in summer 2010 (June 28–August 11) by reaches, Priest Rapids Project, Columbia River, Washington. Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.

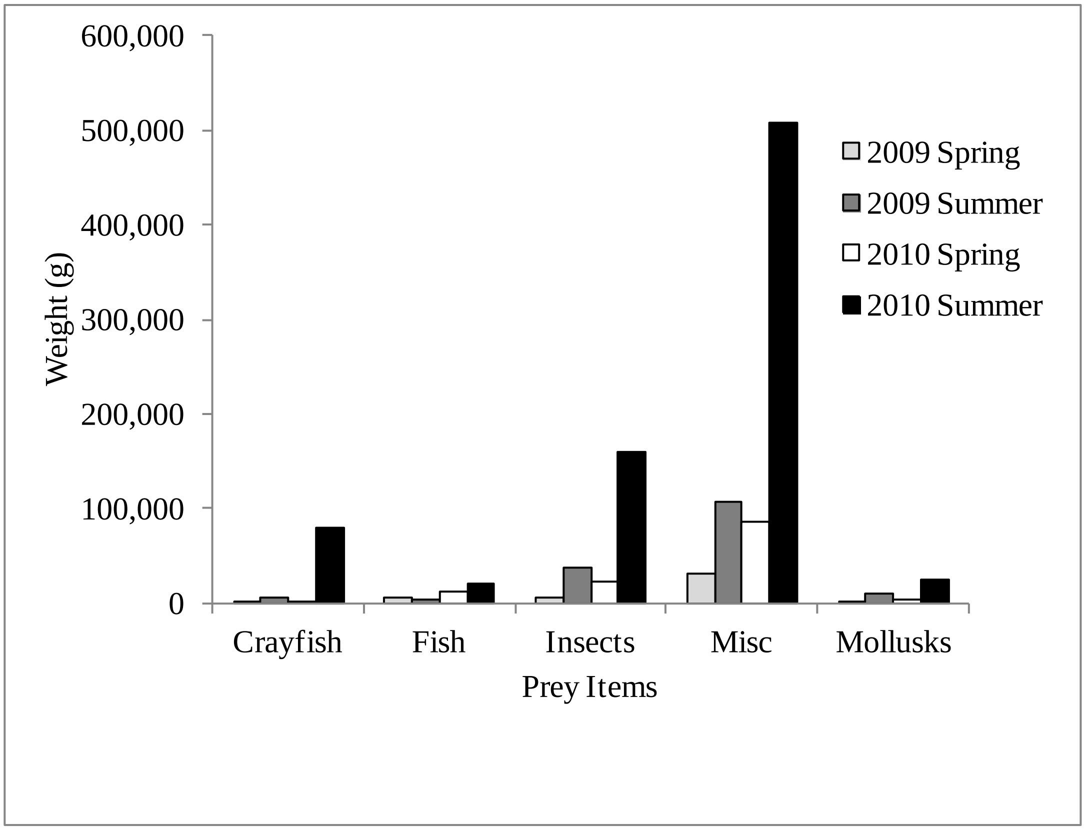


Figure 33. Estimated weights of prey items consumed by northern pikeminnow during the 2009 and 2010 study periods using bioenergetics modeling. Bioenergetics modeling was based on the diets of 928 and 1,118 individuals during the 2009 and 2010 study periods, respectively.

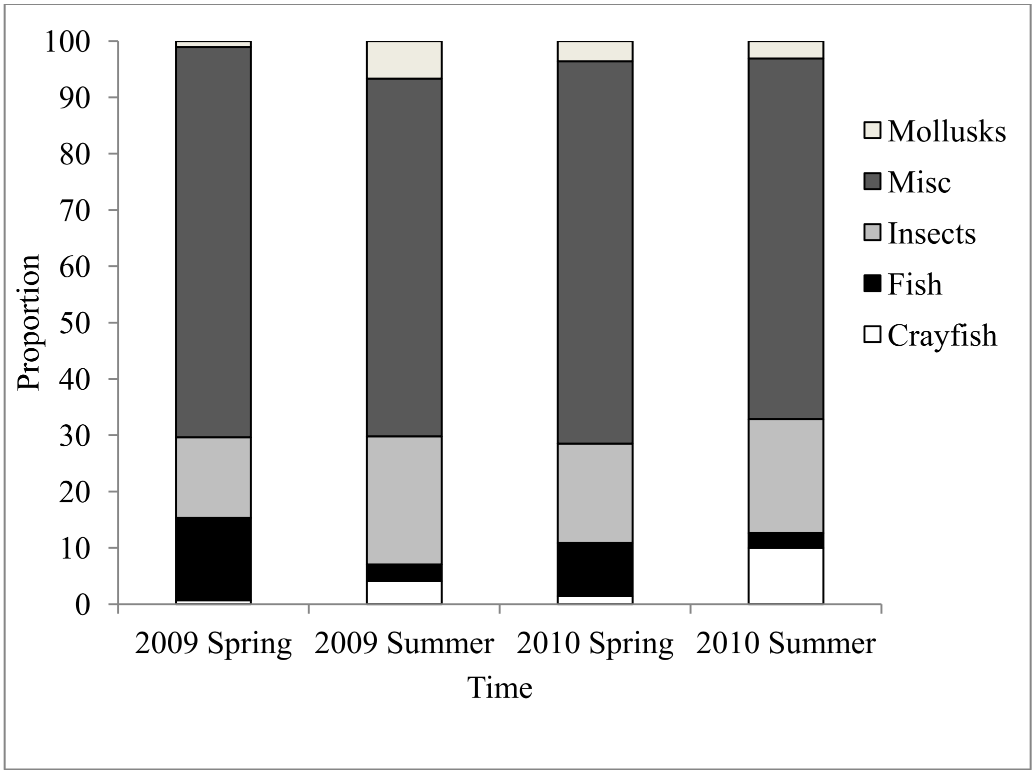


Figure 34. Proportion of prey items consumed by northern pikeminnow from bioenergetics modeling during the 2009 and 2010 study periods. Bioenergetics modeling was based on the diets of 928 and 1,118 individuals during the 2009 and 2010 study periods, respectively.

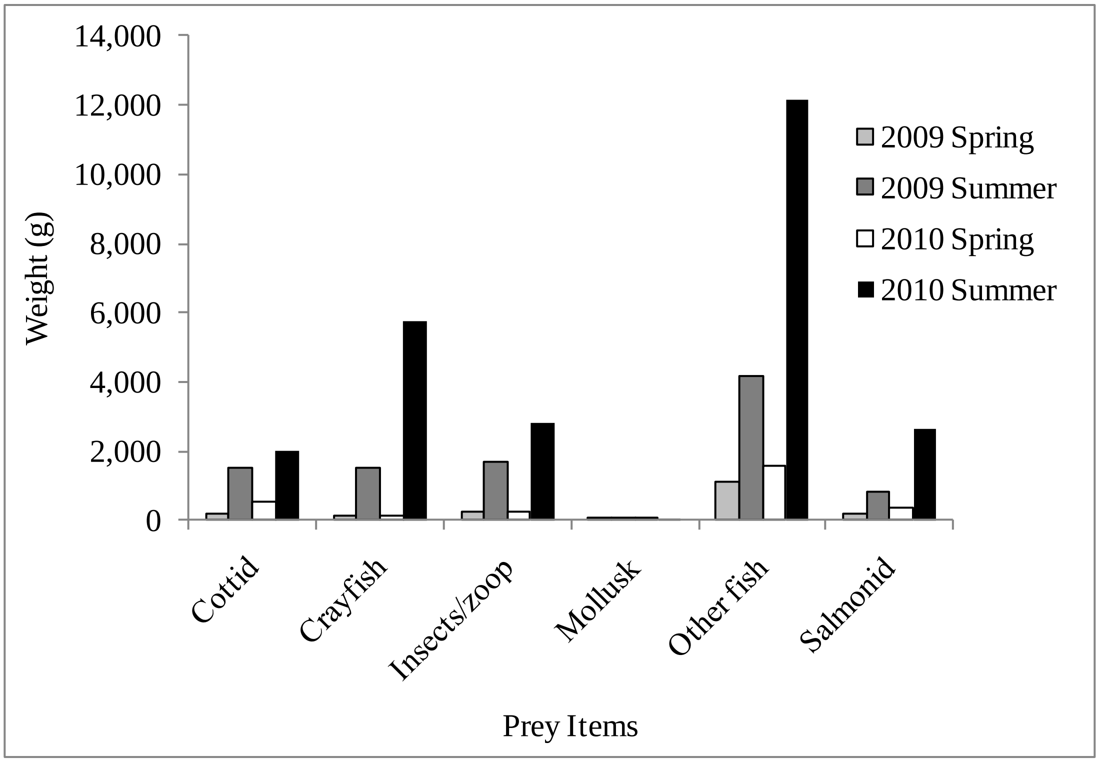


Figure 35. Estimated weights of prey items consumed by smallmouth bass during the 2009 and 2010 study periods using bioenergetics modeling. Bioenergetics modeling was based on the diets of 165 and 372 individuals during the 2009 and 2010 study periods, respectively.

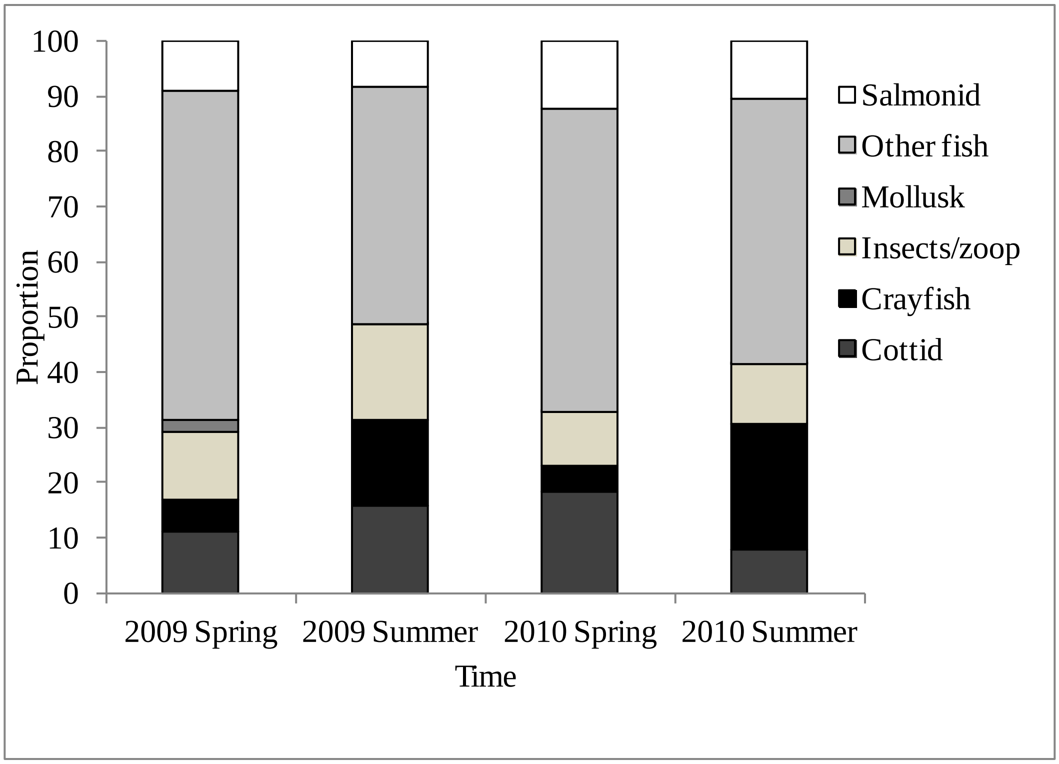


Figure 36. Proportion of prey items consumed by smallmouth bass from bioenergetics modeling during the 2009 and 2010 study periods. Bioenergetics modeling was based on the diets of 165 and 372 individuals during the 2009 and 2010 study periods, respectively.

Table 1. Estimated area of each reach that is less than 3 meters in depth, Priest Rapids Project, Columbia River, Washington, 2009–10.

[BRZ, Boat Restricted Zone in the forebay and tailrace of each dam; HA, hectares; <, less than; M, meters]

YEAR	RESERVOIR	REACHES	AREA (HA) < 3 M DEPTH
2009	Hanford	Priest Rapids Tailrace	120.75
2009	Hanford	Priest Rapids Tailrace BRZ	11.11
2009	Priest Rapids	Priest Rapids Forebay BRZ	0.576
2009	Priest Rapids	Priest Rapids Forebay	101.86
2009	Priest Rapids	Priest Rapids Mid-Reservoir	89.18
2009	Priest Rapids	Wanapum Tailrace	174.51
2009	Priest Rapids	Wanapum Tailrace BRZ	2.33
2009	Wanapum	Wanapum Forebay BRZ	4.44
2009	Wanapum	Wanapum Forebay	134.90
2009	Wanapum	Wanapum Mid-Reservoir	74.88
2009	Wanapum	Rock Island Tailrace	30.46
2010	Hanford	Priest Rapids Tailrace	116.73
2010	Hanford	Priest Rapids Tailrace near-BRZ	2.12
2010	Hanford	Priest Rapids Tailrace BRZ	2.82
2010	Priest Rapids	Priest Rapids Forebay BRZ	1.37
2010	Priest Rapids	Priest Rapids Forebay near-BRZ	5.30
2010	Priest Rapids	Priest Rapids Forebay	88.89
2010	Priest Rapids	Priest Rapids Mid-Reservoir	176.21
2010	Priest Rapids	Wanapum Tailrace	155.1
2010	Priest Rapids	Wanapum Tailrace near-BRZ	19.71
2010	Priest Rapids	Wanapum Tailrace BRZ	3.16
2010	Wanapum	Wanapum Forebay BRZ	3.36
2010	Wanapum	Wanapum Forebay near-BRZ	4.11
2010	Wanapum	Wanapum Forebay	133.37
2010	Wanapum	Wanapum Mid-Reservoir	295.37
2010	Wanapum	Rock Island Tailrace	28.13
2010	Wanapum	Rock Island Tailrace near-BRZ	2.39

Table 2. Percentage of each age class of northern pikeminnow and smallmouth bass captured in 2009 and 2010 in less than 3 m depth in the Priest Rapids Project, Columbia River, Washington.

[Composition is based on the total number of each species sampled during the field season]

	2009		2010	
Age	Northern Pikeminnow	Smallmouth Bass	Northern Pikeminnow	Smallmouth Bass
0	54.0			
1	14.2		12.5	
2	7.5	30.9	13.6	36.6
3	7.0	26.1	24.2	24.2
4	5.4	21.2	19.7	16.9
5	4.2	14.5	12.8	12.1
6	2.6	7.3	7.0	4.8
7	1.6		3.9	1.9
8	1.4		2.7	3.5
9	2.0		3.6	

Table 3. Catch of northern pikeminnow in 10 minute period during Burley and Poe sampling in spring (May 27–June 12) and summer (August 3–20), and during predator index sampling in spring (May 7–June 11) and summer (June 23 - August 5), by reaches, Priest Rapids Project, Columbia River, Washington, 2009.

[Catch per unit effort for Burley and Poe (2009) represents catches of northern pikeminnow greater than 250 millimeters and smallmouth bass greater than 150 millimeters, and for Predator Index 2009 represents catches of northern pikeminnow greater than 170 mm and smallmouth bass greater than 150 millimeters. Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ (Boat Restricted Zone); PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT1, Rock Island Tailrace]

	Catch per 10 minutes							
	Northern pikeminnow				Smallmouth bass			
	Burley and Poe 2009		Predator Index 2009		Burley and Poe 2009		Predator Index 2009	
Reaches	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer
PT1	0.004	0.002	0.012	0.011	0.001	0	0	0.002
PT0	[a]	[a]	0[b]	0.020	[a]	[a]	0.010	0.012
PF0	[a]	[a]	0.007	0.010	[a]	[a]	0.033	0.098
PF1	0.004	0.018	0.009	0.005	0.015	0.012	0.012	0.012
PM3	0.010	0.023	0.026	0.009	0.019	0.003	0.020	0.007
WT1	0.002	0.002	0.003	0.005	0.002	0.002	0	0
WT0	[a]	[a]	0[b]	[c]	[a]	[a]	0	[c]
WF0	[a]	[a]	0.075	0.040	[a]	[a]	0.030	0.035
WF1	0.021	0.013	0	0.016	0.007	0.017	0	0.008
WM3	0.022	0.028	0.039	0.036	0.003	0.0004	0.001	0.006
RT1	0.026	0.038	0.072	0.037	0	0	0	0

a- Boat restricted zones were not sampled as part of the 2009 Burley and Poe sampling due to logistical restraints.
b- Only one electrofishing effort was conducted.
c- Not sampled.

Table 4. Catch of northern pikeminnow (greater than 170 millimeters in length) and smallmouth bass (greater than 150 millimeters in length) per 10 minute period captured during electrofishing runs in spring (May 2–June 9) and summer 2010 (June 27–August 11), by reaches, Priest Rapids Project, Columbia River, Washington.

[Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.]

	Catch per 10 minutes			
	Northern pikeminnow		Smallmouth bass	
Reaches	Spring 2010	Summer 2010	Spring 2010	Summer 2010
PT2	0	0.011	0	0
PT1	0.127	0.064	0	0.010
PT0	0.080	0.008	0.015	0.016
PF0	0.075	0.035	0.155	0.100
PF1	0.018	0.021	0.036	0.087
PF2	0.032	0.033	0.010	0.028
PM3	0.030	0.034	0.020	0.015
WT2	0.030	0.005	0	0.002
WT1	0.046	0	0	0
WT0	0.074	0.025	0	0.020
WF0	0.060	0.010	0.110	0.060
WF1	0.027	0.017	0.013	0.033
WF2	0.006	0.019	0.010	0.007
WM3	0.091	0.098	0.001	0.005
RT2	0.043	0.055	0	0
RT1	0.036	0.052	0	0

Table 5. Predation indices estimated during the Burley and Poe sampling (Burley and Poe, 2009) in spring (May 27–June 12) and summer 2009 (August 3–20), and during Burley and Poe's 1993 study (Burley and Poe, 1994).

[Values presented for Burley and Poe's original study were estimated using a different density index (proportion of positive efforts) that was calculated from the values presented in their report and using different estimates of the areal extent of the proportion of the relevant reaches less than 3 meters in depth]

	Predation Index			
	Northern pikeminnow			
	Burley and Poe 2009		Burley and Poe 1993	
Reaches	Spring	Summer	Spring	Summer
PT1	31.0	0	71.0	109
PF1	0	0	2.38	0
PM3	0	0	0	0
WT1	7.57	0	56.5	120
WF1	2.13	0	17.1	0
WM3	9.42	0	0	0
RT1	0	0	11.6	1.29

Table 6. Predation indices and standard errors (in parentheses) estimated for northern pikeminnow and smallmouth bass captured during predator index sampling in spring (May 7–June 11) and summer 2009 (June 23–August 5), by reaches, Priest Rapids Project, Columbia River, Washington.

[Reach locations: PT1, Priest Rapids Tailrace; PT0, Priest Rapids Tailrace BRZ (Boat Restricted Zone); PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay; PM1, Priest Rapids Mid-Reservoir; WT1, Wanapum Tailrace; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay; WM1,Wanapum Mid-Reservoir; RT1,Rock Island Tailrace]

	Predation Index			
	Northern pikeminnow		Smallmouth bass	
Reaches	Spring 2009	Summer 2009	Spring 2009	Summer 2009
PT1	1.754 (1.637)	0.565(0.565)	0	1.073 (1.073)
PT0	0	0	0	0
PF0	0	0	0.002 (0.002)	0.012 (0.007)
PF1	0	0	0.0.129 (0.129)	0
PM1	0	0	0.240 (0.240)	0.225 (0.225)
WT1	0	0	0	0
WT0	0	0	0	[a]
WF0	0	0	0	0
WF1	0	0	0	0
WM1	0	0	0	0.306 (0.306)
RT1	0	0	0	0

[a] - Not sampled

Table 7. Predation indices and standard errors (in parentheses) estimated for northern pikeminnow and smallmouth bass captured during predator index sampling in spring (May 2–June 9), and summer 2010 (June 27–August 11), by reaches, Priest Rapids Project, Columbia River, Washington.

[Reach locations: PT2, Priest Rapids Tailrace; PT1, Priest Rapids Tailrace near-BRZ; PT0, Priest Rapids Tailrace BRZ; PF0, Priest Rapids Forebay BRZ; PF1, Priest Rapids Forebay near-BRZ; PF2, Priest Rapids Forebay; PM3, Priest Rapids Mid-Reservoir; WT2, Wanapum Tailrace; WT1, Wanapum Tailrace near-BRZ; WT0, Wanapum Tailrace BRZ; WF0, Wanapum Forebay BRZ; WF1, Wanapum Forebay near-BRZ; WF2, Wanapum Forebay; WM3, Wanapum Mid-Reservoir; RT2, Rock Island Tailrace; RT1, Rock Island Tailrace near-BRZ.]

	Predation Index			
	Northern pikeminnow		Smallmouth bass	
Reaches	Spring 2010	Summer 2010	Spring 2010	Summer 2010
PT2	0	0	0	0
PT1	0.117 (0.051)	0	0	0
PT0	0	0	0	0.0
PF0	0	0	0.015 (0.015)	0.012 (0.012)
PF1	0	0	0.114 (0.114)	0.038 (0.025)
PF2	0	0	0	1.055 (0.776)
PM3	0.421(0.421)	0.196 (0.196)	5.940 (2.731)	1.760 (1.152)
WT2	1.018 (1.018)	0	0	0
WT1	0.157 (0.157)	0	0	0
WT0	0.015 (0.015)	0	0	0
WF0	0	0	0.090 (0.090)	0.109 (0.044)
WF1	0.011 (0.011)	0	0	0.113 (0.113)
WF2	0	0	0	0
WM3	1.918 (1.211)	0	0	0
RT2	0.274 (0.184)	0	0	0
RT1	0.011 (0.011)	0.016 (0.016)	0	0

Publishing support provided by the U.S. Geological Survey
Publishing Network, Tacoma Publishing Service Center

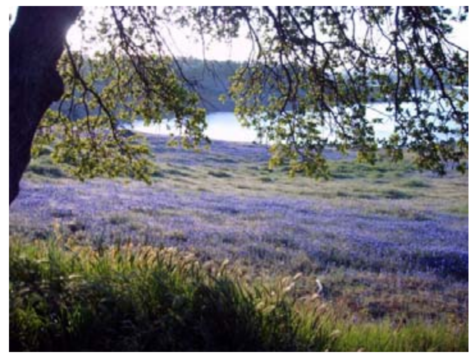
For more information concerning the research in this report, contact the
Director, Western Fisheries Research Center
U.S. Geological Survey
6505 NE 65th Street
Seattle, WA 98115
http://wfrc.usgs.gov/

Counihan and others—**Assessing Native and Introduced Fish Predation on Migrating Juvenile Salmon, Priest Rapids and Wanapum Reservoirs, Columbia River, Wash., 2009–11**—Open-File Report 2012–1130

PREDATION

STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299





Prepared for:
Turlock Irrigation District – Turlock, California
Modesto Irrigation District – Modesto, California

Prepared by:
FISHBIO

January 2013

Predation
Study Report

TABLE OF CONTENTS

List of Figures

List of Tables

List of Attachments

List of Acronyms

ac ....acres

ACEC ....Area of Critical Environmental Concern

AF ....acre-feet

ACOE.........................U.S. Army Corps of Engineers

ADA ....Americans with Disabilities Act

ALJ.............................Administrative Law Judge

APE ....Area of Potential Effect

ARMR........................Archaeological Resource Management Report

ATR…………………Acoustic Tag Receiver

ATS…………………Acoustic Tag Tracking System

BA ....Biological Assessment

BDCP ....Bay-Delta Conservation Plan

BLM...........................U.S. Department of the Interior, Bureau of Land Management

BLM-S ....Bureau of Land Management – Sensitive Species

BMI ....Benthic macroinvertebrates

BMP ....Best Management Practices

BO ....Biological Opinion

CalEPPC ....California Exotic Pest Plant Council

CalSPA.......................California Sports Fisherman Association

CAS............................California Academy of Sciences

CCC............................Criterion Continuous Concentrations

CCIC ....Central California Information Center

CCSF..........................City and County of San Francisco

CCVHJV ....California Central Valley Habitat Joint Venture

CD ....Compact Disc

CDBW........................California Department of Boating and Waterways

CDEC ....California Data Exchange Center

CDFA ....California Department of Food and Agriculture

CDFG ....California Department of Fish and Game (as of January 2013, Department of Fish and Wildlife)

CDMG........................California Division of Mines and Geology

CDOF.........................California Department of Finance

CDPH.........................California Department of Public Health

CDPR.........................California Department of Parks and Recreation

CDSOD......................California Division of Safety of Dams

CDWR........................California Department of Water Resources

CE ....California Endangered Species

CEII...........................Critical Energy Infrastructure Information

CEQA.........................California Environmental Quality Act

CESA ....California Endangered Species Act

CFR ....Code of Federal Regulations

cfs..............................cubic feet per second

CGS............................California Geological Survey

CMAP ....California Monitoring and Assessment Program

CMC...........................Criterion Maximum Concentrations

CNDDB......................California Natural Diversity Database

CNPS..........................California Native Plant Society

CORP ....California Outdoor Recreation Plan

CPUE ....Catch Per Unit Effort

CRAM........................California Rapid Assessment Method

CRLF..........................California Red-Legged Frog

CRRF ....California Rivers Restoration Fund

CSAS..........................Central Sierra Audubon Society

CSBP..........................California Stream Bioassessment Procedure

CT ....California Threatened Species

CTR...........................California Toxics Rule

CTS ....California Tiger Salamander

CVRWQCB ....Central Valley Regional Water Quality Control Board

CWA ....Clean Water Act

CWHR........................California Wildlife Habitat Relationship

Districts......................Turlock Irrigation District and Modesto Irrigation District

DLA ....Draft License Application

DPRA.........................Don Pedro Recreation Agency

DPS ....Distinct Population Segment

EA ....Environmental Assessment
EC ....Electrical Conductivity
EFH ....Essential Fish Habitat
EIR ....Environmental Impact Report
EIS..............................Environmental Impact Statement
EPA ............................U.S. Environmental Protection Agency
ESA ....Federal Endangered Species Act
ESRCD.......................East Stanislaus Resource Conservation District
ESU ....Evolutionary Significant Unit
EWUA........................Effective Weighted Useable Area
FERC..........................Federal Energy Regulatory Commission
FFS.............................Foothills Fault System
FL...............................Fork length
FMU...........................Fire Management Unit
FOT ....Friends of the Tuolumne
FPC ....Federal Power Commission
ft/mi............................feet per mile
FWCA ....Fish and Wildlife Coordination Act
FYLF..........................Foothill Yellow-Legged Frog
g..................................grams
GIS ....Geographic Information System
GLO ....General Land Office
GPS ....Global Positioning System
HCP............................Habitat Conservation Plan
HHWP........................Hetch Hetchy Water and Power
HORB ....Head of Old River Barrier
HPMP.........................Historic Properties Management Plan
ILP..............................Integrated Licensing Process
ISR ....Initial Study Report
ITA.............................Indian Trust Assets
kV...............................kilovolt
m ....meters
M&I............................Municipal and Industrial

MCL..........................Maximum Contaminant Level

mg/kg ....milligrams/kilogram

mg/L..........................milligrams per liter

mgd ....million gallons per day

mi ....miles

mi^2 ....square miles

MID...........................Modesto Irrigation District

MOU ....Memorandum of Understanding

MRH…………………Merced River Hatchery

MSCS........................Multi-Species Conservation Strategy

msl.............................mean sea level

MVA ....Megavolt Ampere

MW ....megawatt

MWh ....megawatt hour

mya............................million years ago

NAE ....National Academy of Engineering

NAHC ....Native American Heritage Commission

NAS...........................National Academy of Sciences

NAVD 88..................North American Vertical Datum of 1988

NAWQA ....National Water Quality Assessment

NCCP ....Natural Community Conservation Plan

NEPA ....National Environmental Policy Act

ng/g ....nanograms per gram

NGOs ....Non-Governmental Organizations

NHI ....Natural Heritage Institute

NHPA........................National Historic Preservation Act

NISC ....National Invasive Species Council

NMFS........................National Marine Fisheries Service

NOAA ....National Oceanic and Atmospheric Administration

NOI ....Notice of Intent

NPS ...........................U.S. Department of the Interior, National Park Service

NRCS ....National Resource Conservation Service

NRHP ....National Register of Historic Places

NRI............................Nationwide Rivers Inventory
NTU ....Nephelometric Turbidity Unit
NWI............................National Wetland Inventory
NWIS ....National Water Information System
NWR ....National Wildlife Refuge
NGVD 29 ....National Geodetic Vertical Datum of 1929
O&M ....operation and maintenance
OEHHA......................Office of Environmental Health Hazard Assessment
ORV ....Outstanding Remarkable Value
PAD............................Pre-Application Document
PDO............................Pacific Decadal Oscillation
PEIR...........................Program Environmental Impact Report
PGA............................Peak Ground Acceleration
PHG............................Public Health Goal
PM&E ....Protection, Mitigation and Enhancement
PMF............................Probable Maximum Flood
POAOR ....Public Opinions and Attitudes in Outdoor Recreation
ppb.............................parts per billion
ppm ....parts per million
PSP.............................Proposed Study Plan
QA..............................Quality Assurance
QC ....Quality Control
RA ....Recreation Area
RBP ....Rapid Bioassessment Protocol
Reclamation ...............U.S. Department of the Interior, Bureau of Reclamation
RM ....River Mile
RMP ....Resource Management Plan
RP...............................Relicensing Participant
RSP ....Revised Study Plan
RST ....Rotary Screw Trap
RWF ....Resource-Specific Work Groups
RWG ....Resource Work Group
RWQCB ....Regional Water Quality Control Board

SC..............................State candidate for listing under CESA

SCD...........................State candidate for delisting under CESA

SCE ....State candidate for listing as endangered under CESA

SCT ....State candidate for listing as threatened under CESA

SD1 ....Scoping Document 1

SD2 ....Scoping Document 2

SE..............................State Endangered Species under the CESA

SFP............................State Fully Protected Species under CESA

SFPUC ....San Francisco Public Utilities Commission

SHPO ....State Historic Preservation Office

SJRA ....San Joaquin River Agreement

SJRGA ....San Joaquin River Group Authority

SJTA ....San Joaquin River Tributaries Authority

SPD ....Study Plan Determination

SRA...........................State Recreation Area

SRMA ....Special Recreation Management Area or Sierra Resource Management Area (as per use)

SRMP........................Sierra Resource Management Plan

SRP ....Special Run Pools

SSC ....State species of special concern

ST..............................California Threatened Species under the CESA

STORET ....Storage and Retrieval

SWAMP.....................Surface Water Ambient Monitoring Program

SWE ....Snow-Water Equivalent

SWRCB.....................State Water Resources Control Board

TAC...........................Technical Advisory Committee

TAF ....thousand acre-feet

TCP ....Traditional Cultural Properties

TDS ....Total Dissolved Solids

TID............................Turlock Irrigation District

TMDL ....Total Maximum Daily Load

TOC...........................Total Organic Carbon

TRT ....Tuolumne River Trust

TRTAC ....Tuolumne River Technical Advisory Committee
UC ....University of California
USDA.........................U.S. Department of Agriculture
USDOC ......................U.S. Department of Commerce
USDOI .......................U.S. Department of the Interior
USFS ..........................U.S. Department of Agriculture, Forest Service
USFWS ......................U.S. Department of the Interior, Fish and Wildlife Service
USGS .........................U.S. Department of the Interior, Geological Survey
USR............................Updated Study Report
UTM...........................Universal Transverse Mercator
VAMP ....Vernalis Adaptive Management Plan
VELB ....Valley Elderberry Longhorn Beetle
VRM ....Visual Resource Management
WPT ....Western Pond Turtle
WSA...........................Wilderness Study Area
WSIP ....Water System Improvement Program
WWTP ....Wastewater Treatment Plant
WY ....water year
μS/cm ....microSeimens per centimeter

1.0 INTRODUCTION

1.1 General Description of the Don Pedro Project

Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir formed by the dam extends 24-miles upstream at the normal maximum water surface elevation of 830 ft above mean sea level (msl; NGVD 29). At elevation 830 ft, the reservoir stores over 2,000,000 acre-feet (AF) of water and has a surface area slightly less than 13,000 acres (ac). The watershed above Don Pedro Dam is approximately 1,533 square miles (mi^2).

Both TID and MID are local public agencies authorized under the laws of the State of California to provide water supply for irrigation and municipal and industrial (M&I) uses and to provide retail electric service. The Project serves many purposes including providing water storage for the beneficial use of irrigation of over 200,000 ac of prime Central Valley farmland and for the use of M&I customers in the City of Modesto (population 210,000). Consistent with the requirements of the Raker Act passed by Congress in 1913 and agreements between the Districts and City and County of San Francisco (CCSF), the Project reservoir also includes a “water bank” of up to 570,000 AF of storage. CCSF may use the water bank to more efficiently manage the water supply from its Hetch Hetchy water system while meeting the senior water rights of the Districts. CCSF’s “water bank” within Don Pedro Reservoir provides significant benefits for its 2.6 million customers in the San Francisco Bay Area.

The Project also provides storage for flood management purposes in the Tuolumne and San Joaquin rivers in coordination with the U.S. Army Corps of Engineers (ACOE). Other important uses supported by the Project are recreation, protection of the anadromous fisheries in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from approximately one mile downstream of the dam to approximately RM 79 upstream of the dam. Upstream of the dam, the Project Boundary runs generally along the 855 ft contour interval which corresponds to the top of the Don Pedro Dam. The Project Boundary encompasses approximately 18,370 ac with 78 percent of the lands owned jointly by the Districts and the remaining 22 percent (approximately 4,000 ac) is owned by the United States and managed as a part of the U.S. Bureau of Land Management (BLM) Sierra Resource Management Area.

The primary Project facilities include the 580-foot-high Don Pedro Dam and Reservoir completed in 1971; a four-unit powerhouse situated at the base of the dam; related facilities including the Project spillway, outlet works, and switchyard; four dikes (Gasburg Creek Dike and Dikes A, B, and C); and three developed recreational facilities (Fleming Meadows, Blue Oaks, and Moccasin Point Recreation Areas). The location of the Project and its primary facilities is shown in Figure 1.1-1.

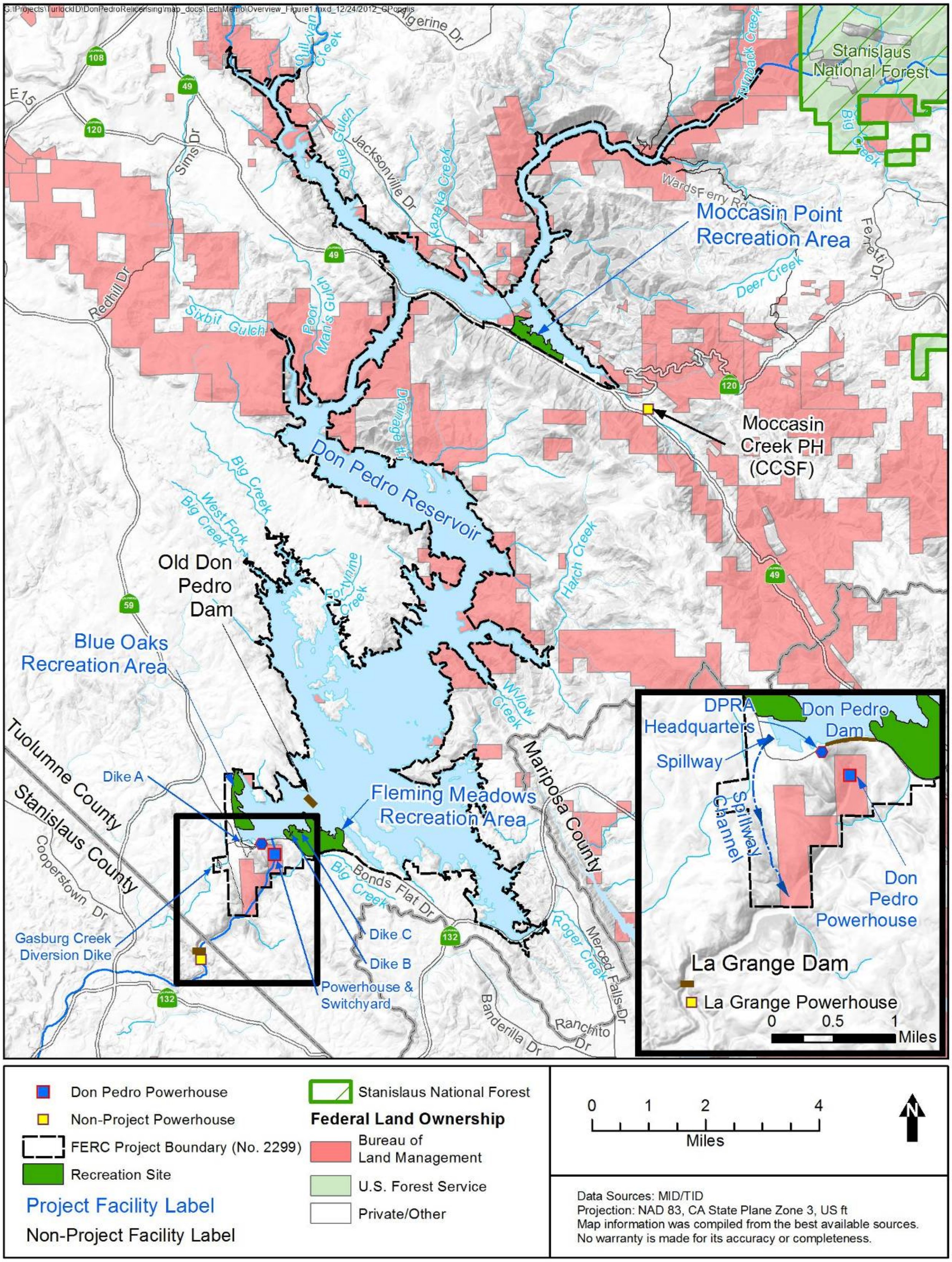


Figure 1.1-1. Don Pedro Project location.

1.2 Relicensing Process

The current FERC license for the Project expires on April 30, 2016, and the Districts will apply for a new license no later than April 30, 2014. The Districts began the relicensing process by filing a Notice of Intent and Pre-Application Document (PAD) with FERC on February 10, 2011, following the regulations governing the Integrated Licensing Process (ILP). The Districts' PAD included descriptions of the Project facilities, operations, license requirements, and Project lands as well as a summary of the extensive existing information available on Project area resources. The PAD also included ten draft study plans describing a subset of the Districts' proposed relicensing studies. The Districts then convened a series of Resource Work Group meetings, engaging agencies and other relicensing participants in a collaborative study plan development process culminating in the Districts' Proposed Study Plan (PSP) and Revised Study Plan (RSP) filings to FERC on July 25, 2011 and November 22, 2011, respectively.

On December 22, 2011, FERC issued its Study Plan Determination (SPD) for the Project, approving, or approving with modifications, 34 studies proposed in the RSP that addressed Cultural and Historical Resources, Recreational Resources, Terrestrial Resources, and Water and Aquatic Resources. In addition, as required by the SPD, the Districts filed three new study plans (W&AR-18, W&AR-19, and W&AR-20) on February 28, 2012 and one modified study plan (W&AR-12) on April 6, 2012. Prior to filing these plans with FERC, the Districts consulted with relicensing participants on drafts of the plans. FERC approved or approved with modifications these four studies on July 25, 2012.

Following the SPD, a total of seven studies (and associated study elements) that were either not adopted in the SPD, or were adopted with modifications, formed the basis of Study Dispute proceedings. In accordance with the ILP, FERC convened a Dispute Resolution Panel on April 17, 2012 and the Panel issued its findings on May 4, 2012. On May 24, 2012, the Director of FERC issued his Formal Study Dispute Determination, with additional clarifications related to the Formal Study Dispute Determination issued on August 17, 2012.

This study report describes the objectives, methods, and results of the Predation Study (W&AR-07) as implemented by the Districts in accordance with FERC's SPD and subsequent study modifications and clarifications. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

1.3 Study Plan

FERC's *Scoping Document 2* identified potential effects of the Project on fish populations in Project-affected reaches. The continued operation and maintenance (O&M) of the Project may contribute to cumulative effects on salmonid fish habitat in the Tuolumne River downstream of La Grange Dam, including the effects of predation on survival of juvenile Chinook salmon and *O. mykiss* in the lower Tuolumne River.

FERC's SPD approved with modifications the Districts' Predation study plan as provided in the Districts' RSP filing. In its SPD, FERC ordered that the Districts include the following provisions: (1) a goal to ensure the ratio of tag to fish weight is less than five percent, (2) any additional hatchery reared fish should be coded-wire-tagged, and (3) if the results of the predation study and the FWS's GIS floodplain inundation study suggest that a second year of study may be needed, the Districts should propose such a study in its initial study report or explain why such a study is not needed.

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study was to increase understanding of the current effects of predation on rearing and outmigrating juvenile Chinook salmon and *O. mykiss* in the lower Tuolumne River. The study consisted of the following three components related to salmonid predation by native and non-native species in the lower Tuolumne River:

(1) Predator abundance - estimate relative abundance of predator fish species such as largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), Sacramento pikeminnow (*Ptychocheilus grandis*), and striped bass (*Morone saxitalis*)

(2) Predation rate - update estimates of predation rate from previous surveys (e.g., TID/MID 1992)

(3) Predator movement tracking - determine relative habitat use by juvenile Chinook salmon and predator species at typical flows encountered during the juvenile salmonid outmigration period.

3.0 STUDY AREA

The study area includes the Tuolumne River from the La Grange Dam (RM 52) downstream to the confluence with the San Joaquin River (RM 0) (Figure 3.0-1). Study sites were selected in habitat units or river reaches that provide suitable habitat for predators and where predators have been documented in prior studies (TID/MID 1992; Brown and Ford 2002; Stillwater Sciences and McBain & Trush 2006). As the majority of predators in the lower Tuolumne River are non-native and are most abundant downstream of approximately RM 31 (Brown and Ford 2002), and the Section 10 permit issued by the National Marine Fisheries Service (NMFS) for take of Central Valley Steelhead limited sampling to locations downstream of RM 31.5 during September - March, predation study sites were generally concentrated in this downstream reach. Specific locations of sampling sites are described in Sections 4.2, 4.3, and 4.4 of this report.

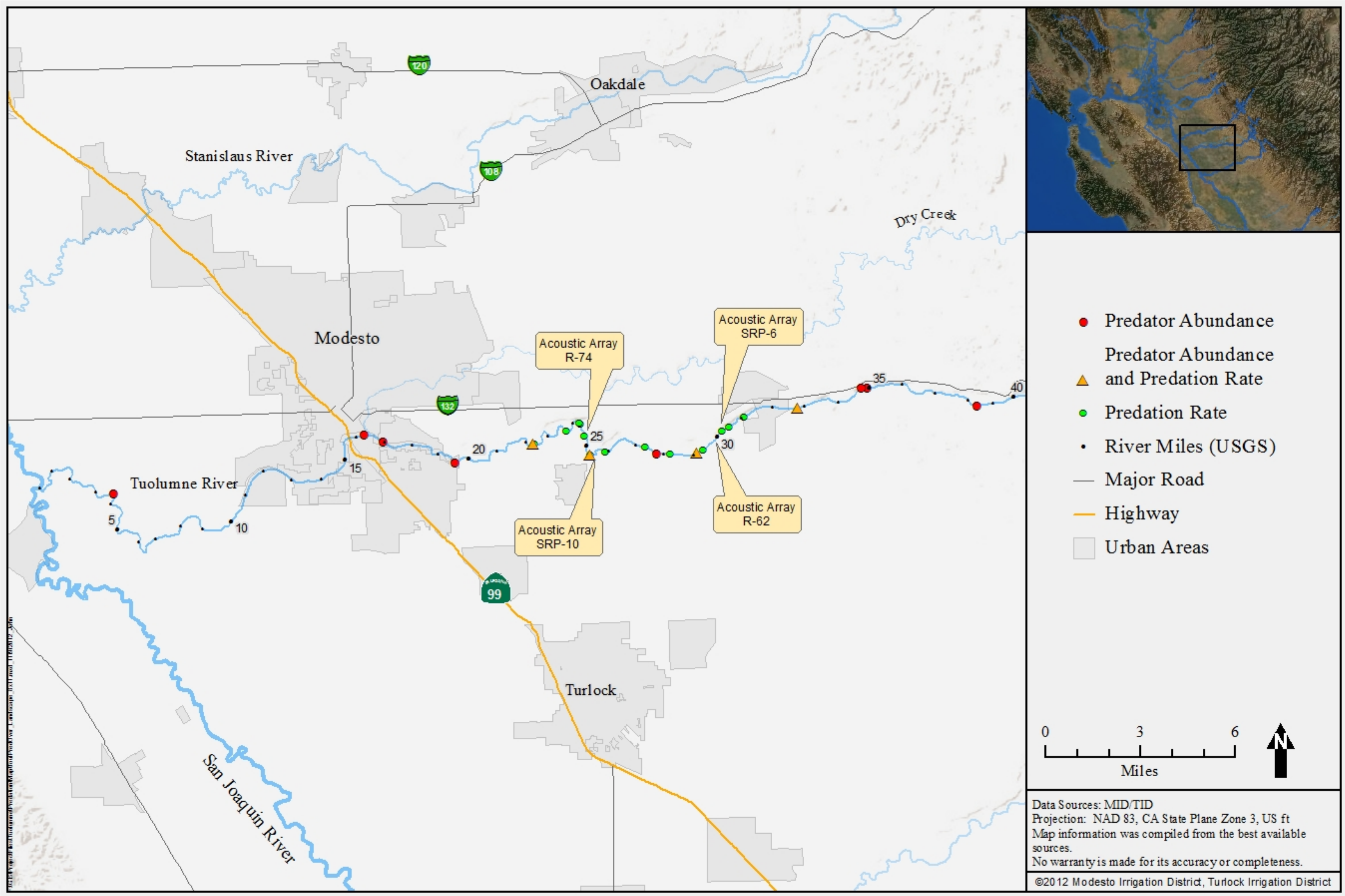


Figure 3.0-1. Map of study area.

4.0 METHODOLOGY

4.1 River Conditions

Provisional daily average flow data for the Tuolumne River at La Grange was obtained from the U.S. Department of the Interior, Geological Survey (USGS) at http://waterdata.usgs.gov/ca/nwis/uv/?site_no=11289650&agency_cd=USGS. Water temperature data were obtained from hourly recording Hobo Pro v2 water temperature data loggers (Onset Computer Corporation) maintained by the Districts at Roberts Ferry Bridge (RM 39.4), Hickman Bridge (RM 31.6), Waterford (RM 29.8), SRP 10 (RM 25.5), Tuolumne River Weir (RM 24.4), and Grayson (RM 5.0).

Daily instantaneous turbidity samples were collected at Waterford (RM 29.8), Tuolumne River Weir (RM 24.4), and Grayson (RM 5.0). Samples were also collected prior to electrofishing each site sampled for predator abundance and predation rate.

4.2 Predator Abundance

4.2.1 Sampling Methods

4.2.1.1 Sampling Locations

Fourteen sampling locations from RM 3.7 to RM 41.3 were selected based on the ability to launch the electrofishing boat at the site or very close by, and a desire to represent three habitat types: (1) slow-water (pools and special run pools [SRP]), (2) fast-water (riffles and runs), and (3) run-pools in the sand-bedded reach downstream of RM 25. Twelve of the selected sites were sampled between RM 3.7 and 38.5 (Figure 4.2-1) during July 25-August 8. On August 8 an adult *O. mykiss* was captured while sampling at RM 38.5, and sampling was suspended in accordance with Section 10 permit terms which required that all electrofishing must cease if any adult *O. mykiss* were captured.

4.2.1.2 Habitat Measurements

Habitat areas and shoreline lengths of each sampled unit were calculated using Geographic Information System (GIS) layers obtained from Turlock Irrigation District (Stillwater Sciences 2010). River flow at La Grange during the inundation mapping and habitat calibration (using 2009 NAIP 1-meter resolution aerial photography) was 230 cubic feet per second (cfs). River flow at La Grange during the sampling period (July 25 to August 8, 2012) was 98 cfs (range = 83 – 130 cfs). As a result of this difference in river flows, estimated habitat areas, and to a lesser degree shoreline lengths, are slightly overestimated relative to actual dimensions at the time fish sampling was conducted. Overestimation of habitat area or shoreline length results in slight underestimation of fish densities. For example, if the actual wetted area of a unit at the time of sampling was 100 m^2 and ten fish were captured in this location the actual density would be one fish per 10 m^2. However, if the mapping conducted at a higher flow estimated the unit area to be 110 m^2, the estimated density would be one fish per 11 m^2. Underestimation of fish density contributes to underestimation of predator abundance as discussed in Section 4.2.2 Data Analysis.

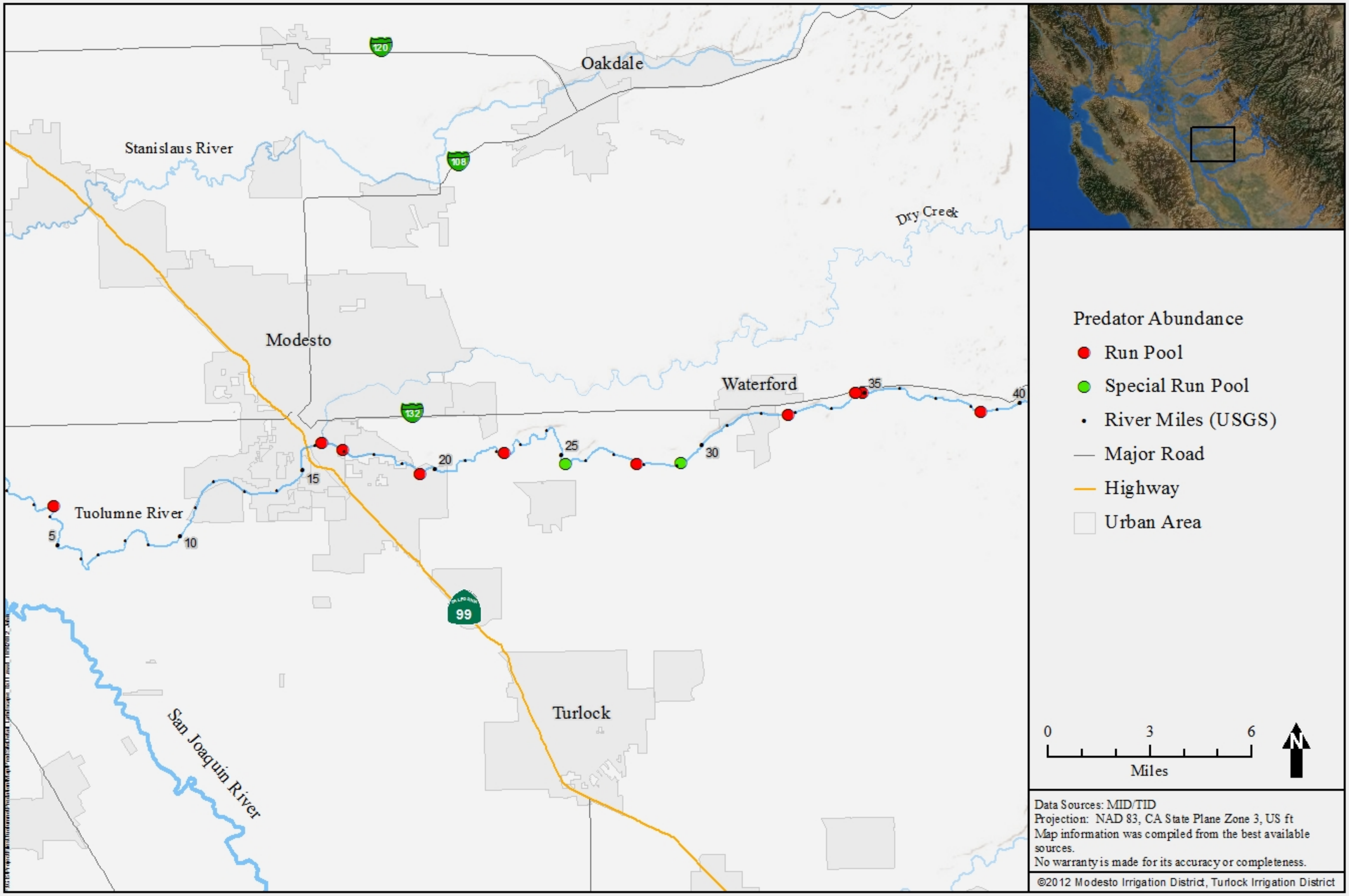


Figure 4.2-1. Map of the predator abundance sampling sites.

4.2.1.3 Electrofishing Methods

A portable 5.0 (5,000 W) generator powered pulsator electrofishing unit (Smith-Root, Vancouver, WA) was mounted on a 16 ft. North River jet boat. All electrofishing was conducted in accordance with NMFS (2000) electrofishing guidelines and electrofishing duration (effort in seconds) at each sampling site was recorded in an electrofishing logbook. Sampling was conducted between July 25 and August 8, 2012. In order to maximize capture rates and to maintain consistency with previous studies (TID/MID 1992; McBain & Trush and Stillwater Sciences 2006), sampling began at around dusk and was conducted until 0200 or 0300 hours the next morning. Each survey began at the downstream of the site and continued upstream along one bank then downstream along the opposite bank. During each pass, the boat was steered in a zigzag pattern through the shallow zone along each bank. Sampling was also conducted in a zigzag pattern through the mid-channel section of each unit.

Block nets were deployed at the upstream and downstream ends of each unit to prevent fish movement into or out of the unit during sampling such that each unit was a closed population. The population was repeatedly sampled *k* times (minimum of three and maximum of four) with the similar effort during each pass (duration of each pass within +/- 10 percent of duration of first pass) amount of effort (shocking time in seconds). On each pass, the number of individuals of each target species greater than 150 mm fork length (FL) was recorded and held in aerated tanks during subsequent passes.

4.2.2 Data Analysis

4.2.2.1 Depletion Estimates

The k-pass removal method was used to estimate abundance of each target species in each sampled unit. Two main assumptions are commonly applied to this type of removal method. First, the population is closed (e.g. animals cannot enter or escape the area); and, second, the probability of capture for an animal is constant for all animals from pass to pass.

If both assumptions are met, then the likelihood function for the vector of successive catches, $\vec{C}$, given the population size, N_0, and probability of capture is:

$$L(\vec{C} \mid N_0, p) = \frac{N_0!\, p^T q^{N_0 k - X - T}}{(N_0 - T)! \prod_{i=1}^{k} C_i!}$$

where $q = 1 - p$ (probability of escape); C_i is the number of animals captured in the *i*th removal period; *k* is the total number of removal periods, and:

$$T = \sum_{i=1}^{k} C_i$$

and:

$$X = \sum_{i=1}^{k}(k-i)C_i$$

The likelihood function is iteratively solved for q and N_0, where the smallest $N_0 > T$ that solves

$$(N_0 + \frac{1}{2})(kN_0 - X - T)^k - (N_0 - T + \frac{1}{2})(kN_0 - X)^k \geq 0$$

is the maximum likelihood estimate (Carle and Strub 1978; Ogle 2011). When the likelihood has been maximized the standard error of the estimate can be calculated with:

$$SE_{\hat{N}_0} = \sqrt{\frac{\hat{N}_0(1-q^k)q^k}{(1-q^k)^2 - (pk)^2 q^{k-1}}}$$

This k-pass removal estimator will fail (not produce an estimate) or will produce very large error bounds if depletion is not achieved (Carle and Strub 1978; Ogle 2011). The estimator will not produce an estimate if more animals are captured on the *k*th pass than the first pass. Additionally, the standard error of $\hat{N}_0$ can be quite large if catches from pass to pass are not sufficiently reduced.

In the two instances that the Carle-Strub estimator failed, a k-pass jackknife depletion estimator was used because it does not fail under the same conditions as the Carle-Strub estimator. The total number of fish ($\hat{y}_i$) and sampling variance, $\hat{V}(\hat{y}_i)$ in the two units where the Carle–Strub estimator failed were estimated using:

$$\hat{y}_i = \sum_{j=1}^{r_i - 1} c_{i\bullet j} + r_i c_{r_i}$$

and:

$$\hat{V}(\hat{y}_i) = r_i(r_i - 1)c_{r_i}$$

where r_i = the number of electrofishing passes in the i^{th} habitat unit; c_{r_i} = the number of fish captured in the r^{th} (last) pass in the i^{th} habitat unit; and $c_{i\bullet j}$ = the number of fish captured in the j^{th} pass of the i^{th} habitat unit.

4.2.2.2 Density Estimates

Density of predators by area and shoreline length was calculated using the 95 percent upper and lower confidence bounds for each site-specific abundance estimate. For example, the high areal density estimate was calculated as the upper bound of the abundance estimate for each species in each sampled unit. To be comparable to previous abundance estimates, all densities are reported in fish per acre and fish per shoreline mile.

4.2.2.3 River Wide Abundance Estimates

Two abundance estimates for each target species were produced for the lower Tuolumne River. Estimates of abundance for each species based on density estimates (shoreline length and area) were calculated using the following general estimator:

$$\hat{\tau}_{Density} = \hat{\mu}_{Density} A_T$$

where $\hat{\tau}_{Density}$ = estimated total abundance based on either shoreline length or area, $\hat{\mu}_{Density}$ = the estimated mean number of fish per unit ($\hat{y}_i$), and A_T = the total unit area available. The variance of $\hat{\tau}_{Density}$ was estimated using:

$$\hat{V}(\hat{\tau}_{Density}) = \frac{A_T}{A_S}\sum_{i=1}^{n}(\hat{y}_i - \hat{\bar{y}})^2 + \frac{A_T}{A_S}\sum_{i=1}^{n}\hat{V}(\hat{y}_i)$$

where A_S = the total unit area sampled and $\hat{\bar{y}}$ = the grand mean of depletion estimates.

According to the FERC Study Plan (Study Plan W&AR-07 - Page 6), overall abundance estimates by habitat type were also to be estimated by expansion of the sampled portions of the Tuolumne River to unsampled portions using (ratio-type) two-phase regression estimators (Särndal et al. 1991) to provide appropriate confidence bounds on the overall abundance estimate.

This type of ratio estimator requires a strong, positive correlation between x_i (the auxiliary variable; generally easy or inexpensive to measure) and y_i (variable of interest; generally difficult or costly to measure) (Thompson 2002). However, we found no strong, positive correlation (visual inspection of x-y plots) between unit size (x_i) and abundance of each of the target species (y_i) (see Attachment A). Only two of the relationships met the requirements of the two-phase regression estimator (corr >0.50): (1) shoreline length of units and depletion estimates of largemouth bass and (2) area of habitat units and depletion estimates of largemouth bass.

4.3 Predation Rate

4.3.1 Collection of Stomach Samples

Sampling was conducted from an 18 ft. Smith-Root EH jet boat equipped with a 5.0 generator powered pulsator electrofishing unit (GPP) and a portable 5.0 (5,000 W) GPP electrofishing unit (Smith-Root, Vancouver, WA) mounted on a 16 ft. North River jet boat. All electrofishing was conducted in accordance with NMFS (2000) electrofishing guidelines and an electrofishing logbook was maintained and updated at each sampling site with a record of electrofishing duration (effort in seconds). Sampling was conducted at twelve sites (5 run-pools and 7 SRPs) between RM 22.4 and RM 31.1 (Figure 4.3-1) during March 22-29 and May 1-9. To maintain consistency with previous studies (TID/MID 1992; McBain & Trush and Stillwater Sciences 2006) and because juvenile salmon and predators are most active during crepuscular periods (Adams et al. 1987; Clark and Levy 1988; Angradi and Griffith 1990; Benkwitt et al. 2009), sampling began after dark to increase the likelihood that prey in predator stomachs would be freshly consumed.

Prey items were collected from piscivorous fish, specifically largemouth bass, smallmouth bass, striped bass and Sacramento pikeminnow > 150 mm FL by inserting an acrylic tube through the esophagus into the stomach and flushing the stomach with water to disgorge the contents (Van Den Avyle and Roussel 1980; Kamler and Pope 2001). Stomach contents from target species (noted above) < 150 mm FL were not collected as predation on juvenile salmonids by predators of this size class has not been observed (TID/MID 1992). Stomach contents were placed in plastic vials and preserved in 70 percent ethanol. The vials were labeled with site, date, and a unique identification number for each individual sampled.

4.3.2 Identification of Prey Items

In the laboratory, all identifiable prey items found in predator stomachs were classified to order and for fish prey, to genus and species. All intact prey items were measured to the nearest millimeter (mm). Standard lengths (SL), fork lengths (FL), and total lengths (TL) of fish were taken when possible. All identifiable prey items, regardless of taxon, were enumerated. Observations of prey items such as amphibians or reptiles were also recorded.

Hard parts from digested fish (e.g. cleithra and dentaries) were used to help identify fish to genus and when possible, were measured to estimate the original prey length. Diagnostic bones from Chinook salmon were identified using bone keys developed by Hansel et al. (1988) and Frost (2000). The diagnostic bones only allow identification to genus (e.g. presence of a cleithrum would allow identification of presence of *Oncorhynchus spp.* but not allow distinction between *O. tshawyscha* or *O. mykiss*). Despite this limitation, we feel justified in calling all cleithrum identified as *Oncorhynchus spp.* as belonging to juvenile Chinook salmon because: (1) of the 30 identifiable *Oncorhynchus spp.*, all were identified as juvenile Chinook, and (2) only one juvenile *O. mykiss* was captured during rotary screw trap monitoring conducted at RM 29.8 near Waterford. Nearly all (>99.9 percent) salmonid captures in the Waterford rotary screw trap during spring 2012 were juvenile Chinook salmon (Sonke and Fuller 2012). The presence of cleithra and dentaries from juvenile Chinook salmon within a particular stomach sample allowed for the identification of highly digested prey items. To aid in the identification of the diagnostic bones from stomach samples, we dissected juvenile Chinook (mortalities from other monitoring programs). The cleithra and dentaries from known Chinook were placed in vials for future reference.

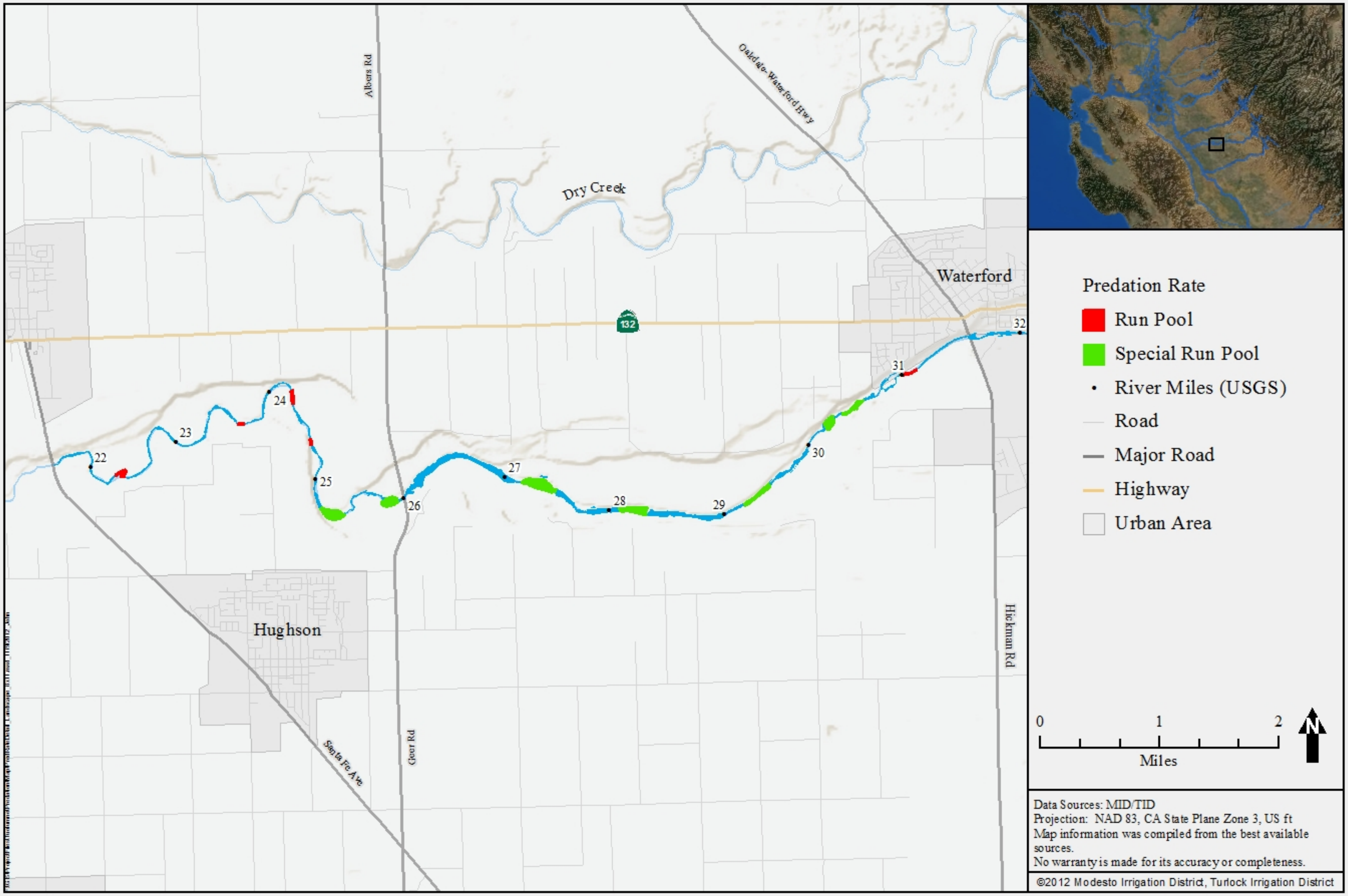


Figure 4.3-1. Predation rate sampling sites.

4.3.3 Data Analysis

4.3.3.1 Water Temperatures Prior to Time of Capture

Water temperature data from 18 h prior to capture was summarized for each captured predator based on capture time and location (refer to section 4.3.3.2 for further explanation). Four temperature recorders (Tuolumne Weir, SRP10, Waterford, and Hickman Bridge) were located within the reach sampled. Based on geographic proximity, sampling locations at Santa Fe, Hughson, Below Tuolumne Weir, Above Tuolumne Weir, and Charles Road used temperature readings from the temperature recorder located at the Tuolumne Weir. Other temperature recorders and associated sampling locations are described in Table 4.3-1. The mean, standard deviation, minimum, and maximum water temperature values were calculated using data from the temperature recorder nearest the capture location of each predator. The minimum and maximum temperatures for any given sampling location and period were used to determine "global" temperature values for the calculation of the gastric evacuation rates.

Table 4.3-1. Location information of temperature recorders and predation rate sampling locations on the lower Tuolumne River during Spring and Summer 2012.

Temperature Recorder Site	River Mile	Associated Sampling Sites
Tuolumne Weir	24.4	Santa Fe, Hughson, Below Tuolumne Weir, Above Tuolumne Weir, and Charles Road
SRP10	25.5	SRP10 and SRP9
Waterford	29.8	SRP8, lower SRP7, and upper SRP7
Hickman Bridge	31.6	Waterford Wastewater Facility

4.3.3.2 Gastric Evacuation Rates

Gastric evacuation rates, the time it takes for food items to be digested, of fish is largely determined by water temperature. Generally, gastric evacuation rates are higher when water temperature is higher, and conversely, rates are lower when water temperatures are lower.

Gastric evacuation rates used for this study were adapted from rates used by TID/MID (1992) based on differences in temperature between the 1992 study and this study. The 1992 study used 10-15 hours for a juvenile Chinook salmon to become unrecognizable at approximately 17°C. Since gastric evacuation rates are slower at cooler temperatures and water temperatures were cooler during 2012 (13-18°C), using the same gastric evacuation rates could inflate estimated predation rates. To adjust for the difference in temperature, gastric evacuation rates of 16 hours and 20 hours were used for this study. Both times were chosen to provide lower and upper estimates of predation rates, similar to the approach used TID/MID study (1992).

4.3.3.3 Predation Ratio and Predation Rates

Predation ratios, or the average number of juvenile Chinook salmon consumed per predator sampled, were calculated for each species, sampling event and habitat type (run-pool or special run-pool). For example, during the first sampling event in run-pools, 19 largemouth bass were sampled. The total number of salmon consumed by those 19 largemouth bass was one, which leads to a predation ratio of 1/19 = 0.053. Confidence intervals for predation ratios were estimated using a normal approximation to the Poisson distribution using the "epitools" package and the software R.2.14.1 (Aragon 2010; R Development Core Team 2010).

Predation rates were then calculated using the gastric evacuation times and predation ratios for each species, sampling event, and habitat type. Using the example from above, the predation ratio for largemouth bass in run-pools during the first sampling event was 0.053 juvenile Chinook consumed per predator. The predation rate at the high digestion rate (using 16 h or 0.667 d) would be equal to 0.053 / 0.667 which is 0.08 juvenile Chinook salmon consumed per largemouth bass per day in run-pool habitats during the first sampling event.

To determine if predation rates were different between sampling events and habitat types, the number of predators that consumed salmon was divided by the total number of predators captured (by species, habitat type and event). To determine if the proportions were different, a two-sample test for equality of proportions with continuity correction was conducted (Crawley 2007). All tests were conducted at $\alpha = 0.05$.

4.4 Predator Movement Tracking

4.4.1 Acoustic Tag System Overview

Fish movements were monitored with an acoustic tracking system. The project incorporated an HTI Acoustic Tag Tracking System (ATS), which uses a fixed array of underwater hydrophones to track movements of fish implanted with acoustic tags. As fish approached the array, the transmitted signal from each tag was detected and the arrival time recorded at several hydrophones. The difference in tag signal times at each hydrophone were used to calculate a two-dimensional (2-D) position.

All tags used in this study operated at 307 kilohertz (kHz) frequency and were encapsulated with a non-reactive, inert, low toxicity resin compound. The tags utilized "pulse-rate encoding" which provided increased detection range, improved the signal-to-noise ratio and pulse-arrival resolution, and decreased position variability when compared to other types of acoustic tags (Ehrenberg and Steig 2003). Pulse-rate encoding uses the interval between each transmission to detect and identify the tag. Each tag was programmed with a unique pulse-rate to track movements of individual tagged fish.

The pulse-rate is measured from the leading edge of one pulse to the leading edge of the next pulse in sequence. By using slightly different pulse-rates, tags can be individually identified. The timing of the start of each transmission is precisely controlled by a microprocessor within the tag. Each tag was programmed to have its own tag period to uniquely identify between tags. Test tag periods ranged between 2.007 and 4.086 seconds. The amount of time that the tag actively transmits is the pulse length. For this study, the transmit pulse length was 3.0 milliseconds.

In addition to the tag period, the HTI tag subcode option can be used to increase the number of unique tag ID codes available. Using this tag coding option, each tag is programmed with a defined primary tag period, and also with a defined secondary transmit signal, called the subcode. This subcode defines a precise elapsed time period between the primary and secondary tag transmissions. Two subcodes were used for this study; with subcode 8 used for predators, and subcode 5 for Chinook.

4.4.2 Predator Tagging

Hook and line (angling) surveys as well as electrofishing were conducted between April 26 and May 16, 2012, with the objective of capturing potential salmonid predators (largemouth bass, smallmouth bass, striped bass, and Sacramento pikeminnow) ≥150 mm total length.

Sampling was conducted at SRP 6 (RM 30.3), SRP 10 (RM 25.4), Riffle 62 (RM 30.2), and Riffle 74 (RM 24.9) (Figure 4.4-1), as well as areas near these sites where habitat conditions appeared to be suitable for predators. Light- and medium-weight spinning rod and reel combinations with monofilament 8-20 lb test fishing lines were used during sampling. Anglers used lures meant to mimic prey fish 60-150 mm in length, and fished from the surface down to the river bottom. Additional tagging was conducted opportunistically of predators captured by electrofishing as part of the predation rate sampling.

All predators captured were placed in holding containers with fresh river water. Fish were not anesthetized with tricaine methanesulfonate due to possible issues if released fish are subsequently captured and consumed by humans, and no other anesthetizing agents were used. Prior to tagging, fork length (nearest mm) and weight (nearest 0.1 g) were recorded for each fish. Non-biological data was also recorded including the time and location (GPS coordinates) of capture, specific habitat type at capture site, and general physical conditions (i.e., weather conditions, water temperature, turbidity, conductivity, and dissolved oxygen).

Predatory fish larger than 150 mm were tagged with an acoustic tag. All tagging was conducted near the original site of capture. Tags were placed externally and consisted of an HTI (Hydroacoustic Technology, Inc., Seattle WA) acoustic tag (LG-type) affixed directly under the dorsal fin. Acoustic tags were programmed just before entering the field. Tags were programmed with a three millisecond pulse width, and tag periods ranging from 2007–4086 milliseconds. At these settings, the predicted tag lives were 40–50 days. During the tagging process, fish were held in a canvas sling and submerged in running water to keep them calm. The acoustic tag, mounted to a thin rubber plate with a nylon coated wire leader, was attached by passing the wires through the body of the fish under the dorsal fin using hypodermic syringe needles. The wires and tag were secured in place by wire connector sleeves. A t-anchor Floy tag (Floy Tag Inc, Seattle, WA) was also attached directly below the posterior portion of the dorsal fin. Each Floy tag had unique ID and contact information for anglers to return tags from any captured fish. This tagging procedure is comparable to that used by California Department of Water Resources (CDWR) staff in the Delta for similar tracking studies.

Tagged fish were allowed to recover in a live well and released back into the river near the original site of capture. During the recovery period, tagged fish were monitored to confirm the operational status of each transmitter. Fish not selected for tagging were released immediately after necessary biological data was collected. All fish were acclimated to river conditions prior to release.

4.4.3 Chinook Salmon Releases

Acoustic tags were surgically implanted into 222 coded wire tagged Chinook salmon provided by CDFG from the Merced River Hatchery (MRH). An additional 600 coded wire tagged Chinook salmon, also provided from MRH, were marked photonically and were released to accompany the acoustic tagged fish. All tagging and marking was conducted at MRH.

4.4.3.1 Acoustic Tagging of Chinook Salmon

Acoustic tags were soaked for at least 24 hours prior to programming, and each tag was programmed with a unique code the day prior to tagging. After programming, tags were sniffed in a cup of water using a HTI sniffer and monitored through at least three transmission cycles. At least five attempts were made to program each tag. Function and coding of all activated tags was verified with a hydrophone immediately after programming and prior to surgical implantation in study fish to confirm tag function and programming. Only three tags failed to initialize, and all programmed tags were heard during validation immediately after programming. Tags were expected to remain active for 10-16 days after programming.

During each tagging session, fish were surgically implanted with HTI Model 795 Lm micro acoustic tags following implantation procedures outlined in Adams et al. 1998 and Martinelli et al. 1998. These tags weighed 0.63 g to 0.70 g, and were 16.4 mm long with a diameter of 6.7 mm. Prior to transmitter implantation, fish were anesthetized in 70 mg/L tricaine methanesulfonate buffered with an equal concentration of sodium bicarbonate until they lost equilibrium. Fish were removed from anesthesia, and were measured (FL to nearest mm) and weighed (to nearest 0.1 g), fish were surgically implanted with acoustic transmitters. Typical surgery times were less than 3 min.

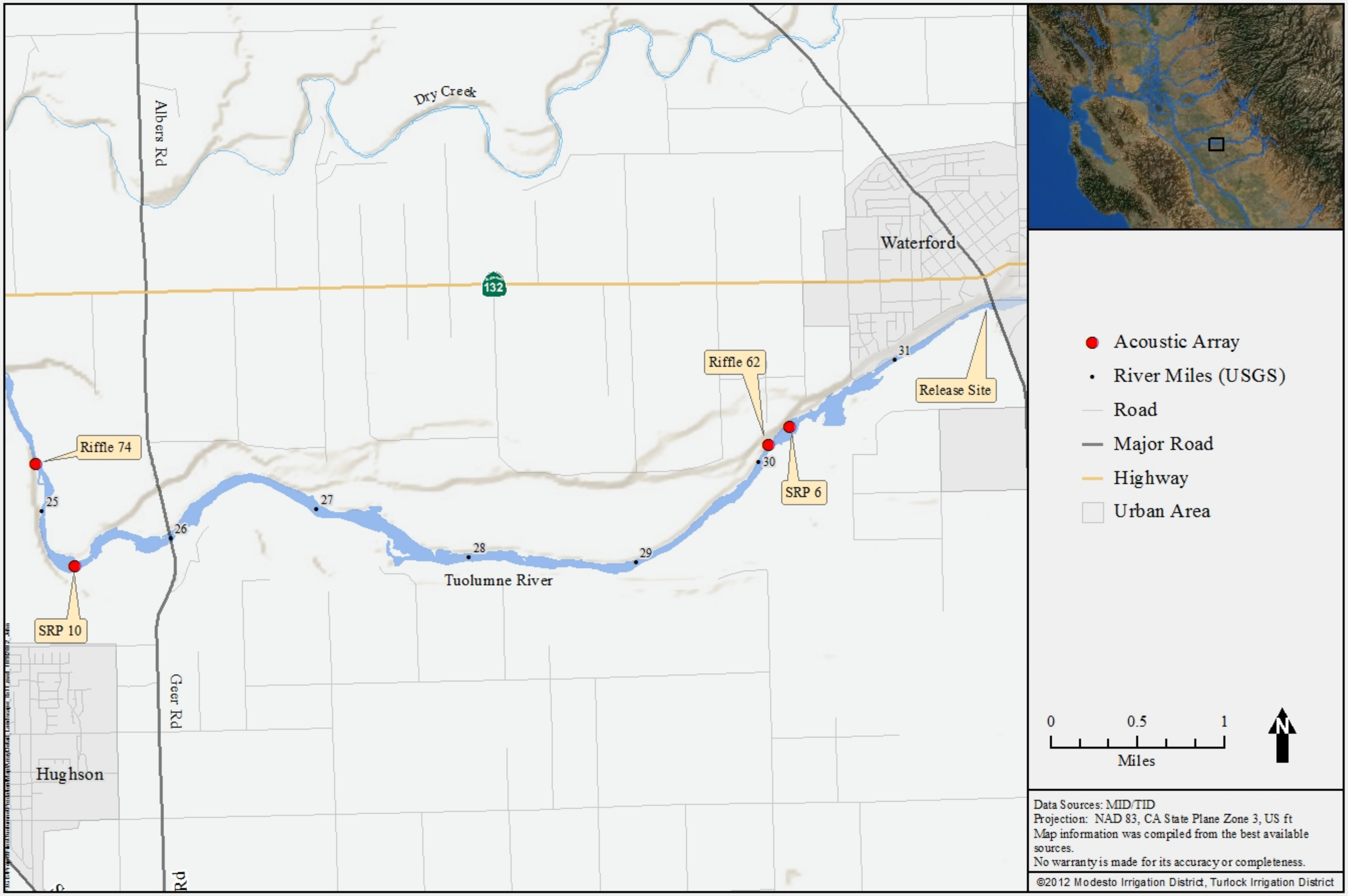


Figure 4.4-1. Acoustic array deployment locations.

Fish were then placed into perforated 19 L buckets in a tank inside the egg building at MRH to recover from anesthesia effects. Buckets were perforated, starting 15 cm from the bottom, to allow water exchange. The non-perforated section of the bucket held 7 L of water to allow transfer without complete dewatering and without the need to net fish, thereby reducing stress. Each bucket was stocked with up to three tagged fish, and was covered with a snap-on lid.

In order to evaluate the effects of tagging and transport, 12 Chinook salmon were implanted with inactive transmitters during each tagging session. Inactive tags were interspersed randomly into the tagging order for each release group. Procedures for tagging these fish, transporting them to the release site, and holding them at the release site were the same as for fish with active transmitters. Dummy-tagged fish were evaluated for condition (i.e., percent scale loss, body color, fin hemorrhaging, eye quality, and gill coloration) and mortality after being held at the release site for approximately 40-60 hours.

4.4.3.2 Photonic Marking of Chinook Salmon

A photonic marking system was used for marking fish to accompany the acoustic tagged fish. All fish were anesthetized with tricaine methanesulfonate before marking. A marker tip was placed against the anal fin and orange photonic dye was injected into the fin rays. The photonic dye (DayGlo Color Corporation, Cleveland, OH) was chosen because of its known ability to provide a highly visible, long-lasting mark.

4.4.3.3 Transport and Holding of Chinook Salmon

Once each tagging session was complete, buckets containing acoustic tagged Chinook salmon were transferred to a dual chambered 250 gallon insulated aluminum hauling tank for transport to the release site at Hickman Bridge (RM 31.6). At the release site acoustic tagged Chinook salmon were transferred from the buckets to perforated 32 gallon trash cans suspended in the river in an area of low velocity along the south bank under the bridge. A total of 18-21 Chinook salmon were transferred to each of the four perforated trash cans.

Photonic marked Chinook salmon were netted from the transport tank and carried in buckets to live cars suspended in the river adjacent to the trash cans holding the acoustic tagged Chinook salmon. An in-river holding period prior to release provided time for study fish to recover from surgery and transport, and to adjust to in-river water quality for approximately 30-60 hours. Prior to release, tagged fish were monitored by hydrophones to confirm the operational status of each tag. All tags were confirmed to be functional during this evaluation.

4.4.3.4 Releases of Tagged and Marked Chinook Salmon

Releases of tagged and marked Chinook salmon were made on May 9-10, May 16-17, and May 21-22, and were timed to occur at flows of 2100 cfs, 280 cfs, and 415 cfs (Table 4.4-1). Each of the three releases groups of 73-75 acoustic tagged Chinook salmon was paired with a release 200 photonic marked Chinook salmon. To account for potential diurnal differences in Chinook salmon and predator behavior, approximately half of each group was released shortly before dawn and half shortly before dusk to allow observation of movement during day and night.

Releases were made by first inspecting the trash can (acoustic tagged) or live car (photonic marked) for any mortalities or Chinook salmon exhibiting abnormal behavior or otherwise appearing unhealthy. All Chinook salmon were in good condition at release and no mortality was observed during the periods between tagging and release. After inspection, the trash can or live car was tipped to allow fish to exit volitionally.

Table 4.4-1 Releases of acoustic tagged Chinook salmon.

Release	Date	Time	River flow at La Grange (cfs)	Number Released	Avg. fork length (mm)	Avg. weight (g)	Tag weight: body weight
1a	5/9/2012	20:00	2100	36	108.3	15.8	4.2%
1b	5/10/2012	4:00	2100	39	107.0	15.3	4.4%
2a	5/16/2012	20:00	280	36	108.2	15.7	4.3%
2b	5/17/2012	4:00	280	38	107.9	15.6	4.3%
3a	5/21/2012	20:00	415	36	108.6	16.3	4.1%
3b	5/22/2012	4:00	415	37	110.2	17.8	3.8%

4.4.4 Acoustic Array Deployment and Maintenance

A network of HTI acoustic receivers (Hydroacoustic Technology, Inc., Seattle WA) was deployed within the Tuolumne River to detect movements of both tagged Chinook and tagged predators. At SRP 6 and SRP 10, arrays capable of two-dimensional tracking of fish movement were deployed. These 2D arrays consisted of four hydrophones connected to a Model 291 Portable Acoustic Tag Receiver (ATR). Detection on one hydrophone confirms the presence of an acoustic tag, but to be accurately positioned in two-dimensions a tag must be detected on at least three hydrophones. Two-dimensional tag coordinates with sub-meter accuracy are achieved using hydrophones located in known positions, at the same horizontal plane and within direct line of sight of the tag. The precise location of hydrophones in each array was recorded using a GPS unit. The effective range of detection in the array was examined by actively moving transmitting tags through the array at various depths and verifying consistent detection and positioning of the tag. These arrays were both deployed and began receiving data on April 19, 2012 and recorded continuously through May 29, 2012.

Single hydrophone arrays were deployed directly above and directly below Riffle 62 and Riffle 74. These arrays consisted of a single hydrophone attached to a Model 295-G Acoustic Tag Data Logger, and detected tags as they moved past the hydrophones. Additionally, a single hydrophone array was deployed at Grayson (RM 5.0) in order to detect tagged fish moving out of the river.

At each acoustic monitoring site, the data loggers were secured on the streambank in a metal lock box. Receivers were powered by a bank of 12V deep-cycle batteries, and in some cases charged by a small solar array. The Model 291 ATR is designed to receive four separate channels; one channel assigned to each hydrophone. Each ATR is connected to a personal computer used to store the acoustic data. An individual raw data file is created for each sample hour. Filters in the ATR are set to identify the acoustic tag sound pulse and discriminate tags from ambient background noise. The ATR pulse measurements are reported for each single echo from each hydrophone and written to Raw Acoustic Tag files (*.RAT) using the AcousticTag program. Each *.RAT file contains header information for data acquisition settings followed by the raw echo data. Each raw echo data file contains all acoustic signals detected during the time period, including signals from tagged fish as well as some additional unfiltered acoustic noise. Receiver sites were visited a minimum of three days per week during the acoustic monitoring period. On each visit, acoustic data was saved to a USB drive and the 12V batteries were replaced as needed.

At the end of the monitoring period, all acoustic data were auto-marked using HTI's MarkTags software. After the data were marked, the files from the SRP6 and SRP 10 arrays were were geo-referenced and given 2D positions by HTI staff using AcousticTag software. The 2D positions were then imported into Eonfusion software (Myriax Software Pty Ltd) to allow for viewing of all of the acoustic tracks. The data were reviewed in Eonfusion and the fate of each acoustic tagged Chinook salmon was classified as either a successful passage, likely consumed by a predator, unknown, or not present. Tag fates were determined based on characteristics of the tag tracks including length of detection, direction of travel, habitat usage (near-shore vs. mid-channel) and comparison to tracks of known tagged predators. Predator tags were classified by species (largemouth bass, smallmouth bass, striped bass, or Sacramento pikeminnow).

Habitat use by tagged predators and Chinook salmon was evaluated by measuring the relative density of acoustic tracks within the 2D arrays at the 90 percentile level. These values were used to calculate the areas of overlap and non-overlap between the successful Chinook passages and the various predator species using the Eonfusion software package.

5.0 RESULTS

5.1 River Conditions

Flows during the study period ranged from 94 cfs to 2120 cfs (Figure 5.1-1). Predator abundance sampling was conducted July 25 to August 8, 2012 at an average flow of 98 cfs. Predation rate sampling was conducted on two occasions: March 22 to March 29 and May 1 to May 9, 2012. During the first sampling period flows were steady at 315 cfs. The second sampling event occurred on the front end of a pulse flow, with releases ranging from 667 cfs to 2120 cfs. Predator tracking occurred from April 19 to May 29, 2012, with flows ranging from 195 cfs to 2120 cfs.

Figure 5.1-2 shows the range of water temperatures between Roberts Ferry Bridge (RM 39.4) and Grayson (RM 5.0) throughout the study period.

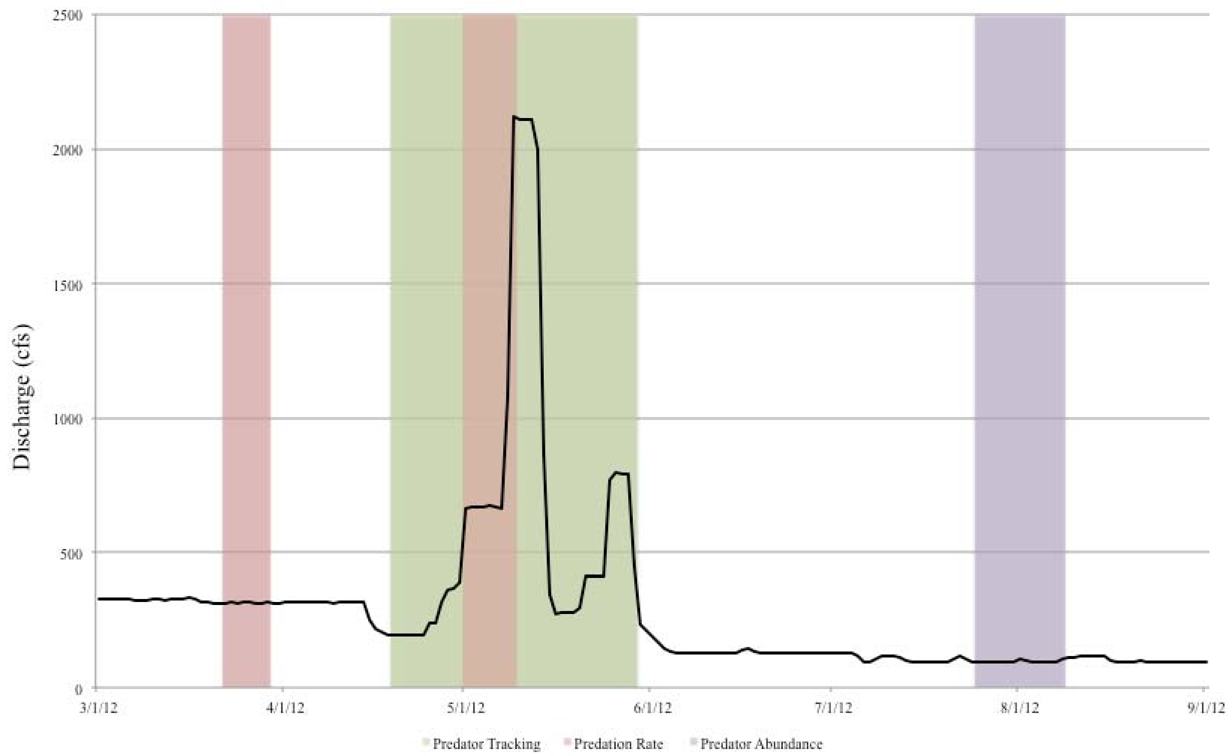


Figure 5.1-1. Daily mean discharge at La Grange (LGN) March 1 through August 31 and timing of sampling events.

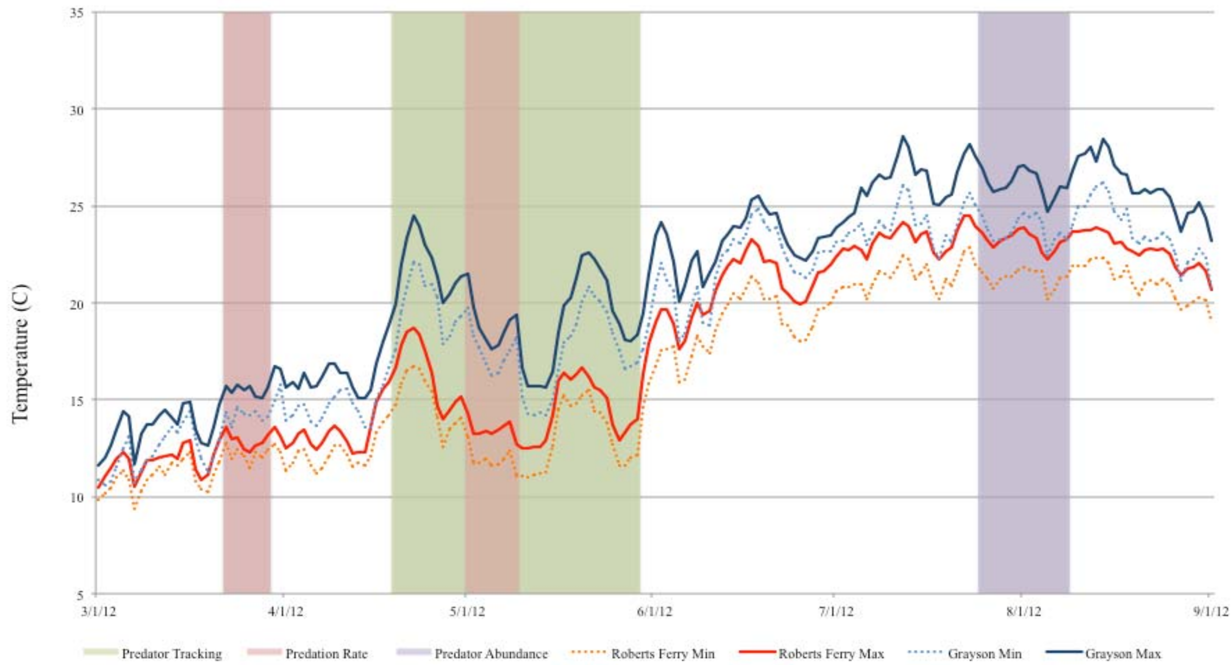


Figure 5.1-2. **Daily minimum and maximum water temperatures at Roberts Ferry (RM 39.4) and Grayson (RM 5.0) March 1 through August 31 and timing of sampling events.**

5.2 Predator Abundance

5.2.1 Habitat Measurements

Measurements of each run-pool and special run-pool are provided in Table 5.2-1. Ten run-pools ranging in size from 0.69 acres to 2.44 acres and two special run-pools measuring 1.61 and 10.46 acres in area were sampled between Shiloh (RM 3.7) and 7-11 Gravel (RM 38.4).

Table 5.2-1. **Habitat sizes of sampled units in the lower Tuolumne River measured in GIS.**

Site Name	Habitat Type	River Mile	Shoreline Length (m)	Area (m^2)	Shoreline Length (ft)	Area (ft^2)	Area (ac)
Shiloh	Run-Pool	3.7	482	7,972	1,580	85,609	1.97
7th Street Bridge	Run-Pool	16.2	215	3,116	704	33,669	0.77
Legion Park	Run-Pool	17.1	950	11,412	3,117	122,679	2.82
Mitchell Rd	Run-Pool	19.5	296	4,532	972	48,954	1.12
Hughson Nut Farm (Santa Fe)	Run-Pool	22.4	211	2,752	692	29,645	0.68
SRP 10	SRP	25.5	953	42,330	3,128	455,540	10.46
Fox Grove	Run-Pool	27.8	221	4,047	725	43,764	1.00
SRP 7	SRP	29.2	346	6,515	1,136	70,238	1.61
Waterford	Run-Pool	32.9	562	9,874	1,842	106,312	2.44
George Reed (d/s of bridge)	Run-Pool	34.8	419	4,816	1,375	51,787	1.19
George Reed	Run-Pool	35.0	430	6,354	1,412	68,571	1.57
7-11 Gravel	Run-Pool	38.4	401	4047	1317	43385	1.00

5.2.2 Site-Specific Abundance and Density

Largemouth bass >150 mm were captured in all units sampled between RM 3.7 and RM 32.9, and no largemouth bass >150 mm FL were captured in sites at or above RM 34.8. Depletion estimates using the Carle-Strub estimator could not be generated for one of the nine units. Instead, the k-pass jackknife estimator was used for this particular unit. Site-specific abundance estimates of largemouth bass >150 mm FL ranged from 2 to 42 (Table 5.2-2).

Smallmouth bass >150 mm FL were captured in all twelve sampled units (Table 5.2-3). Below RM 25, abundance estimates of smallmouth bass >150 mm FL ranged from 7 to 37. Above RM 25, site-specific abundance estimates of smallmouth bass ranged from 2 to 50.

Striped bass >150 mm FL were captured in four of the twelve units sampled (Table 5.2-4). Depletion estimates using the Carle-Strub estimator could not be generated for one of the four units. Instead, the k-pass jackknife estimator was used for this particular unit. Site-specific abundance estimates of striped bass ranged from two to nine.

Sacramento pikeminnow greater than 150 mm FL were only captured in units above RM 27 (Table 5.2-5). In units above RM 27, Sacramento pikeminnow were captured in five of six sampled units. Estimated abundance of Sacramento pikeminnow in the five units where they were captured ranged from 2 to 15.

Table 5.2-2. Site-specific depletion estimates of largemouth bass >150 mm and associated density estimates on the lower Tuolumne River during summer 2012.

River Mile	Habitat Type	Estimated Abundance $\hat{N}$	SE	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Density (# / acre)	Density (# / Bank Mile)
3.7	Run-Pool	27	4.1	19	35	10 - 18	63 - 117
16.2	Run-Pool	6	3.9	0	14	0 - 18	0 - 103
17.1	Run-Pool	35	5.3	24	46	9 - 16	41 - 77
19.5	Run-Pool	2	2.0	0	6	0 - 5	0 - 33
22.4	Run-Pool	13	1.5	10	16	15 - 24	76 - 122
25.5	SRP	17	2.6	12	22	1 - 2	20 - 37
27.8	Run-Pool	16	3.6	9	23	9 - 23	64 - 169
29.2	SRP	3	1.4	0	6	0 - 4	1 - 27
32.9	Run-Pool	42[1]	17.0	8	76	3-31	23-218
34.8	Run-Pool	0	--	--	--	--	--
35.0	Run-Pool	0	--	--	--	--	--
38.4	Run-Pool	0	--	--	--	--	--

[1] Carle-Strub depletion estimator failed, used k-pass jackknife depletion estimator

Table 5.2-3. Site-specific depletion estimates of smallmouth bass >150 mm and associated density estimates on the lower Tuolumne River during summer 2012.

River Mile	Habitat Type	Estimated Abundance $\hat{N}$	SE	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Density (# / acre)	Density (# / Bank Mile)
3.7	Run-Pool	37	7.1	23	51	12 - 26	76 - 171
16.2	Run-Pool	7	3.1	1	13	1 - 17	7 - 98
17.1	Run-Pool	9	1.8	5	13	2 - 4	9 - 21

River Mile	Habitat Type	Estimated Abundance $\hat{N}$	SE	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Density (# / acre)	Density (# / Bank Mile)
19.5	Run-Pool	26	5.1	16	36	14 - 32	86 - 197
22.4	Run-Pool	14	1.5	11	17	16 - 25	83 - 130
25.5	SRP	9	5.6	0	20	0 - 2	0 - 34
27.8	Run-Pool	15	1.8	11	19	11 - 19	82 - 136
29.2	SRP	2	2.0	0	6	0 - 4	0 - 28
32.9	Run-Pool	15	1.4	12	18	5 - 7	35 - 51
34.8	Run-Pool	50	7.7	35	65	29 - 55	132 - 251
35.0	Run-Pool	2	2.9	0	8	0 - 5	0 - 29
38.4	Run-Pool	32	1.3	29	35	29 - 35	118 - 139

Table 5.2-4. Site-specific depletion estimates of striped bass >150 mm and associated density estimates on the lower Tuolumne River during summer 2012.

River Mile	Habitat Type	Estimated Abundance $\hat{N}$	SE	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Density (# / acre)	Density (# / Bank Mile)
3.7	Run-Pool	9	3.0	3	15	2 - 8	10 - 50
16.2	Run-Pool	0	--	--	--	--	--
17.1	Run-Pool	0	--	--	--	--	--
19.5	Run-Pool	0	--	--	--	--	--
22.4	Run-Pool	0	--	--	--	--	--
25.5	SRP	0	--	--	--	--	--
27.8	Run-Pool	4	1.5	1	7	1 - 7	7 - 51
29.2	SRP	0	--	--	--	--	--
32.9	Run-Pool	0	--	--	--	--	--
34.8	Run-Pool	4[1]	0	4	4	3-3	15-15
35.0	Run-Pool	2	5.5	0	13	0 - 8	0 - 48
38.4	Run-Pool	0	--	--	--	--	--

[1] Carle-Strub depletion estimate failed, used k-pass jackknife depletion estimator.

Table 5.2-5. Site-specific depletion estimates of Sacramento pikeminnow >150 mm and associated density estimates on the lower Tuolumne River during summer 2012.

River Mile	Habitat Type	Estimated Abundance $\hat{N}$	SE	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Density (# / acre)	Density (# / Bank Mile)
3.7	Run-Pool	0	--	--	--	--	--
16.2	Run-Pool	0	--	--	--	--	--
17.1	Run-Pool	0	--	--	--	--	--
19.5	Run-Pool	0	--	--	--	--	--
22.4	Run-Pool	0	--	--	--	--	--
25.5	SRP	0	--	--	--	--	--
27.8	Run-Pool	2	2.9	0	8	0 - 8	0 - 57
29.2	SRP	0	--	--	--	--	--
32.9	Run-Pool	15	1.8	11	19	5 - 8	32 - 54
34.8	Run-Pool	3	3.5	0	10	0 - 8	0 - 38
35.0	Run-Pool	12	4.0	4	20	2 - 13	15 - 75
38.4	Run-Pool	12	1.8	8	16	8 - 16	34 - 62

5.2.3 River Wide Abundance Estimates

Correlation values between habitat size (shoreline lengths and habitat areas) and site-specific abundance estimates were low and ranged from .033 to .606 (Attachment A). With the exception of largemouth bass, all correlations between habitat size and predator abundance estimates failed to meet the minimum suggested level of 0.5 to use a ratio-regression estimator (Thompson 2002; Hankin, unpublished); therefore the ratio-regression estimator could not be used to generate river-wide abundance estimates.

Two abundance estimates for each species were produced for the lower Tuolumne River. The first is based on areal density and the second is based on shoreline density (Table 5.2-6). River wide abundance estimates (for all run-pools and special run-pools from RM 0 to RM 39.4) derived from area density estimates were slightly higher than those derived from shoreline density estimates. Smallmouth bass were estimated to be the most abundant predators, with 9,092 and 6,764 based on area and shoreline length, respectively. A standard error term could not be produced for either of the striped bass estimates since depletion was not achieved at RM 34.8.

Table 5.2-6. Abundance estimates and associated standard errors based on estimated densities (by area and shoreline length of run-pools and special run-pools) of each target species on the lower Tuolumne River (RM 0 to RM 39.4).

Species	Area $\hat{\tau}$	SE
Bass < 150 mm	121,756	4,360
Largemouth bass	4,794	252
Sacramento pikeminnow	1,590	98
Smallmouth bass	9,092	251
Striped bass	692	55
Species	**Shoreline Length** $\hat{\tau}$	
Bass < 150 mm	95,198	4,506
Largemouth bass	4,185	261
Sacramento pikeminnow	1,161	101
Smallmouth bass	6,764	260
Striped bass	588	57

5.3 Predation Rate

A total of 295 piscivores > 150 mm FL were captured during the two sampling occasions. The first sampling occasion took place from March 22, 2012 to March 29, 2012 and the second sampling took place from May 1, 2012 to May 9, 2012. No further sampling to estimate predation rates was conducted after May 9, 2012. Smallmouth and largemouth bass were the most common piscivores collected. A total of 49 piscivores had no food contents in their stomach when examined. Similar numbers of empty stomachs were observed for smallmouth bass (15.2 percent) and largemouth bass (14.5 percent). About 35 percent of striped bass sampled (9 of 26) had empty stomachs when examined (Table 5.3-1).

Table 5.3-1. Numbers of predatory fish (> 150 mm FL) stomachs sampled and number and percentage of predatory fish with empty stomachs during electrofishing on the lower Tuolumne River during spring 2012.

Species	Number Sampled	Number Empty	Percentage of Predators with Empty Stomach
Smallmouth bass	132	20	15.2%
Largemouth bass	131	19	14.5%
Striped bass	26	9	34.6%
Sacramento pikeminnow	6	1	16.7%

5.3.1 Diet Composition

At the taxonomic class level, insects (many orders) made up a majority (74 percent) of identifiable prey items observed in the 246 stomach samples examined. Other notable prey items included fish (various orders) at approximately 13.5 percent of all identifiable prey items and crayfish at approximately 4 percent of all identifiable prey items (Figure 5.3-1). All other prey items combined made up only eight percent of the identifiable prey items observed in the stomach samples.

The most frequently occurring prey items were macroinvertebrates of the orders Tricoptera and Ephemeroptera (Figure 5.3-2). Of the 246 stomach samples examined, 100 (41 percent) contained at least one trichopteran (either larvae or adult) and 92 (37 percent) contained at least one ephemeropteran (larvae or adult). Seventy-nine or about 32 percent of stomach samples examined contained at least one unidentified fish (no identifiable juvenile Chinook salmon were included in this count). Crayfish were present in about 26 percent of all stomach samples examined. Thirty fish identified as juvenile Chinook salmon occurred in about 12 percent of the stomach samples.

When identifiable prey items were counted by order, nearly 46 percent were of the order Ephemeroptera (Figure 5.3-3). The second-most frequent prey item by order was Trichoptera (13 percent).

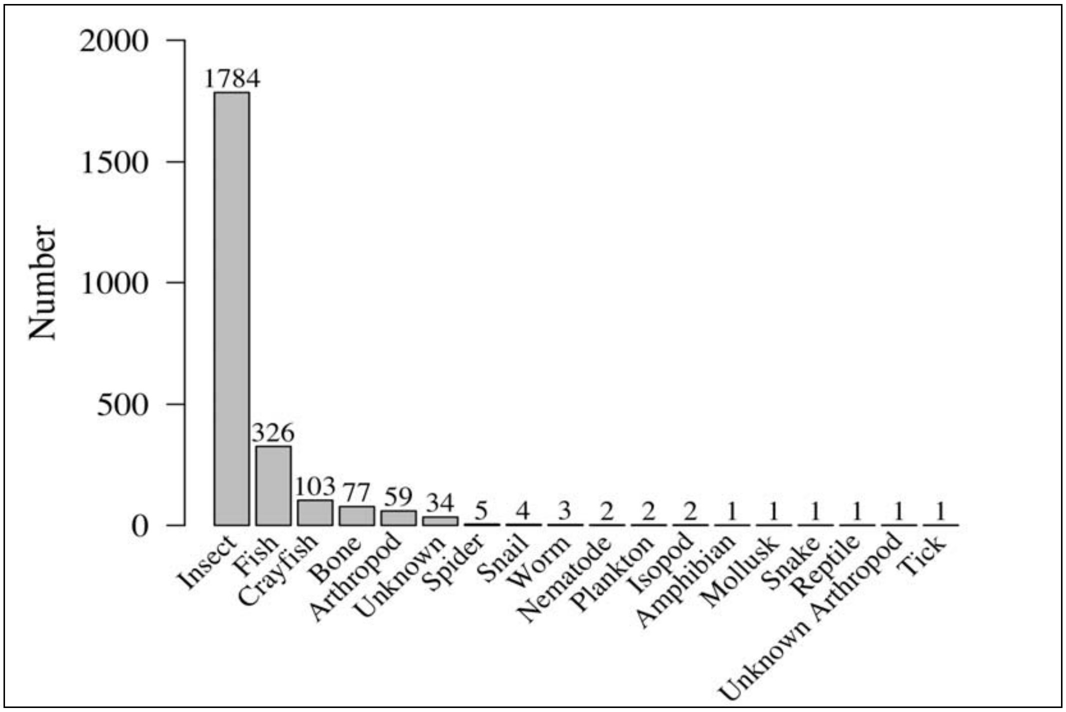


Figure 5.3-1. Number of identifiable prey items observed in stomach samples (n = 246) collected in the lower Tuolumne River. Invertebrates (insects and crayfish) and fish (various species) made up the majority of identifiable prey items.

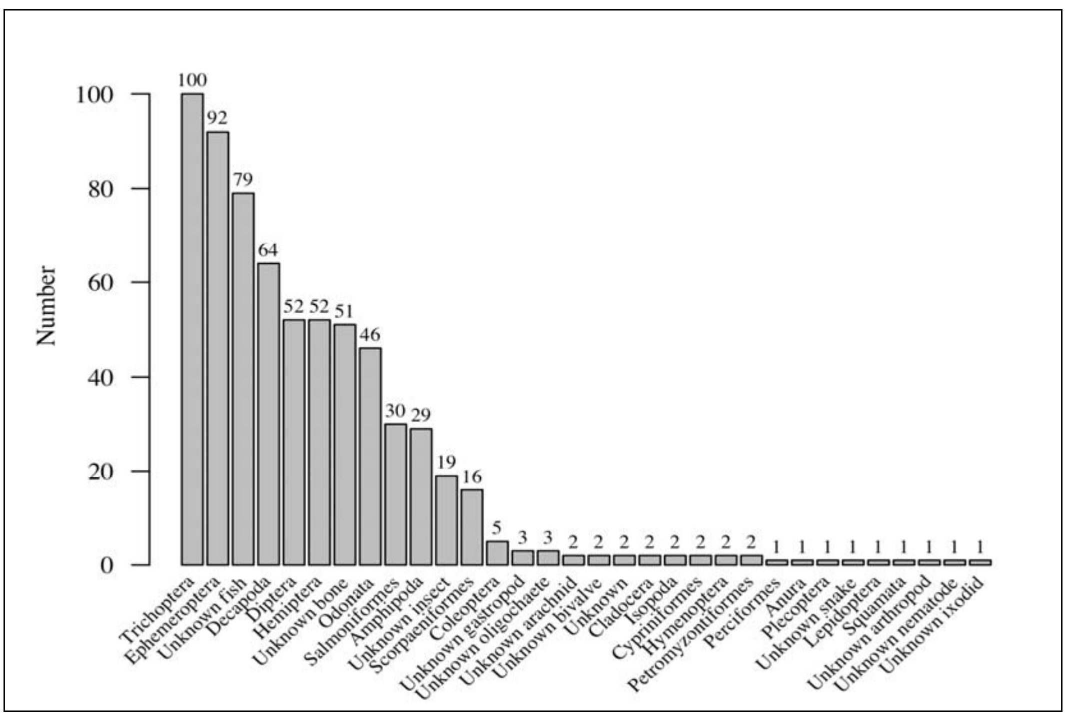


Figure 5.3-2. Number of stomach samples (n = 246) that contained at least one of each type of prey item collected on the lower Tuolumne River.

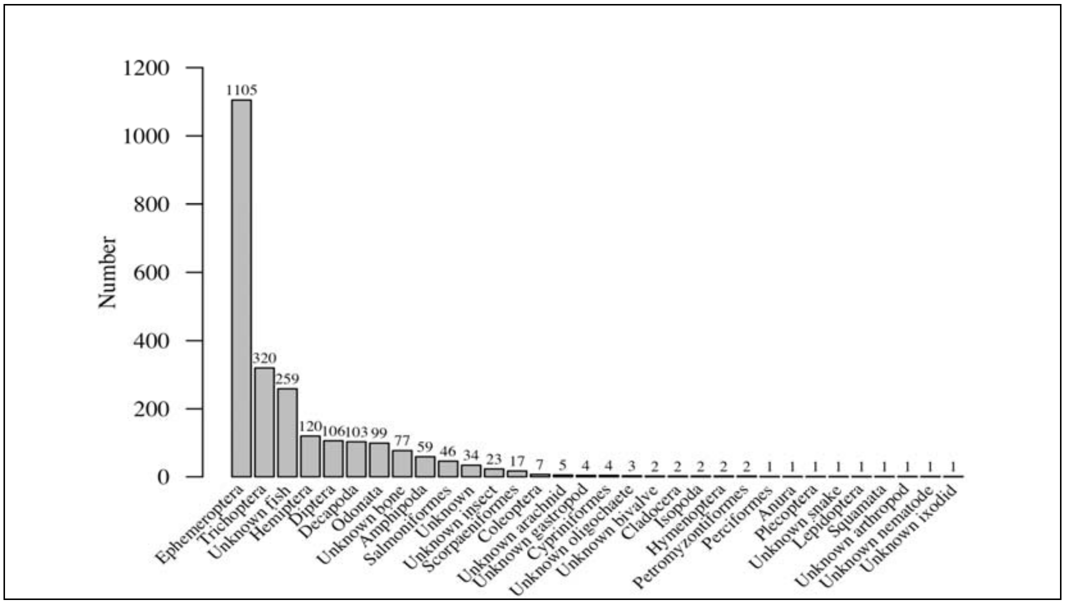


Figure 5.3-3. Number of prey items (by order) observed in stomach samples (n = 246) collected in the lower Tuolumne River.

5.3.2 Predation of juvenile Chinook salmon

Of the 246 stomach samples examined, 30 contained juvenile Chinook salmon, with eight of these samples from smallmouth bass, 11 from largemouth bass, and 11 from striped bass. No juvenile Chinook salmon were observed in the stomach contents of Sacramento pikeminnow. Smallmouth bass that consumed juvenile Chinook salmon were at least 185 mm FL, largemouth bass were at least 207 mm FL, and striped bass were at least 180 mm FL (Figure 5.3-4).

During the March sampling event, standard lengths (SL) (measured from snout to hypural plate) of 13 intact juvenile Chinook salmon found in the stomach contents of sampled predators were measured. The mean SL was 51.6 mm (sd = 11.0). The smallest observed juvenile Chinook salmon during the March sampling event was 30 mm SL and the largest was 68 mm SL.

Standard lengths of 14 intact juvenile Chinook salmon were measured from specimens observed in stomach samples collected during the May sampling event. The mean standard length was 71.4 mm (sd = 5.3), about 20 mm larger on average than mean SL observed in the March sampling event. The smallest observed juvenile Chinook salmon during the May sampling event was 62 mm SL and the largest was 78 mm SL.

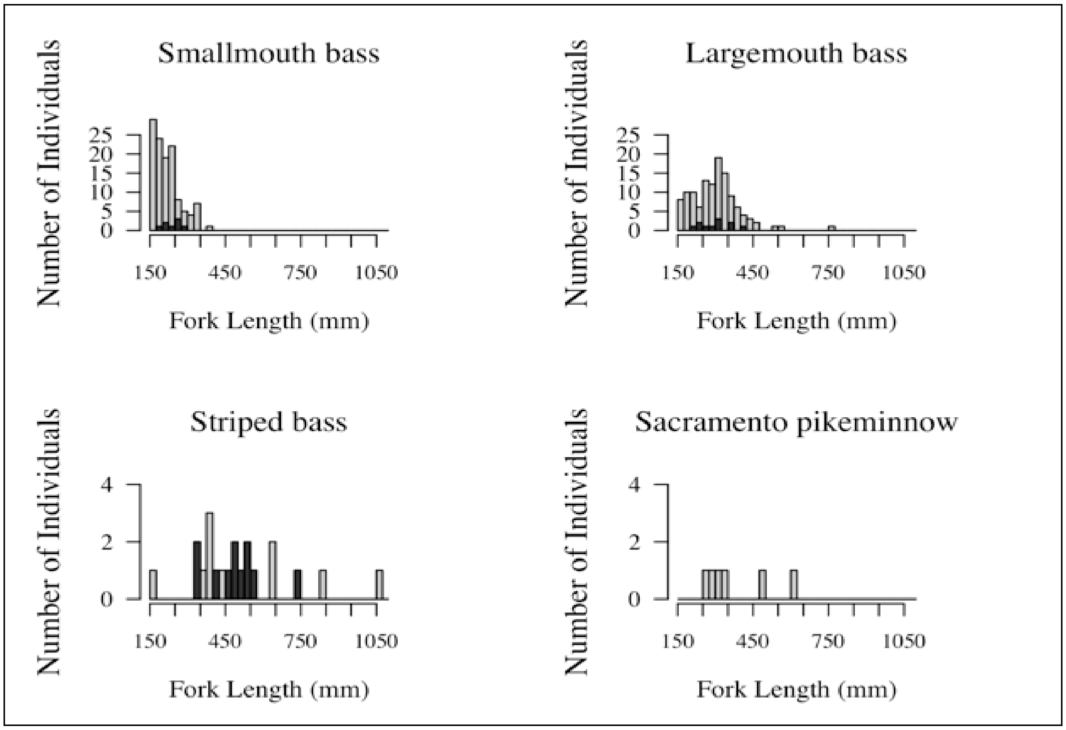


Figure 5.3-4. Lengths of captured smallmouth bass, largemouth bass, striped bass, and Sacramento pikeminnow that consumed juvenile Chinook salmon (dark bars) and those that did not (light bars).

5.3.3 Differences between sampling events and habitat types

With one exception, no significant differences in frequencies of predators consuming at least one juvenile Chinook salmon were found. All frequencies used for these tests can be derived from Table 5.3-2 by dividing the number of predators with salmon by the number of predators sampled. When frequencies were calculated using all predators sampled during March, the proportion that consumed at least one juvenile Chinook salmon was significantly higher in special run-pools than in run-pools (p-value = 0.0176). During the first sampling event in SRPs, 15 predators examined contained salmon out of 114 total (0.132) while only 1 of 66 (0.015) predators captured in RPs contained at least one salmon (Test 1; Figure 5.3-5). A similar test conducted for sampling during May showed that there was no significant difference between the two habitat types (Test 2; Figure 5.3-5; p-value = 1.000).

No significant differences were found for tests between the pooled frequencies (all predators from sampling during March, 16/180 or 0.089) compared to the pooled frequencies from sampling during May (14/115 or 0.122; p-value = 0.4759) (Test 3; Figure 5.3-5). Additionally, no significant difference was found between frequencies from habitat types (both events pooled; p-value = 0.093), though the predation frequency in special run-pools was 0.130 (22/169) compared to 0.063 (8/126) in run-pools (Test 4; Figure 5.3-5).

No statistically significant differences were found when comparing predation frequencies for smallmouth bass, largemouth bass, or striped bass between sampling events or between habitat types. However, no comparisons could be made for striped bass during March, since no striped bass were captured in run-pool habitats during that sampling period. No species-specific tests were conducted for Sacramento pikeminnow since only six Sacramento pikeminnow > 150 mm FL were captured during March and May.

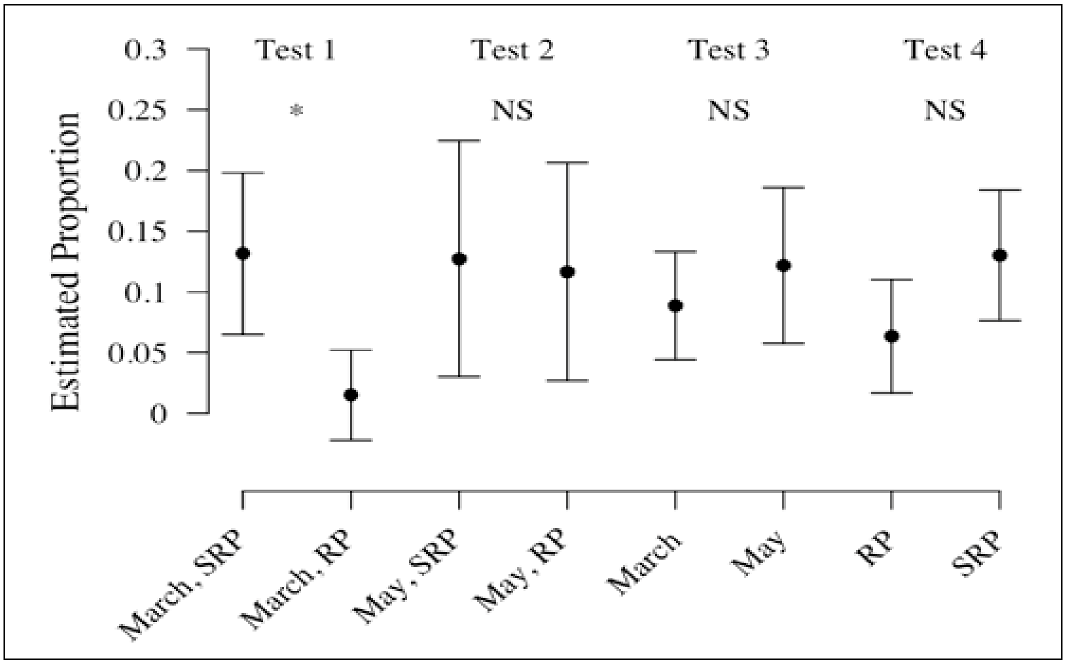


Figure 5.3-5. Comparison of estimated predation frequency and 95 percent confidence intervals by habitat type and event. Statistically significant difference denoted by "*"and "NS" indicates no significant difference.

5.3.4 Water temperatures

Water temperatures during the 18 hours prior to the time of capture of each predator ranged from 13°C to 16°C during March and from 14°C to 17°C during May depending upon location of capture.

5.3.5 Predation rates on juvenile Chinook salmon

Predation ratios and predation rates are summarized in Table 5.3-2. During the first sampling event, 180 predators > 150 mm FL were captured. Twenty-two juvenile Chinook salmon were detected upon examination of the 180 stomach samples collected (total includes empty stomachs). No predation ratios could be calculated for striped bass or Sacramento pikeminnow in run-pool habitats since neither of those species were captured in this habitat type during the first sampling event. Predation ratios, or the mean consumption of juvenile Chinook per predator, ranged from 0.0 to 1.2 salmon consumed per predator. For sampling conducted in March, and using the slow gastric evacuation rate of 20 hours, predation rates ranged from 0.00 to 1.44 juvenile Chinook consumed per predator per day (Table 5.3-2). If the faster gastric evacuation rate of 16 hours is used, predation rates range from 0.00 to 1.80. Striped bass predation rates were the highest (1.44–1.80) in SRP habitats during the first sampling event. Predation rates were similar between smallmouth bass and largemouth bass in SRP habitats. No salmon were consumed by the 4 Sacramento pikeminnow captured.

During the second sampling event, 115 predators > 150 mm FL were captured. Twenty-three juvenile Chinook salmon were detected upon examination of the 115 stomach samples collected (total includes empty stomachs). Predation ratios ranged from 0.0 to 1.0 salmon consumed per predator. For sampling conducted in May, and using the slow gastric evacuation rate of 20 hours, predation rates ranged from 0.00 to 1.20 juvenile Chinook consumed per predator per day (Table 5.3-2). With the faster gastric evacuation rate of 16 hours, predation rates ranged from 0.00 to 1.50 juvenile Chinook consumed per predator per day. Similar to March, predation rates during May were highest for striped bass in comparison to the other predator species examined. No salmon were consumed by the two Sacramento pikeminnow captured.

Table 5.3-2. Summary of largemouth bass (LMB), smallmouth bass (SMB), striped bass (STB), and Sacramento pikeminnow (SASQ) predation of juvenile Chinook salmon in the lower Tuolumne River during March and May 2012.

	Habitat Type	Species	Number With Salmon	Number Without Salmon	Largest Number Salmon In One Predator	Total Number Salmon	Predation Ratio	Lower 95% Confidence Interval	Upper 95% Confidence Interval	Low Predation Rate	High Predation Rate
MARCH	SRP	SMB	3	26	1	3	0.10	0.00	0.73	0.12	0.16
		LMB	6	65	2	6	0.08	0.00	0.65	0.10	0.13
		STB	6	4	5	12	1.20	0.00	3.35	1.44	1.80
		SASQ	0	4	0	0	0.00	0.00	0.00	0.00	0.00
	RP	SMB	0	47	0	0	0.00	0.00	0.00	0.00	0.00
		LMB	1	18	1	1	0.05	0.00	0.50	0.06	0.08
		STB	0	0	--	--	--	--	--	--	--
		SASQ	0	0	--	--	--	--	--	--	--
MAY	SRP	SMB	2	18	2	3	0.15	0.00	0.91	0.18	0.23
		LMB	4	28	2	5	0.16	0.00	0.93	0.19	0.23
		STB	1	1	2	2	1.00	0.00	2.96	1.20	1.50
		SASQ	0	1	0	0	0.00	0.00	0.00	0.00	0.00
	RP	SMB	3	33	2	5	0.14	0.00	0.87	0.17	0.21
		LMB	0	9	0	0	0.00	0.00	0.00	0.00	0.00
		STB	4	10	4	8	0.57	0.00	2.05	0.69	0.86
		SASQ	0	1	0	0	0.00	0.00	0.00	0.00	0.00

5.4 Predator Movement Tracking

5.4.1 Predator Tagging

Total hook and line sampling effort was 112 hours at SRP 10 and SRP 6, with the time split equally between the two sites. Hook and line sampling resulted in 17 predators of suitable size captured, and 15 of these successfully tagged. Additionally, predators were captured by electrofishing and opportunistically tagged during spring predation rate sampling. Electrofishing occurred in the area of the four acoustic monitoring sites on six nights, providing 60 captured predators of which 57 were tagged.

A total of 72 predators >150 mm were acoustic tagged consisting of: 36 largemouth bass, 16 smallmouth bass, 19 striped bass, and 1 Sacramento pikeminnow. The fork length of tagged largemouth bass ranged from 250–572 mm (avg. 340 mm), and weight 200–2,468 g (avg. 677 g); smallmouth bass ranged from 168–345 mm (avg. 240 mm), and weight 56–739 g (avg. 264 g); striped bass ranged from 260–1,070 mm (avg. 556 mm), and weight 567–15,141 g (avg. 3,040 g); and the single Sacramento pikeminnow captured was 508 mm and weighed 907 g. The tag weights of the HTI G-type tags used for predator tagging ranged from 4.20–4.48 g, for a tag-body weight ratio ranging from 0.0003–0.0755 (Table 5.4-1).

Twenty-eight tagged predators were released into SRP 6; consisting of 18 largemouth bass, 2 smallmouth bass, 7 striped bass, and 1 Sacramento pikeminnow. Two additional predators (one largemouth bass and one smallmouth bass) were released directly downstream in Riffle 62. Twenty-nine predators were tagged at SRP 10; consisting of 15 largemouth bass, 5 smallmouth bass, and 9striped bass. The remaining 13 tagged predators were released near Riffle 74; consisting of two largemouth bass, eight smallmouth bass, and three striped bass.

Table 5.4-1. Summary of predator species acoustically tagged.

Tag Period	Sub Code	Tag wt (g)	Species[1]	Fork length (mm)	Fish wt (g)	Release Date	Location	Floy Tag #
2028	8	4.32	SMB	325	680.4	26-Apr	SRP 10	52
2049	8	4.27	LMB	295	453.6	26-Apr	SRP 10	53
2070	8	4.27	LMB	310	68.4	26-Apr	SRP 10	54
2091	8	4.38	LMB	290	367.4	1-May	SRP 6	39
2112	8	4.28	LMB	410	1360.8	1-May	SRP 6	40
2133	8	4.32	SMB	275	367.4	1-May	SRP 6	41
2154	8	4.35	STB	665	3460.9	26-Apr	SRP 6	26
2175	8	4.29	STB	260	1247.4	26-Apr	SRP 6	27
2196	8	4.26	LMB	375	626.0	27-Apr	SRP 6	28
2217	8	4.32	LMB	334	567.0	27-Apr	SRP 6	31
2238	8	4.33	LMB	250	199.6	28-Apr	SRP 10	55
2259	8	4.35	LMB	325	567.0	28-Apr	SRP 10	56
2280	8	4.42	LMB	340	480.8	1-May	SRP 6	38
2301	8	4.35	LMB	360	680.4	29-Apr	SRP 10	32
2322	8	4.38	LMB	335	--	1-May	SRP 10	58
2343	8	4.35	LMB	305	426.4	5-May	R74	63
2364	8	4.26	SMB	230	186.0	5-May	R74	64
2385	8	4.4	LMB	572	1732.7	5-May	R74	66
2406	8	4.24	SMB	228	170.1	5-May	R74	67

Tag Period	Sub Code	Tag wt (g)	Species[1]	Fork length (mm)	Fish wt (g)	Release Date	Location	Floy Tag #
2427	8	4.28	SMB	168	56.7	5-May	R74	68
2448	8	4.33	LMB	315	538.6	1-May	SRP 6	42
2469	8	4.4	SMB	265	283.5	4-May	SRP 10	59
2490	8	4.31	SMB	345	739.4	1-May	SRP 6	45
2511	8	4.32	STB	350	567.0	1-May	SRP 6	47
2532	8	4.31	STB	385	766.6	1-May	SRP 6	48
2553	8	4.48	LMB	250	226.8	4-May	R62	60
2574	8	4.35	SMB	260	313.0	4-May	R62	62
2595	8	4.32	LMB	340	623.7	1-May	SRP 6	34
2616	8	4.28	LMB	325	567.0	1-May	SRP 6	35
2637	8	4.3	LMB	305	567.0	1-May	SRP 6	36
2658	8	4.43	LMB	310	510.3	1-May	SRP 6	33
2679	8	4.32	SMB	183	140.6	5-May	R74	69
2700	8	4.2	SMB	169	56.7	5-May	R74	71
2721	8	4.31	STB	389	680.4	5-May	SRP 10	72
2805	8	4.35	SMB	225	204.1	7-May	SRP 10	83
2826	8	4.36	STB	1070	15140.9	5-May	SRP 10	78
2847	8	4.35	STB	750	4735.5	5-May	SRP 10	75
2868	8	4.43	STB	445	1192.9	5-May	SRP 10	80
2889	8	4.41	SMB	195	85.0	5-May	R74	74
2910	8	4.36	STB	645	3855.5	5-May	SRP 10	79
2931	8	4.36	LMB	267	412.8	7-May	SRP 10	85
2952	8	4.32	SMB	220	255.1	5-May	R74	77
2973	8	4.3	LMB	262	299.4	7-May	SRP 10	86
2994	8	4.42	LMB	272	317.5	7-May	SRP 10	87
3015	8	4.33	STB	572	2494.8	8-May	SRP 6	90
3036	8	4.41	STB	332	1728.2	8-May	SRP 6	89
3057	8	4.3	STB	490	1501.4	8-May	SRP 6	88
3078	8	4.32	LMB	302	426.4	8-May	SRP 6	91
3099	8	4.34	LMB	310	399.2	8-May	SRP 6	92
3120	8	4.32	LMB	394	880.0	8-May	SRP 6	93
3141	8	4.35	LMB	310	480.8	8-May	SRP 6	94
3162	8	4.41	LMB	540	2467.5	8-May	SRP 6	95
3183	8	4.32	LMB	318	426.4	8-May	SRP 6	96
3204	8	4.38	LMB	352	739.4	8-May	SRP 6	97
3225	8	4.31	LMB	257	226.8	8-May	SRP 6	102
3246	8	4.3	LMB	321	453.6	8-May	SRP 10	103
3267	8	4.31	LMB	440	1388.0	8-May	SRP 10	106
3288	8	4.3	LMB	409	1192.9	8-May	SRP 10	107
3309	8	4.35	SMB	255	255.1	8-May	SRP 10	108
3330	8	4.38	LMB	356	707.6	8-May	SRP 10	109
3351	8	4.36	SMB	245	254.0	8-May	SRP 10	110
3372	8	4.36	LMB	367	821.0	8-May	SRP 10	111
3414	8	4.32	SMB	245	170.1	9-May	R74	113
3435	8	4.3	STB	650	3515.3	9-May	R74	114
3456	8	4.33	STB	410	793.8	9-May	R74	115
3477	8	4.32	STB	850	7257.5	9-May	R74	116
3498	8	4.26	LMB	395	880.0	9-May	SRP 10	117
3519	8	4.38	STB	535	1900.6	9-May	SRP 10	118
3540	8	4.37	STB	730	4449.7	9-May	SRP 10	119
3561	8	4.35	STB	615	1701.0	16-May	SRP 10	120

Tag Period	Sub Code	Tag wt (g)	Species[1]	Fork length (mm)	Fish wt (g)	Release Date	Location	Floy Tag #
3582	8	4.33	SASQ	508	907.2	16-May	SRP 6	121
3603	8		STB	419	766.6	16-May	SRP 10	122

[1] SMB= smallmouth bass, LMB= largemouth bass, STB= striped bass, SASQ= Sacramento pikeminnow

5.4.2 Detections of Acoustic Tagged Fish

Fate determinations for fish detection in the arrays at SRP 6 and SRP 10 are summarized in Table 5.4-2. Of the 75 acoustic tagged Chinook salmon released at Hickman Bridge (RM 31.6) on May 9–10 at a flow level of 2,100 cfs, 69 were detected in SRP 6 (RM 30.3). Sixty-three (91.3 percent) of these successfully passed through SRP 6, two (2.9 percent) were likely consumed by predators, and the fates of four tags (5.8 percent) were classified as unknown (Table 5.4-2). Travel time from the release site of Chinook that successfully passed through SRP 6 ranged from 0.4 to 9.5 hours (median= 0.5 hours), and duration of detection within SRP 6 ranged from 0.6 to 87.4 minutes (median= 3.7 minutes). The total area covered by tagged Chinook that successfully passed was 4,546 m^2. The overlap of the 90^{th} percentile of acoustic tracks between tagged Chinook and predator species was 8.0 percent for largemouth bass and 27.4 percent for striped bass (Figure 5.4-1, Table 5.4-3).

Table 5.4-2. Summary of fate determinations for acoustic tagged Chinook salmon in SRP 6 and SRP 10, and river flow at La Grange, and water temperature at Roberts Ferry.

	Release Group		
	1	**2**	**3**
Release Dates	May 9-10	May 16-17	May 21-22
Target Flow at La Grange (cfs)	2,100	280	415
Water Temperature at Roberts Ferry (°C)	12.6 (range: 11.0-14.3)	16.3 (range: 14.6-18.7)	16.7 (range: 13.8-17.1)
Total #Released	75	74	73
	--	--	--
SRP 6	--	--	--
Detected	69	55	63
Passed	91.3 % (n=63)	54.5% (n=30)	31.7% (n=20)
Consumed	2.9% (n=2)	30.9% (n=17)	60.3% (n=38)
Unknown	5.8% (n=4)	14.5% (n=8)	7.9% (n=5)
	--	--	--
SRP 10	--	--	--
Detected	57	22	7
Passed	75.4% (n=43)	50.0% (n=11)	28.6% (n=2)
Consumed	15.8% (n=9)	31.8% (n=7)	71.4% (n=5)
Unknown	8.8% (n=5)	18.2% (n=4)	0.0% (n=0)

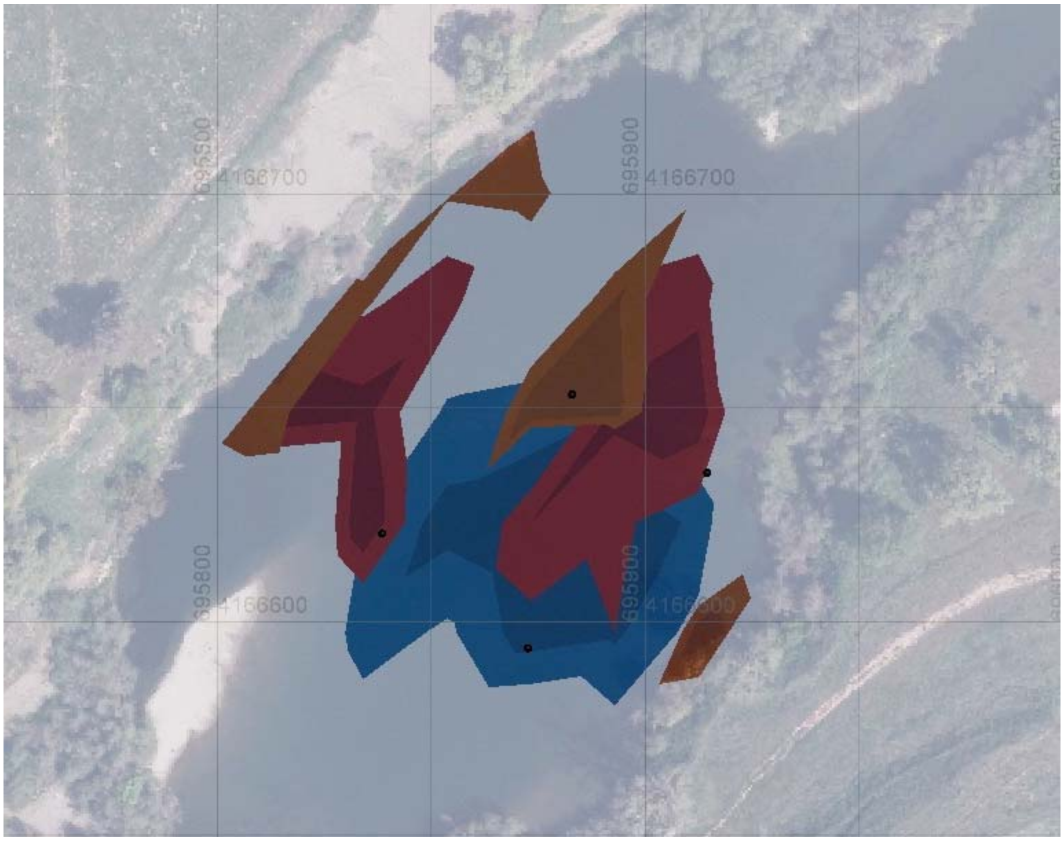


Figure 5.4-1. Densities of acoustic tagged Chinook salmon and predators in SRP 6 at 2,100 cfs (Chinook salmon: blue, largemouth bass: orange, and striped bass: red). Darker shaded areas represent 90th percentile, and lighter shading represents 95th percentile densities. Note: where polygons overlap, not all species present may be visible.

In SRP 10 (RM 25.4), 57 Chinook salmon tags were detected at 2,100 cfs. Forty-three (75.4 percent) tagged salmon were classified as successful passages, nine (15.8 percent) were likely consumed by predators, and five (8.8 percent) were unknown. The travel time from SRP 6 to SRP 10 of Chinook that successfully passed through SRP 10 ranged from 3.1 to 21.6 hours (median= 6.2 hours), and duration of detection within SRP 10 ranged from 0.8 to 67.8 minutes (median= 5.0 minutes). The total area covered by tagged Chinook that successfully passed was 7,569 m^2. The overlap of the 90th percentile of acoustic tracks between tagged Chinook and predator species was 6.4 percent for largemouth bass, 33.2 percent for smallmouth bass, and 19.9 percent for striped bass (Figure 5.4-2, Table 5.4-3).

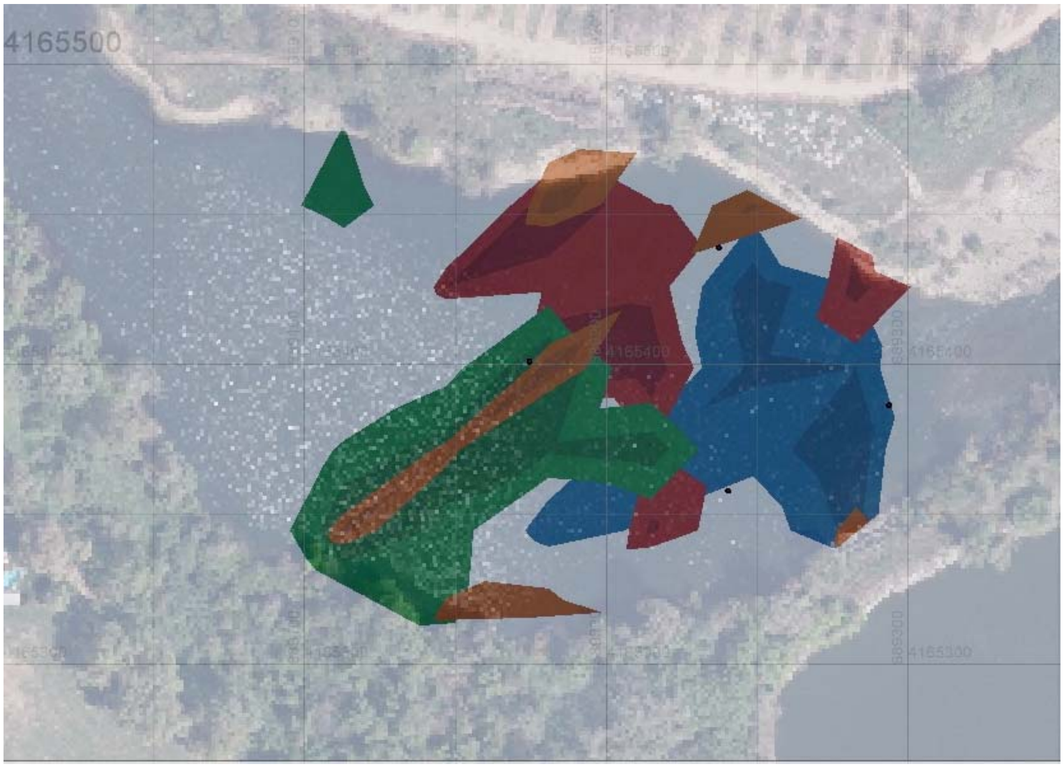


Figure 5.4-2. Densities of acoustic tagged Chinook salmon and predators in SRP 10 at 2,100 cfs (Chinook salmon: blue, largemouth bass: orange, smallmouth bass: green, and striped bass: red). Darker shaded areas represent 90th percentile, and lighter shading represents 95th percentile densities. Note: where polygons overlap, not all species present may be visible.

Of the 74 acoustic tagged Chinook salmon released at Hickman Bridge on May 16-17 at a flow level of 280 cfs, 55 were detected in SRP 6. Thirty (54.5 percent) of these successfully passed through SRP 6, seventeen (30.9 percent) were classified as likely consumed by predators, and eight (14.5 percent) were unknowns. The travel time from the release site of Chinook that successfully passed through SRP 6 ranged from 2.3 to 34.2 hours (median= 6.0 hours), and duration of detection within SRP 6 ranged from 1.0 to 25.1 minutes (median- 4.3 minutes). The total area covered by tagged Chinook that successfully passed was 2,839 m^2. The overlap of the 90th percentile of acoustic tracks between tagged Chinook and predator species was 6.9 percent for largemouth bass, 1.8 percent for smallmouth bass. 18.4 percent for striped bass, and 42.4 percent for Sacramento pikeminnow (Figure 5.4-3, Table 5.4-3).

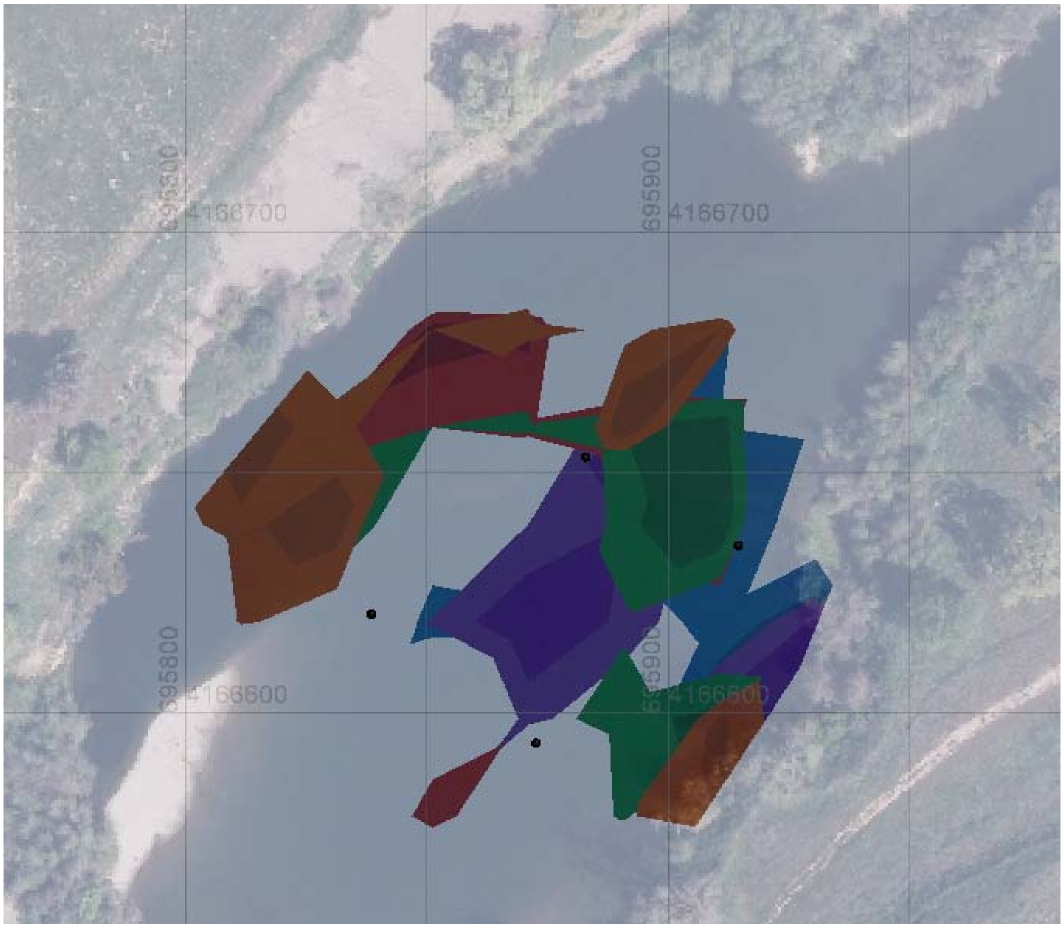


Figure 5.4-3. SRP 6 Low flow densities of tagged Chinook and predators (Chinook salmon: blue, largemouth bass: orange, smallmouth bass: green, striped bass: red, and Sacramento pikeminnow: purple). Darker shaded areas represent 90th percentile, and lighter shading represents 95th percentile densities. Note: where polygons overlap, not all species present may be visible.

In SRP 10, 22 of the Chinook salmon tags were detected at 280 cfs with 11 (50.0 percent) classified as passages, 7 (31.8 percent) as likely consumed by predators, and 4 (18.2 percent) as unknown. The travel time from SRP 6 of Chinook that successfully passed through SRP 10 ranged from 4.0 to 31.2 hours (median= 5.0 hours), and duration of detection within SRP 10 ranged from 3.3 to 12.7 minutes (median= 6.9 minutes). The total area covered by tagged Chinook that successfully passed was 7,958 m^2. The overlap of the 90th percentile of acoustic tracks between tagged Chinook and predator species was 30.5 percent for largemouth bass, 35.6 percent for smallmouth bass, 33.4 percent for striped bass, and 53.6 percent for Sacramento pikeminnow (Figure 5.4-4, Table 5.4-3).

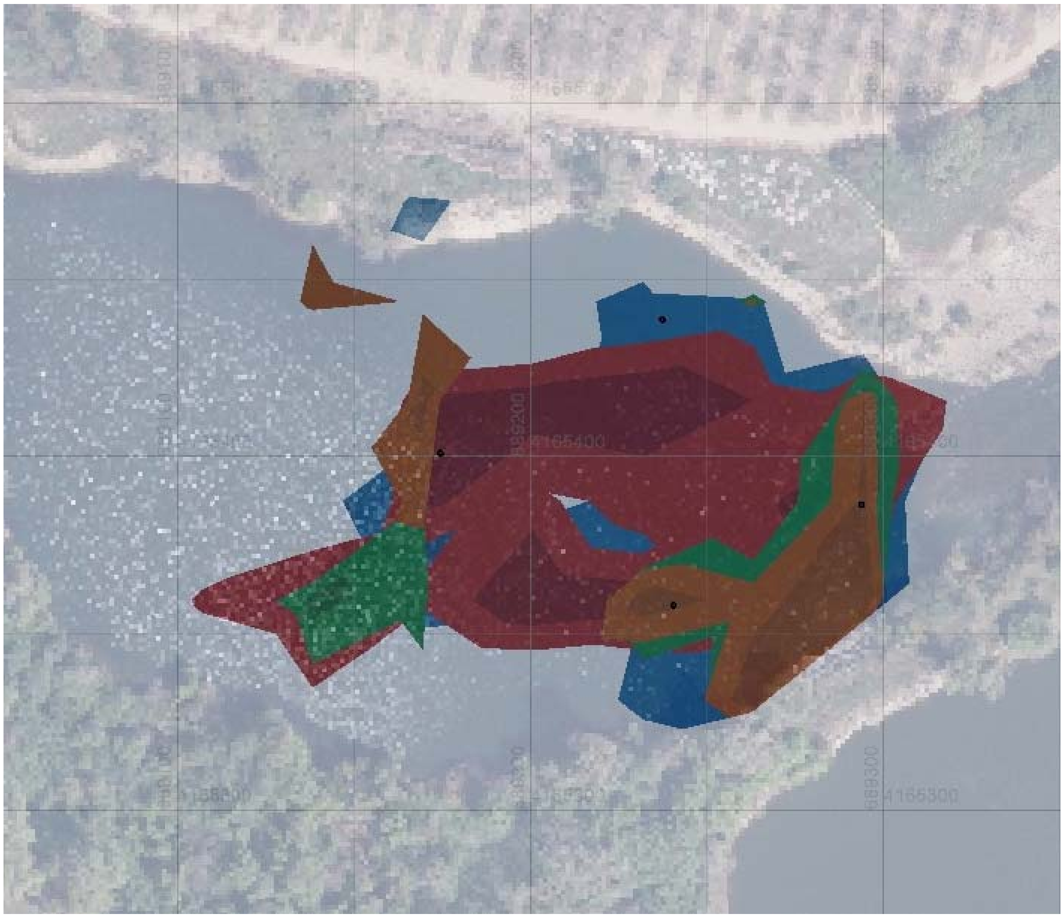


Figure 5.4-4. SRP 10 Low flow densities of tagged Chinook and predators (Chinook salmon: blue, largemouth bass: orange, smallmouth bass: green, and striped bass: red). Darker shaded areas represent 90th percentile, and lighter shading represents 95th percentile densities. Note: where polygons overlap, not all species present may be visible.

Of 73 acoustic tagged Chinook salmon released on May 21–22, 2012 at 415 cfs, 63 Chinook were detected in SRP 6. Twenty (31.7 percent) were classified as successful passages 38 (60.3 percent) were classified as likely consumed by predators and 5 (7.9 percent) were unknowns. The travel time from the release site of fish that successfully passed through SRP 6 ranged from 2.3 to 12.0 hours (median- 6.9 hours) and duration of detection within SRP 6 ranged from 0.4 to 42.7 minutes (median= 6.5 minutes). The total area covered by tagged Chinook that successfully passed was 4,037 m^2. The overlap of the 90th percentile of acoustic tracks between tagged Chinook and predator species was 16.6 percent for largemouth bass, 38.2 percent for smallmouth bass, and 39.1 percent for striped bass (Figure 5.4-5, Table 5.4-3).

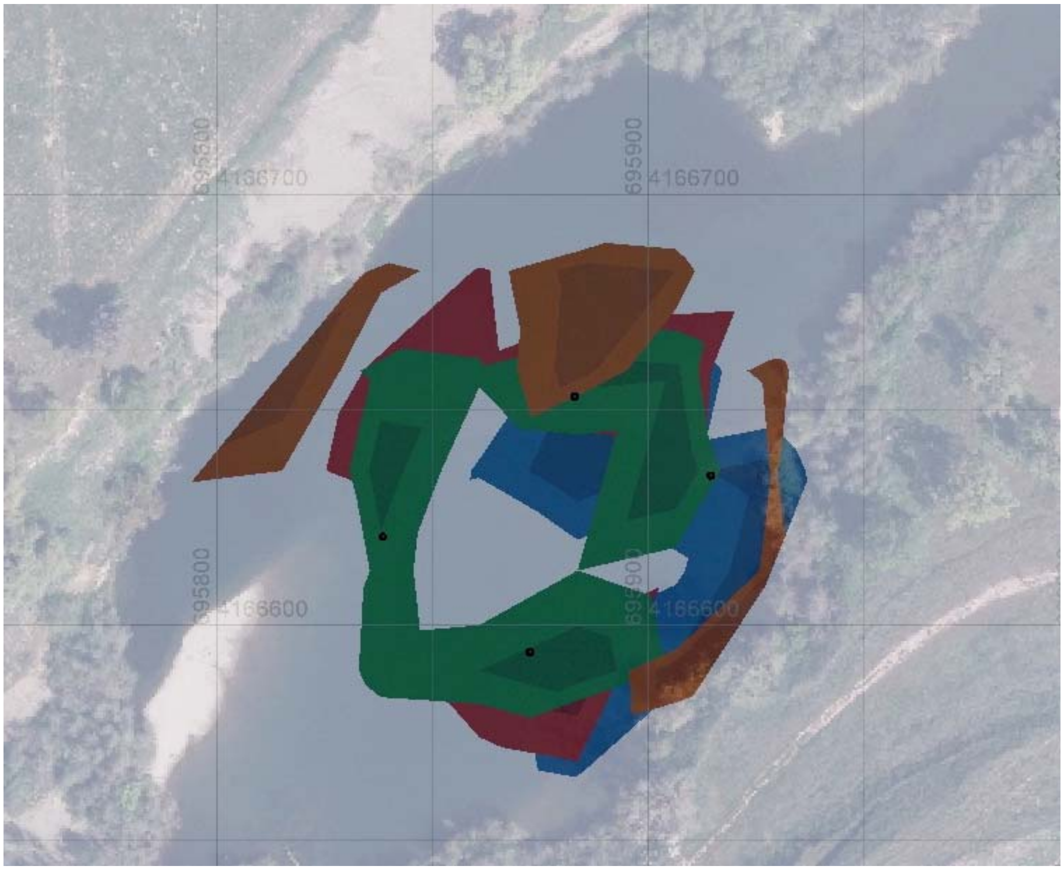


Figure 5.4-5. SRP 6 Mid flow densities of tagged Chinook and predators (Chinook salmon: blue, largemouth bass: orange, smallmouth bass: green, and striped bass: red). Darker shaded areas represent 90th percentile, and lighter shading represents 95th percentile densities. Note: where polygons overlap, not all species present may be visible.

In SRP 10 during the middle flow monitoring event, only seven tags entered the array; with five (71.4 percent) classified as likely consumed by predators and two (28.6 percent) successful passages. Travel time from SRP 6 to SRP 10 of Chinook that successfully passed through SRP 10 ranged from 14.1 to 69.9 hours, and duration of detection within SRP 10 ranged from 4.5 to 9.3 minutes. The total area covered by tagged Chinook that successfully passed was 5,847 m^2. The overlap between acoustically tagged Chinook and predator species was 5.8 percent for largemouth bass, 0.2 percent for smallmouth bass, and 46.3 percent for striped bass (Figure 5.4-6, Table 5.4-3).

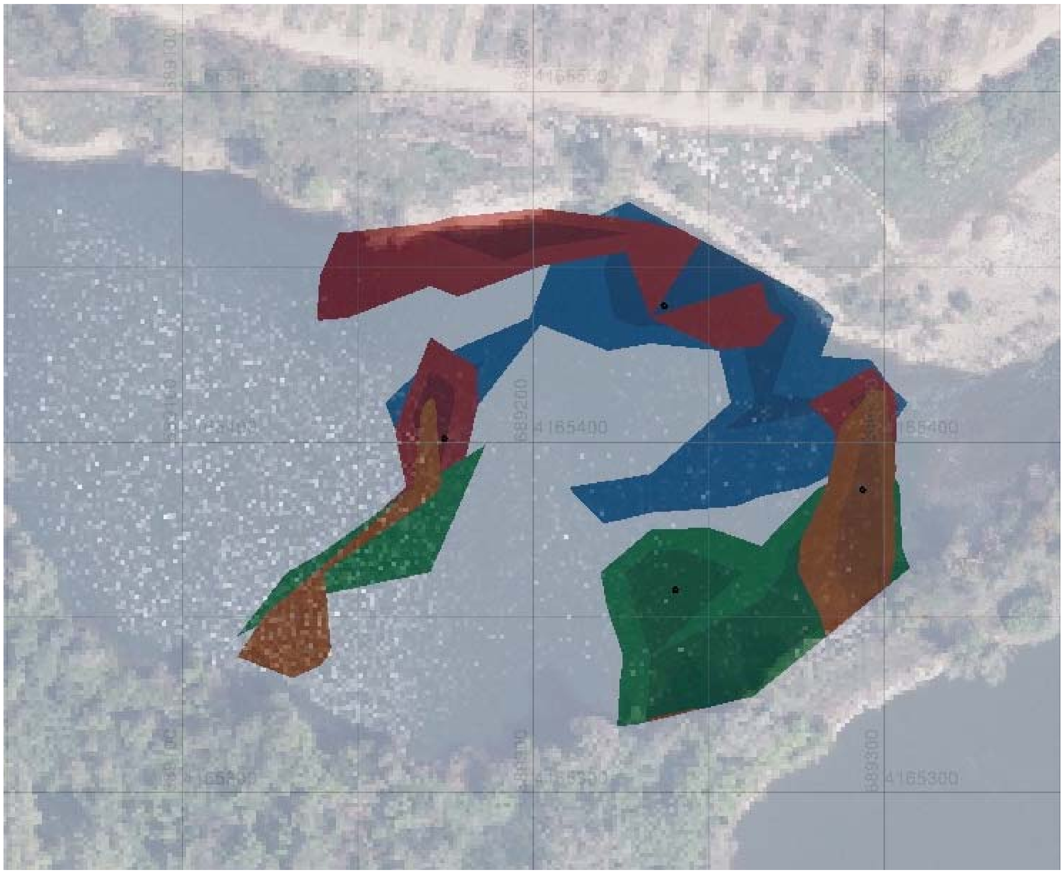


Figure 5.4-6. SRP 10 Mid flow densities of tagged Chinook and predators (Chinook salmon: blue, largemouth bass: orange, smallmouth bass: green, and striped bass: red). Darker shaded areas represent 90th percentile, and lighter shading represents 95th percentile densities. Note: where polygons overlap, not all species present may be visible.

Table 5.4-3. Summary of overlap in habitat use at the 90th percentile between acoustic tagged Chinook salmon and predators in SRP 6 and SRP 10.

Site	Release Group	Flow (cfs)	Chinook Passed	Chinook Area (m^2)	Percent Overlap			
					LMB	SMB	STB	SASQ
SRP 6	1	2,100	63	4,546	8.0	---	27.4	---
	2	280	31	2,839	6.9	1.8	18.4	42.4
	3	415	26	4,037	16.6	38.2	39.1	---
SRP 10	1	2,100	43	7,569	6.4	33.2	19.9	---
	2	280	11	7,958	30.5	35.6	33.4	53.6
	3	415	2	5,847	5.8	0.2	46.3	---

5.4.2.1 Transit Times of Acoustic Tagged Chinook Salmon

Transit times of acoustic tagged Chinook salmon from the release site to SRP 6 at 2,100 cfs were significantly less than transit times at 280 cfs (Wilcoxon rank sum test, p-value = < 0.00001) and 415 cfs (p-value = < 0.00001). The difference between the median transit times of Chinook salmon at 2,100 cfs and at 280 cfs was 4.3 hours. The difference between the median transit times of Chinook salmon at 2,100 cfs and at 415 cfs was 6.2 hours. No significant differences in median transit times of Chinook salmon were found between flows of 280 cfs and 415 cfs (p-value = 0.883) (Figure 5.4-7).

No significant differences in median transit times between SRP 6 and SRP 10 were found between 2,100 cfs and 280 cfs (Wilcoxon rank sum test, p-value = 0.3588) (Figure 5.4-8). The sample size of fish arriving at SRP 10 at 415 cfs was too small (n=2) for comparison.

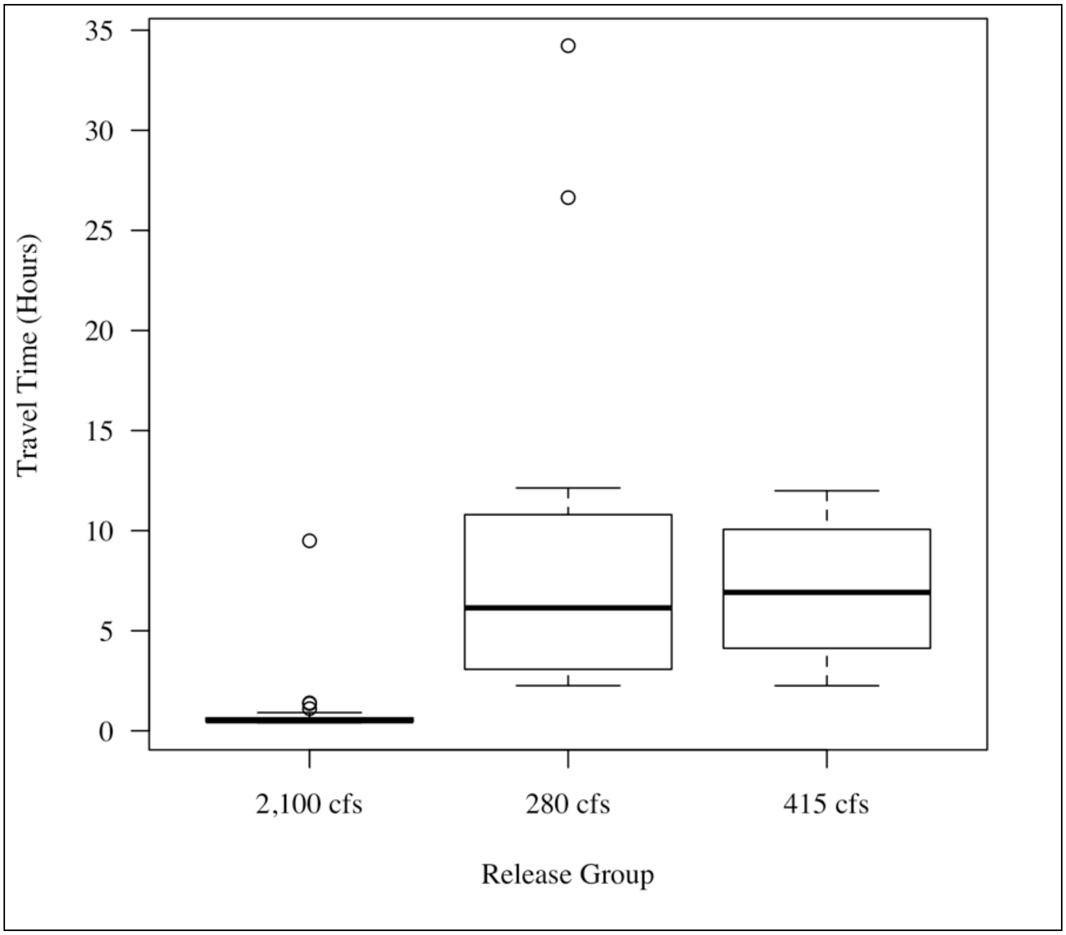


Figure 5.4-7. Transit times from Hickman Bridge to SRP 6 of acoustic tagged juvenile Chinook salmon (n = 109 total; n = 59 at 2,100 cfs; n = 30 at 280 cfs; and, n = 20 at 415 cfs).

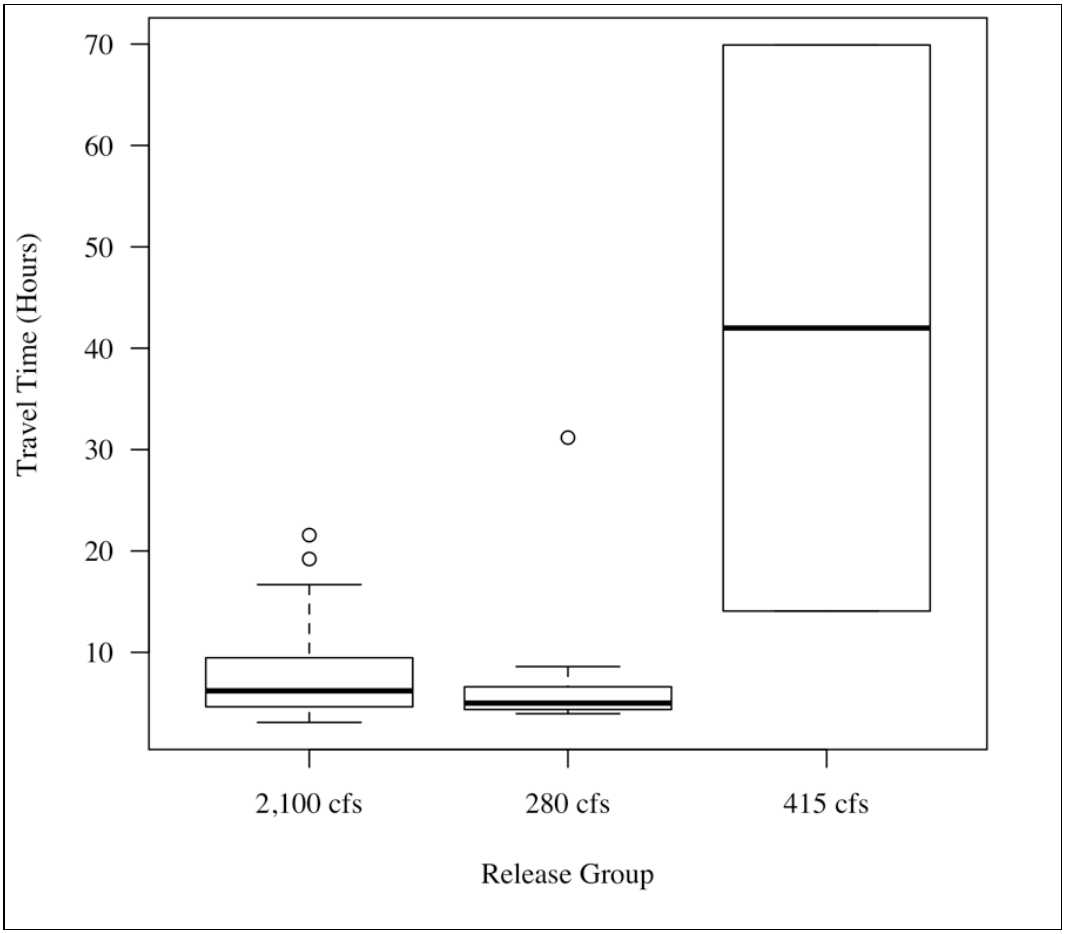


Figure 5.4-8. Transit times from SRP 6 to SRP 10 of acoustic tagged juvenile Chinook salmon (n = 53 total; n = 40 at 2,100 cfs; n = 11 at 280 cfs; and, n = 2 at 415 cfs).

5.4.2.2 Residence Times Within Special Run-Pools

Using a Wilcoxon rank sum test to compare differences in median residence times of juvenile Chinook salmon in SRP 6, residence time at 415 cfs was significantly higher (2.1 minutes higher) compared to the residence times at 280 cfs (Wilcoxon rank sum test, p-value = 0.02335). No other statistically significant differences (e.g. residence times at 2,100 cfs compared to 280 cfs) were found (Figure 5.4-9).

In SRP 10 no significant differences in median residence times were found between flows of 2,100 cfs and 280 cfs (Wilcoxon rank sum test, p-value = 0.3236). Differences in residence times at 415 cfs could not be assessed due to few detections of that release group in SRP 10 (n = 2) (Figure 5.4-10).

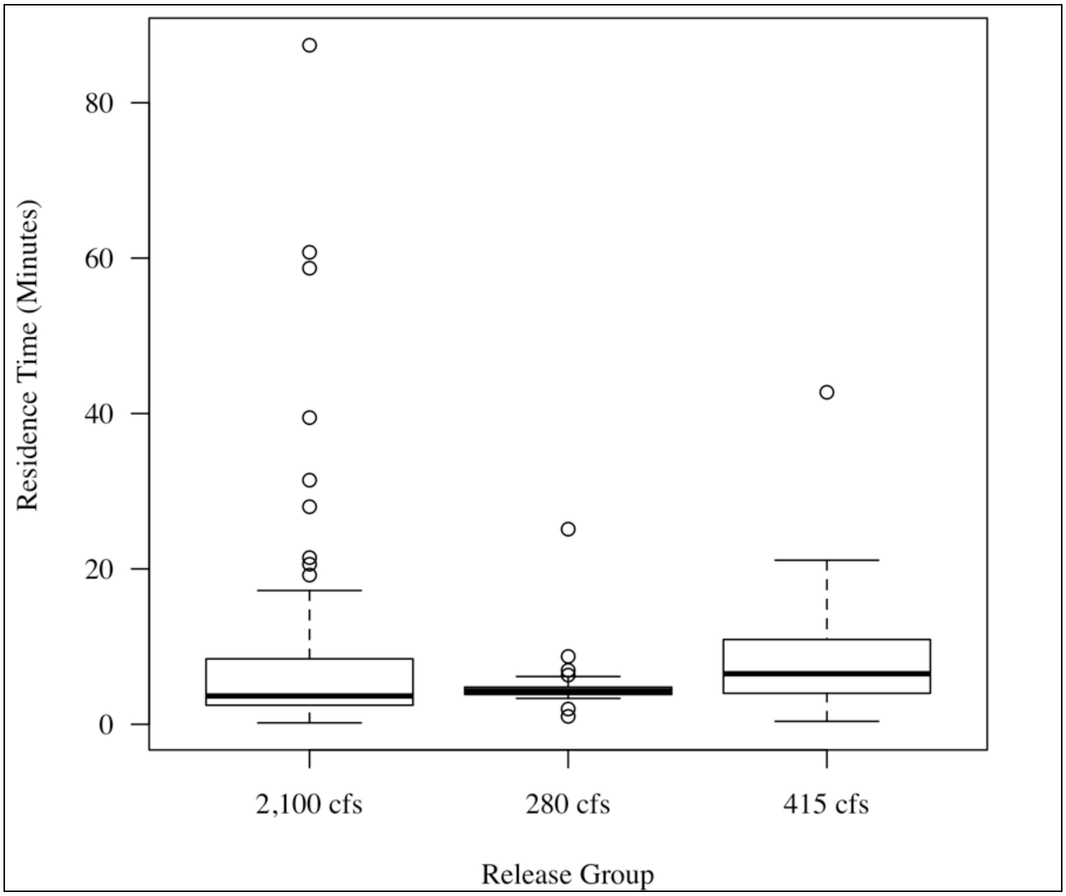


Figure 5.4-9. Residence times (in minutes) at SRP 6 of acoustic tagged juvenile Chinook salmon (n = 109 total; n = 59 for 2,100 cfs; n = 30 for 280 cfs; and, n = 20 for 415 cfs).

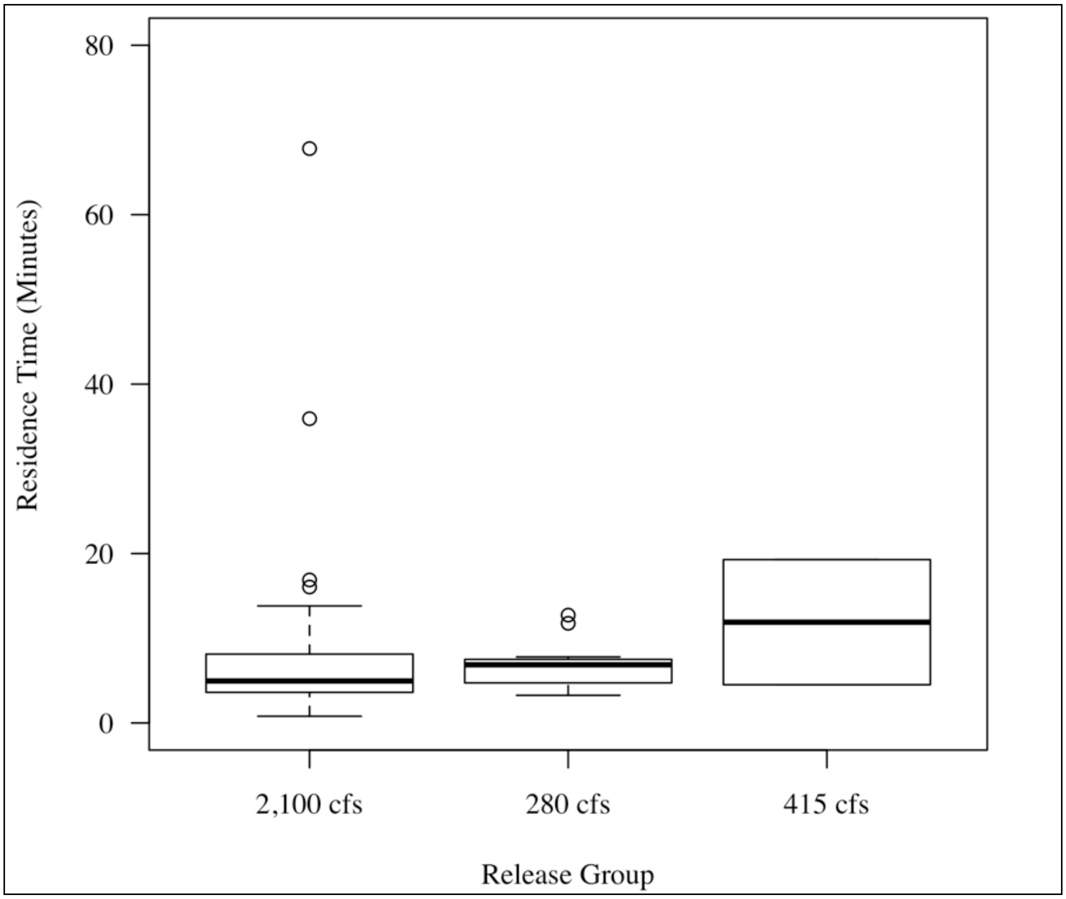


Figure 5.4-10. Residence times (in minutes) at SRP 10 of acoustic tagged juvenile Chinook salmon (n = 55 total; n = 42 for 2,100 cfs; n = 11 for 280 cfs; and, n = 2 for 415 cfs).

5.4.2.3 Riffle Monitoring

The goal of the single hydrophone arrays deployed above and below Riffle 62 and Riffle 74 was to evaluate differential habitat use between Chinook salmon and predator fish within these riffle habitats. Unlike monitoring in the SRPs, two-dimensional positioning was not possible due to the limited depth and increased background noise in the riffle habitats. Equipment malfunctions did not allow us to monitor Chinook movements through the riffles, however we did monitor movements of tagged predators though the riffles. A total of 101 riffle passage events (44 upstream, 57 downstream) were recorded at flows ranging from 244 cfs to 2,160 cfs. A riffle passage event was classified as detection at the upstream or downstream array and a subsequent detection at the opposite side of the riffle. Based on the difference in time of detection at the two arrays we were able to calculate residence times within the riffle habitats. Residence times within the monitored riffles were determined for 70 passage events and ranged from 0.9 to 83.5 minutes (median 15.8 minutes).

6.0 DISCUSSION AND FINDINGS

6.1 Predator Abundance

6.1.1 Riverwide Abundance Estimates

In 1990, largemouth bass abundance was estimated for the entire lower Tuolumne River (RM 0.0 to RM 52.0) based on shoreline lengths (TID/MID 1992). The abundance estimate for largemouth bass was 11,074 (Table 2; TID/MID 1992). During 2012, abundance of largemouth bass from RM 0.0 to RM 39.4 was estimated to be 3,323 based on shoreline length and 3,891 based on habitat area. However differences in study methods preclude making any conclusions based on comparison of these estimates. Notable differences include no use of block nets to create a closed population during the 1990 study, differences in geographic scope of sampling, and differences in length criteria used to estimate abundance.

For instance, the 1990 study included largemouth bass between 100 and 150 mm, whereas the 2012 study only estimated abundance of largemouth bass >150 mm. Bass <150 mm were not identified to species during 2012, and the estimated abundance of bass <150 mm (all species combined) was 95,198-121, and 756.

Capture rates of smallmouth bass, striped bass, and Sacramento pikeminnow were insufficient to produce abundance estimates during the 1990 study so no comparison can be made to estimated abundance in 2012.

6.1.2 Site-specific Abundance Estimates

Site-specific abundance estimates of piscivore-size (> 150 mm FL) largemouth bass ranged from 0 to 42 across 12 sites sampled (Table 5.2-2). McBain & Trush and Stillwater Sciences (2006) used similar depletion methods and reported that site-specific estimates of piscivore-size (180-380 mm FL) largemouth bass ranged from 0 to 18 in 1998 (5 sites sampled); from 2 to 40 in 1999 (6 sites sampled); and, from 5 to 95 in 2003 (6 sites sampled). Using various mark-recapture estimation methods, TID/MID (1992) reported that site-specific estimates averaged 80 largemouth bass (range = 11 – 181 largemouth bass).

Site-specific abundance estimates of piscivore-size (> 150 mm FL) smallmouth bass ranged from 2 to 50 across 12 sites sampled during late summer 2012 (Table 5.2-3). Site-specific estimates of piscivore-size (180-380 mm FL) smallmouth bass ranged from 0 to 2 in 1998 (5 sites sampled); from 0 to 13 in 1999 (6 sites sampled); and, from 2 to 49 in 2003 (6 sites sampled) (McBain & Trush and Stillwater Sciences 2006). Previous research, conducted by TID/MID (1992), showed that site-specific abundance estimates averaged 20 smallmouth bass (range = 9 – 29 smallmouth bass).

Site-specific abundance estimates of both Sacramento pikeminnow and striped bass are provided in Tables 5.2-4 and 5.2-5. We attempted to compare these estimates with previous estimates from McBain & Trush and Stillwater Sciences (2006), however, differences in length criteria for Sacramento pikeminnow and very low capture rates of striped bass during 1998, 1999, and 2003

(McBain & Trush and Stillwater Sciences 2006) do not allow for meaningful comparison.

6.1.3 Smallmouth and Largemouth Bass Densities

Density estimates for largemouth bass and smallmouth bass reported by McBain & Trush and Stillwater Sciences (2006) were converted from number of fish per 1000 ft of shoreline to number of fish per shoreline mile for comparison (Tables 5.2-2 and 5.2-3). However, densities calculated in the 2012 study used piscivores defined as 150 mm FL and above whereas the densities calculated in the McBain & Trush and Stillwater Sciences (2006) study used only piscivores between 180 and 380 mm TL.

Density estimates (converted to fish per mile) from McBain & Trush and Stillwater Sciences (2006) for smallmouth bass (collected in 1998, 1999, and 2003) ranged from 2 to 97 fish per mile. In comparison, site-specific density estimates of smallmouth bass from the current study ranged from 0 to 251 fish per mile (Table 5.2-3). For largemouth bass, site-specific density estimates ranged from 0 to 218 largemouth bass per mile, compared with 4 to 196 largemouth bass per mile (Table 12; McBain & Trush and Stillwater Sciences, 2006) (Table 5.2-2).

6.1.4 General Spatial Distribution

Twelve sites total were sampled for the predator abundance study from RM 3.7 to RM 38.4 during late July and early August 2012. Potential spatial patterns in presence and absence of target predator species emerged from examining Tables 5.2-2 through 5.2-5. Of the 12 sites, smallmouth bass and striped bass (> 150 mm FL) were captured at 12 and 4 sites, respectively. The capture locations of striped bass, however, were located in the entire reach, from RM 3.7 to RM 35.0. Similarly, capture locations of smallmouth bass were located from RM 3.7 to RM 38.4. In contrast, no largemouth bass (> 150 mm FL) were captured at or above RM 34.8 and no Sacramento pikeminnow (> 150 mm FL) were captured at or below RM 25.5.

If the spatial distributions of striped bass and smallmouth bass are nearly river wide, this may have implications for relating their predation rates with their relative abundances. One important assumption, however, is that the distribution of target species during abundance sampling (late summer) was relatively similar to the distribution during predation rate sampling (early to mid Spring). The combination of smallmouth bass and striped bass may account for more predation on juvenile Chinook salmon due to the combination of their widespread distribution, predation rates, and relative abundance. The distribution of largemouth bass during late summer may be determined in some part by river location (e.g. more largemouth bass in lower gradient, warmer lower reaches of the Tuolumne). Likewise, the distribution of Sacramento pikeminnow during late summer may be confined to the mid- to upper-portions of the lower Tuolumne River.

6.2 Predation Rate

Predation frequencies (# of predators with at least one Chinook salmon / total # of predators) were significantly higher in SRPs compared to RPs during March 2012, although no evidence of a difference in predation frequencies by habitat type was detected in May (Figure 5.3-6). No statistically significant differences in predation frequencies were found between sampling events or between habitat types when combined across sampling events.

Predation rates (# of Chinook salmon per predator) were generally highest for striped bass, followed by predation rates of smallmouth bass and largemouth bass. Average consumption per predator (not scaled by gastric evacuation rates) in a previous study ranged from 0 to 1.67 (TID/MID 1992; Table 3) compared to 0 to 1.2 in this study with striped bass having the three highest consumption rates (Table 5.3-3). Juvenile Chinook salmon consumption rates for largemouth and smallmouth bass (0 – 0.16) observed in this study were lower compared to the consumption rates for those species (0 – 1.67) in the TID/MID (1992) report. A review by Carey et al. (2011; Table 4) reported that predation rates (number Chinook salmon consumed per day) for smallmouth bass from Columbia River basin ranged from 0 to 3.89 Chinook consumed per day, with most values less than 0.1 Chinook salmon per day. The predation rate for striped bass on juvenile Chinook salmon in the lower Tuolumne River was reported to be zero (TID/MID 1992). However, only eight striped bass were examined in the course of that earlier study. No striped bass were captured during predation rate sampling subsequently conducted by Stillwater Sciences and McBain & Trush (2006).

Chinook salmon were only detected in the stomach samples of smallmouth bass, largemouth bass, and striped bass. No predation on juvenile Chinook salmon by Sacramento pikeminnow was observed, however, only six individuals were sampled. Previous research indicates that predation on juvenile Chinook salmon by Sacramento pikeminnow may be quite low in the lower Tuolumne River. Of 68 Sacramento pikeminnow captured and examined for the presence of juvenile Chinook salmon in 1992, none were found to have consumed juvenile Chinook salmon (TID/MID 1992). No Sacramento pikeminnow were captured during predation rate sampling conducted by Stillwater Sciences and McBain & Trush (2006).

Water temperatures were between 13°C and 16°C during the first sampling period (March 22 – March 29) among the sampling locations. During the second sampling period (May 1 – May 9), water temperatures ranged from 14°C to 17°C among the sampling locations. The water temperatures observed during this study may have partially influenced the predation rate compared with previous work conducted by Stillwater Sciences and McBain & Trush (2006). In that study, very few target species (n = 4) were captured, but of those captured, none contained juvenile salmon. Water temperatures were much lower during the earlier study, ranging from 10.7°C to 12.8°C, compared to 13°C to 17°C observed in the current study (Figure 5.1-2). Discharge during the previous study was significantly higher (6,740 cfs to 9,120 cfs) than discharges observed during predation rate sampling in this study (about 350 cfs to about 2,100 cfs) (Figure 5.1-1).

Turbidity during predation rate sampling ranged from 0.77 NTU to 2.83 NTU, and these levels were similar to those reported in the TID/MID (1992) study. The results of neither study suggested any connection between predation rates and turbidity, and while the ranges of turbidity during sampling were quite narrow, they are representative of the range of typical baseline turbidity conditions in the lower Tuolumne River. Other studies have found that turbidity greater than 25 NTU reduces the incidence and risk of piscivory on salmonid prey (Gregory and Levings 1998).

6.2.1 Diet Composition

Invertebrates (insects and crayfish) made up a large portion (by frequency of occurrence and by total count) of identifiable prey items among the stomach samples examined. Crayfish were present in about 26 percent of all stomach samples from the target species examined. This result is similar to the TID/MID (1992) report, where 17 percent and 33 percent of fish sampled (consisting of smallmouth bass, largemouth bass, Sacramento pikeminnow, striped bass, bluegill, redear sunfish, green sunfish, channel catfish, white catfish, and brown bullhead) contained crayfish.

Thirty fish identified as juvenile Chinook salmon occurred in about 12 percent of the stomach samples or 30 of the 246 non-empty stomach samples examined. However, juvenile Chinook salmon only made up about 10 percent of all the fish (n = 326) observed in stomach samples. Other fish consumed were unidentified larval fish (observed in 79 of 246 non-empty stomachs), sculpin (16 of 246), and lamprey and cyprinids (2 of 246).

6.3 Synthesizing Abundance and Predation Rates

The cumulative impact of predation was assessed by estimating the abundance of target species between RM 5.1 (location of the Grayson rotary screw trap) and RM 30.3 (location of the Waterford rotary screw trap). Methods to estimate abundance based on shoreline lengths in this reach are described in Section 4.2.2.3. The abundance in this reach was then combined with the species-specific predation rates observed in this study (see Sections 4.3.3.3 and 5.3.6 “Predation rates on juvenile Chinook salmon”).

We estimated abundance of predatory fish based on a total shoreline distance (feet) of 298,163 between the Waterford and Grayson rotary screw traps. Density estimates of predators were calculated using only site-specific abundance estimates from sites sampled between RM 5.1 and RM 30.3, so that abundance data from only seven of the twelve sites was used. All estimators for abundance and variance for this calculation are provided in Section 4.2.2.3.

Abundance estimates of piscivore-sized fish (>150 mm FL) between Waterford and Grayson were 3,013 largemouth bass (SE±156), 117 (SE±18) Sacramento pikeminnow, 3,626 (SE±111) smallmouth bass, and 235 (SE±21) striped bass. Species-specific predation rates for the lower predation rate (e.g. the rate based on a 20-hour gastric evacuation time) were averaged for all habitat types and sampling events. Predation rates were 0.10 Chinook per predator per day for largemouth bass, 0.0 Chinook per predator per day for Sacramento pikeminnow, 0.11 Chinook per predator per day for smallmouth bass, and 1.1 Chinook per predator per day for striped bass (see Table 5.3-3). To be conservative in the cumulative impact assessment of predation between the two rotary screw traps, we used the lower 95 percent confidence bounds for each species abundance estimate which were 21,701 largemouth bass, 81 Sacramento pikeminnow, 3,404 smallmouth bass and 193 striped bass. The total estimate of juvenile Chinook salmon potentially consumed was estimated by multiplying the number of predators, the migration period (in days), and the estimated predation rate (in number of juvenile Chinook salmon consumed per day). For example, the estimated number of juvenile Chinook salmon consumed by largemouth bass over a 90-day migratory period was 24,309 (2,701 * 90 * 0.1). We used 60-, 90-, or 120-day migratory periods which assumed that the daily numbers of juvenile Chinook migrating was uniformly distributed and that all equally vulnerable to predation at the average rate.

The estimated numbers of juvenile Chinook consumed in the reach between the Waterford and Grayson rotary screw traps are reported in Table 6.3-1. Despite making up only a small fraction (< 4 percent) of the total of piscivore-sized fish (> 150 mm FL), striped bass were estimated to consume nearly 25 percent of the total potential juvenile Chinook salmon consumed. Smallmouth bass were estimated to consume about 44 percent of juvenile Chinook salmon and largemouth bass were estimated to consume about 32 percent of juvenile Chinook salmon.

Table 6.3-1. Estimated cumulative impact of predation in the lower Tuolumne River between RM 30.3 and RM 5.1 under a low predation rate (gastric evacuation time set at 20-hours) by length of migratory period of juvenile Chinook salmon.

Species	$\hat{N}$	Predation Rate	60-Day Migratory Period	90-Day Migratory Period	120-Day Migratory Period	Percent of Impact
Largemouth bass	2,701	0.1	16,206	24,309	32,412	31.5%
Sacramento pikeminnow	81	0	0	0	0	0.0%
Smallmouth bass	3,404	0.11	22,466	33,700	44,933	43.7%
Striped bass	193	1.1	12,738	19,107	25,476	24.8%
		Total	**51,410**	**77,116**	**102,821**	

Total potential consumption of juvenile Chinook salmon was estimated to be about 77,000 for a 90-day migratory period (Table 6.3-1). Estimated abundance of juvenile Chinook salmon at the Waterford rotary screw trap during January 3 - June 15, 2012 was 68,650, suggesting that consumption of juvenile Chinook salmon by predators between the Waterford and Grayson rotary screw traps could equal or exceed the number passing the Waterford trap. Only 2,969 Chinook salmon were estimated to have survived migration through the 25 miles between the trapping sites (Sonke and Fuller 2012), making it plausible that most, if not all, losses of juvenile Chinook salmon in the lower Tuolumne River between Waterford and Grayson during 2012 could be attributed to non-native predatory species.

Predation rate sampling and predator abundance sampling did not temporally overlap, it was assumed that predator abundance in summer was similar to predator abundance during the juvenile Chinook salmon migration. Given the similarity in densities of predatory species between this study and previous studies conducted on the lower Tuolumne River, and the similarities between predation rates between this study and other predation rates observed from the same species, we feel justified that the cumulative impacts of predation on juvenile Chinook salmon in the lower Tuolumne River during the spring of 2012 were substantial.

Losses of juvenile Chinook salmon between the rotary screw traps at Waterford and Grayson ranged between approximately 76 percent and 98 percent during 2007-2011, with the actual numbers of individuals estimated to be lost ranging from approximately 22,000 to 330,000. If the predation rates and predator abundances in these years were similar to those documented in the 2012 study, it is plausible that the overwhelming majority of Chinook salmon mortality was due to predation.

6.4 Differential Habitat Use

Two-dimensional acoustic tracking was used to evaluate the role of flow in segregating potential predators from outmigrating Chinook salmon within the special run-pools. Results showed overlap between acoustically tagged Chinook and predators at the three tested flows (280 cfs, 415 cfs, and 2,100 cfs). Striped bass were found to have the greatest overlap in habitat use with Chinook salmon (18.4 percent - 46.3 percent), followed by largemouth bass (5.8 percent -30.5 percent), and smallmouth (0.2 percent - 38.2 percent).

Residence times of Chinook salmon within SRPs were also found to be similar between release groups, with the only significant difference in the medians found between 415 cfs and 280 cfs in SRP 6. It should be noted that the highest range in residence times at both SRPs was found during the 2,100 cfs event. Based on review of individual acoustic tracks, extended residence times were due to fish circling within the array rather than passing directly through the SRP. Circling was likely caused by hydraulic conditions within the SRPs at the higher flows.

An earlier study on the Tuolumne River (McBain & Trush and Stillwater Sciences, 2006) hypothesized that at flows exceeding 300 cfs, higher velocities would increase Chinook salmon migration rates through SRP sites. The results of this study do not support this hypothesis as transit times across SRP 6 and SRP 10 were fastest at 280 cfs, suggesting that higher flows actually decrease transit rates through the SRPs. Comparison of transit rates at each site at a given flow found no statistically significant difference in transit rates between sites, suggesting that this trend may also apply to other SRP sites that were not studied in 2012.

Acoustic detections within riffle 62 and riffle 74 and estimated residence times within riffles suggest that predator species (largemouth bass, smallmouth bass, and striped bass) were able to move unrestricted through riffle habitats at all test flows. Tracking technology did not allow for precise determination of tagged fish locations within the riffles.

6.5 Potential Additional Studies to Be Conducted in 2013

The Districts are considering conducting an additional year of predator abundance and predation rate sampling in 2013 using the same methodology as employed in the 2012 study. It is apparent from the 2012 results that predation is a significant factor affecting salmon smolt survival on the Tuolumne River. Additional information may provide greater detail related to potential protection, mitigation and enhancement measures.

7.0 STUDY VARIANCES AND MODIFICATIONS

The study was conducted consistent with the approved study plan. No variances occurred.

The study is complete. No modifications are proposed.

8.0 REFERENCES

Adams, N. J, D. R. Barton, R. A. Cunjak, G. Power, and S. C. Riley. 1987. Diel patterns of activity and substrate preference in young Arctic char from the Koroc River, northern Quebec. Canadian Journal of Zoology 66:2500–2502.

Adams, N.S., D.W. Rondorf, S.D. Evans, and J.E. Kelly. 1998. Effects of Surgically and Gastrically Implanted radio Transmitters on Growth and Feeding Behavior of Juvenile Chinook Salmon. Transactions of the American Fisheries Society 127: 128-136.

Angradi, T. R., and J. S. Griffith. 1990. Diel feeding chronology and diet selection of rainbow trout (*Oncorhynchus mykiss*) in the Henry's Fork of the Snake River, Idaho. Canadian Journal of Fisheries and Aquatic Sciences 47:199–209.

Aragon, T. 2010. epitools: Epidemiology Tools. R package version 0.5-6. http://CRAN.R-project.org/package=epitools

Benkwitt, C.E., R.D. Brodeur, T.P. Hurst, E.A. Daly. 2009. Diel Feeding Chronology, Gastric Evacuation, and Daily Food Consumption of Juvenile Chinook Salmon in Oregon Coastal Waters.

Brown, L.R., and T. Ford. 2002. Effects of flow on the fish communities of a regulated California river: implications for managing native fishes. River Research and Applications 18:331-342.

Carey, M. P., B. L. Sanderson, T. A. Friesen, K. A. Barnas, and J. D. Olden. 2011. Smallmouth bass in the Pacific Northwest: a threat to native species; a benefit for anglers. Reviews in Fisheries Science 19: 305-315.

Carle, F. L., and M. R. Strub. 1978. A new method for estimating population size from removal data. Biometrics 34:621-630.

Clark, C. W., and D. A. Levy. 1988. Diel vertical migrations by pelagic planktivorous fishes and the antipredator window. American Naturalist 131:271–290.

Crawley, M.J. 2007. The R Book. John Wiley & Sons, Inc., New York, New York.

Ehrenberg, J.E. and T.W. Steig. 2003. Improved techniques for studying the temporal and spatial behavior of fish in a fixed location. ICES J of Mar. Sci, 60: 700-706.

Frost, C.N. 2000. A key for identifying preyfish in the Columbia River based on diagnostic bones. U.S. Geological Survey, Columbia River Research Laboratory, Western Fisheries Research Center, Cook, Washington, 50 pp.

Gregory, R. S., and C. D. Levings. 1998. Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon. Transactions of the American Fisheries Society 127:275–285.

Hankin, D.G. 2009. Sampling Theory. Unpublished Manuscript. Preprint from D.G. Hankin, Department of Fisheries Biology, Humboldt State University, Arcata, CA.

Hansel, H.C., S.D. Duke, P.T. Lofy, and G.A. Gray.1998. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society 117:1, 55-62.

Kamler, J. F. and K. L. Pope. 2001. Nonlethal Methods of Examining Fish Stomach Contents. Reviews in Fisheries Science 9(1): 1-11.

Martinelli, T.L., H.C. Hansel, and R.S. Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling Chinook salmon. Hydrobiologia 371/372: 78-87.

McBain & Trush and Stillwater Sciences. 2006. Special Run Pool 9 and 7/11 Reach: post-project monitoring synthesis report. Prepared for the Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, USFWS Anadromous Fish Restoration Program, and California Bay-Delta Authority, by McBain & Trush, Arcata and Stillwater Sciences, Berkeley, CA.

Ogle, D. H. 2011. fishR Vignette – Depletion Methods for Estimating Abundance. Available online at: http://www.ncfaculty.net/dogle/fishR/gnrlex/Depletion/Depletion.pdf

R Development Core Team (2010). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Särndal, C.E., Swensson, B., and Wretman, J. 1992. Model Assisted Survey Sampling. New York: Springer-Verlag.

Sonke, C. and A. Fuller. 2012. Outmigrant Trapping of Juvenile Salmon in the Lower Tuolumne River, 2012. Prepared for Turlock and Modesto Irrigation Districts by FISHBIO, Oakdale, CA.

Stillwater Sciences and McBain & Trush. 2006. Lower Tuolumne River Predation Assessment Final Report. Prepared for the Tuolumne River Technical Advisory Committee, Turlock and Modesto Irrigation Districts, USFWS Anadromous Fish Restoration Program, and California Bay-Delta Authority, by Stillwater Sciences, Berkeley, CA and McBain & Trush, Arcata, CA.

Stillwater Sciences. 2010. Tuolumne River Floodplain Inundation Maps.

Thompson, S.K. 2002. Sampling, 2nd Edition. John Wiley & Sons, Inc., New York, New York

Turlock Irrigation District and Modesto Irrigation District (TID/MID). 1992. Lower Tuolumne River Predation Study Report. Appendix 22 to Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No.

2299 Vol. VII. Prepared by T. Ford, Turlock and Modesto Irrigation Districts and EA Engineering, Science, and Technology, Lafayette, California.

U.S. Department of Commerce, National Marine Fisheries Service (NMFS). 2000. Guidelines for Electrofishing Waters Containing Salmonids Listed Under the Endangered Species Act. National Marine Fisheries Service. Available online at: http://www.nwr.noaa.gov/ESA-Salmon-Regulations-Permits/4d-Rules/upload/electro2000.pdf.

Van Den Avyle, M. J. and J. E. Roussel. 1980. Evaluation of a Simple method for removing food Items from live black bass. Progressive Fish-Cult. 42: 222-223.

NOAA
National Marine
Fisheries Service

Fishery Bulletin
established 1881

Spencer F. Baird
First U.S. Commissioner
of Fisheries and founder
of *Fishery Bulletin*

Development of underwater recorders to quantify predation of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in a river environment

Nicholas J. Demetras (contact author)[1]
David D. Huff[2]
Cyril J. Michel[1]
Joseph M. Smith[3]
George R. Cutter[4]
Sean A. Hayes[5]
Steven T. Lindley[5]

Email address for contact author: nicholas.demetras@noaa.gov

[1] University of California, Santa Cruz
Affiliated with Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
110 Shaffer Road
Santa Cruz, California 95060

[2] Point Adams Research Station
Fish Ecology Division
Northwest Fisheries Science Center, NOAA
PO Box 155, Hammond, OR 97121

[3] School of Aquatic and Fishery Sciences
University of Washington
1122 NE Boat Street
Seattle Washington, 98105

[4] Fisheries Resource Division
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
8901 La Jolla Shores Drive
La Jolla, California 92037-1508

[5] Fisheries Ecology Division
Southwest Fisheries Science Center
National Marine Fisheries Service, NOAA
110 Shaffer Road
Santa Cruz, California 95060

Abstract—Recent acoustic tagging of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in the southern portion of California's Sacramento–San Joaquin Delta has revealed extremely low survival rates (<1%), possibly due to predation by piscivorous fishes. We evaluated predation as a cause of low survival by designing and testing freely floating GPS-enabled predation-event recorders (PERs) baited with juvenile Chinook salmon. We estimated predation rates and identified predation locations within a 1-kilometer reach of the Lower San Joaquin River. We modeled the relationship between time to predation and environmental variables with a Cox proportional hazards analysis that accounts for censored data. Our results indicated that an increase of 1 m/s in water velocity elevated the minute-by-minute hazard of predation by a factor of 9.6. Similarly, each increase in median depth decreased the predation hazard by a factor of 0.5. The mean relative predation rate in the study area was 15.3% over 9 sampling events between March and May 2014. Waterproof video cameras attached to a subset (48 of 216) of PERs successfully identified predator species 25% of the time. Our GPS-enabled PERs proved to be an inexpensive and reliable tool, which quantified predation, identified predation locations, and provided complementary information for acoustic telemetry and predator diet studies.

Manuscript submitted 9 July 2015.
Manuscript accepted 3 February 2016.
Fish. Bull. 114:179–185 (2016).
Online publication date: 23 February 2016.
doi: 10.7755/FB.114.2.5

Predation on juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and other native fishes within California's Sacramento–San Joaquin Delta has raised considerable debate over the last several decades (Bennet and Moyle, 1996; Mount et al., 2012). Traditionally, juvenile Chinook salmon survival within this delta has been estimated by using acoustic tagging data or coded-wire tag recoveries from mid-water trawls (Brandes and McLain, 2001; Newman and Rice, 2002; Buchanan et al., 2013; Michel et al., 2013; Pyper et al., 2013; Newman, 2003; Newman[1]). It is currently not clear what proportion of juvenile salmonid mortality may be directly attributed to fish predation. It is also difficult to interpret results regarding population-level survivorship in the Delta because these data have limited spatial scales, used various tagging methodologies, and do not clearly connect tag loss or mortality to predation (Grossman et al.[2]). Be-

[1] Newman, K. B. 2008. An evaluation of the four Sacramento-San Joaquin River Delta juvenile salmon survival studies, 181 p. U.S. Fish Wildl. Serv., Stockton, CA. [Available at website, accessed October 2014.]

[2] Grossman, G. D., T. Essington, B. Johnson, J. Miller, N. E. Monsen, and T. N. Pearsons. 2013. Effects of fish predation on salmonids in the Sacramento River–San Joaquin Delta and associated ecosystems, 71 p. [Available at website, accessed October 2014.]

cause most survival data come from acoustic tagging studies, it is essential to improve our understanding of the underlying cause of mortality events (i.e. predation, environmental, or other) from these types of instruments. We developed a tool to address this research need by designing floating, baited, predation-event recorders (PERs). These recorders allow estimation of relative predation rates in various environments, and reveal information about mortality produced by different species of fish predators.

Our objectives were to investigate the feasibility of 1) developing and constructing a passive, baited, GPS-enabled PER, 2) evaluating relative risk of predation mortality and 3) observing and identifying individual predators and associated predation events. We estimated relative predation mortality and identified predation hot spots upon juvenile Chinook salmon to compliment ongoing acoustic telemetry surveys. We were able to accurately identify the location of individual predation events, reliably identify predators, and the recorder system was easily deployed and retrieved by a boat-based crew of 2 people.

Materials and methods

PER construction

PERs were constructed from an approximately 75 cm length of 76 mm diameter, schedule 40 polyvinyl chloride (PVC) pipe. The bottom end was fitted with a PVC cap which was glued in place and the top end was fitted with a two part threaded, removable cap. Attached to the top cap was a GARMIN® TT™10[3] GPS transponder (available at website) set to update and record its position every five seconds. A predation-activated timer was attached to the bottom cap. The design of the timer, similar to that of Somerton et al. (1988), is connected to a baited line attached to a magnet**,** which is slotted inline into a receptacle on the timer, housing a magnetic switch (Fig. 1). When the bait is pulled, the magnet is removed, activating the timer that records the precise timing of the predation event. All GPS trackers were controlled and their tracks recorded with a GARMIN® Alpha 100®[1] handheld base-station unit plugged into a laptop computer located on board the boat. Up to 20 GPS trackers may be tracked simultaneously in real-time with one Alpha 100® handheld unit, as long as all trackers are within approximately 14 kilometers line-of-sight. More trackers can be tracked if multiple base stations are used.

Attached to each predation timer was a 50 cm length of 3.6 kg breaking-strength fluorocarbon leader. A sub yearling fall-run juvenile Chinook salmon from the Mokelumne River fish hatchery was attached to the distal end of the fluorocarbon leader by means of a loop threaded through the mouth and operculum. A seven-gram split-shot style weight was placed approximately 10 cm above the fish. Approximately 2.25-kg of lead shot was placed inside the bottom of each PER as ballast, which served to keep PERs upright while submerging all but the upper most 10 to 15 cm, where the GPS receiver was attached. GoPro[3] underwater cameras, with 64 gigabyte storage SanDisk[3] memory cards (available at website), were attached to a subset of 3 PERs opposite the predation timer and aimed directly at the attached smolt (Fig. 1). PERs were spray painted in a green and brown camouflage pattern to reduce visibility and obtrusiveness in the upper water column, but the top 10 to 15 cm above the water line were painted a bright safety orange and marked with reflective tape for easier visual identification by passing watercraft. Onset® HOBO®[3] pendant temperature and light data loggers (available at website) were attached to each PER (Fig. 1) so that we could relate environmental variables to predation events.

Field trials

All field trials were conducted within a 1-km study site (lat. 37.806°N, long. 121.317°W, lat. 37.799°N, long. 121.313° W) on the lower San Joaquin River located approximately 1.5 km downstream from Mossdale, CA. The depth of the sampling site ranged from 3.65 m to 0.6 m and had a mean depth of 1.98 m; the minimum effective depth of the PERs was 0.6 m, which represented approximately 88% of the total wetted stream channel. Depth of the entire sampling site was measured and mapped with boat-mounted sonar. River velocities ranged from 0.49 m/s to –0.32 m/s (mean velocity: 0.27 m/s. Negative values denote a flood tide and reversal of flow going upstream. Channel width ranged from approximately 70 m to 90 m. The sinuosity index (SI) of the study reach was 1.21. SI is a measurement of a river or stream's deviation from the shortest possible downslope path. A value of 1.0 indicates a perfectly straight channel, whereas increasing values of 1 are representative of increased meandering (Mueller, 1968). Ten PERs were repeatedly deployed on 9 separate trials, either one hour before sunrise or one hour before sunset by a 2-person boat crew, all trackers remained within line of site of the boat while deployed. Each trial consisted of 2 separate deployments mid channel; if a tether became beached or fouled it was promptly retrieved and redeployed at mid-channel. Each re-deployment was considered a unique deployment on its own.

The procedure for deploying PERs was 1) activation of GPS transponders/GoPro cameras (30 sec/PER), 2) attachment of the salmon smolt to predation timers (1 min/timer), 3) release of PERs (1 min/PER), 4) transit of PER through study site (45 min. to 1 h. depending upon river velocity), 5) retrieval of PERs and recording of timer data (20–30 min). Digital predation timers were immediately recorded upon retrieval. The cumulative time spent preparing, deploying, fishing, and re-

[3] Mention of trade names or commercial companies for identification purposes only and does not imply endorsement by the National Marine Fisheries Service.

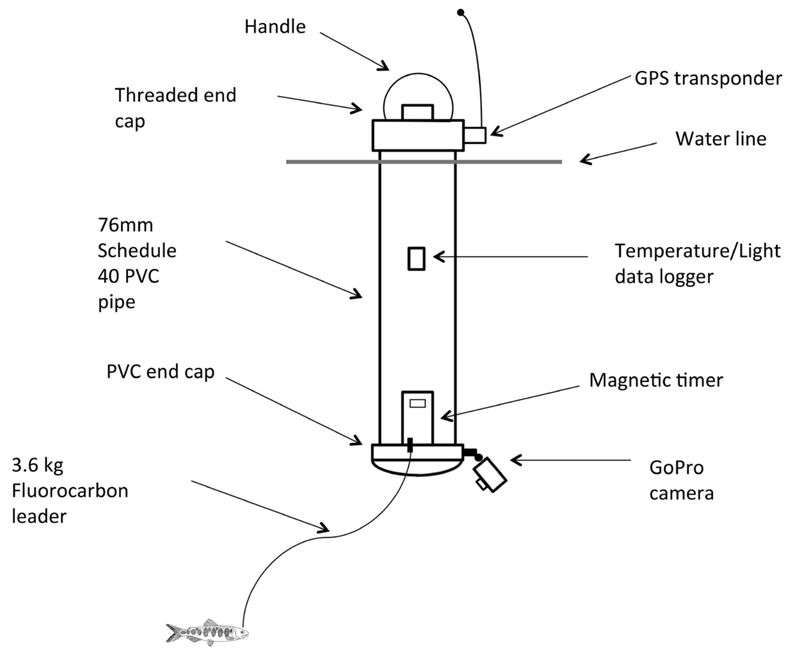


Figure 1

Schematic of a predation-event recorder (PER) with attached salmon smolt as bait. PERs were used to evaluate predation rates and environmental variables in the Sacramento–San Joaquin Delta, California from March through May of 2014.

trieving ten PERs by a 2-person boat crew ranged from 90 to 115 minutes.

Owing to extremely low flows during our study period in the spring of 2014, the lower San Joaquin River was under direct tidal influence over the course of the study and experienced a mixed, semidiurnal tidal pattern. The tidal nature of the San Joaquin River during this period required extra effort to determine the correct mid-channel placement of the PERs so that they would remain within the site for approximately 45 minutes or longer. If a PER did not remain within a study site for at least 45 minutes, or became beached or otherwise fouled, it was promptly retrieved, re-baited and redeployed within the study site.

Data processing and analysis

PER GPS transponders recorded a location every 5 seconds, whereas predation timers recorded the timing of predation events. By cross-referencing predation data from the predation timer (time of predation) with PER GPS data (time/latitude/longitude) we were able to obtain locations of each predation event. GoPro video footage was captured with a widescreen aspect ratio of 16:9, resolution 1920×1080 (1080p HD "Superview"), at 30 frames per second at the low light setting. Each camera produced on average approximately 12 to 20 gigabytes of data per deployment depending on individual PER sampling time. Video footage was later viewed to confirm predation events and to identify predator species.

The relationship between survival of tethered smolt, exposure time, and environmental factors was modeled with a Cox proportional-hazards regression for censored data (Cox, 1972) by using the OIsurv package, vers. 0.2 (Diez, 2013) in R statistical software, vers. 3.2.0 (R Core Team, 2015). Before model construction, we examined correlation coefficients of candidate covariate pairs to identify collinearity and only included one variable of a pairwise comparison that had correlations greater than 0.7 (Dormann et al., 2013). The candidate covariates for the model were total distance traveled (m), median light intensity (lux), median depth (m), standard deviation of depth (m), median water temperature (^{o} C), and median water velocity (ms^{-1}). Akaike's information criterion (AIC; Burnham and Anderson, 2002) was used to select the most parsimonious model with the best fit to the data in a forward and backward step-wise fashion. Model residuals were examined to evaluate the model fit.

Results

We conducted 216 PER deployments between late March and late May 2014. Of the 216 deployments, we recorded 33 total predation events (15%), 12 of which were captured on video by the GoPro camera. Throughout the study we were able to easily combine the timer data with the corresponding GPS data to produce accurate maps of PER pathways and predation event locations within the study site (Fig. 2).

Water conductivity and water velocity were collinear at r=–0.75. Water conductivity was excluded, however, from the analysis because it was within the physiological range of both juvenile Chinook salmon and predators and was assumed to have minimal impact on their ability to forage. AIC model selection indicated that water velocity and median depth best explained variation in predation rate. The coefficient for water velocity was 2.3 and median depth was –0.7. The exponentiated coefficient for water velocity was 9.6 and median depth was 0.5. Exponentiated coefficients are interpretable as multiplicative effects on the hazard. For example, by holding the median depth constant, an additional meter per second increase in water velocity increases the minute-by-minute hazard of predation by a factor of 9.6. Similarly, each increase in median depth decreases the hazard by a factor of 0.5. The likelihood-ratio [LR]

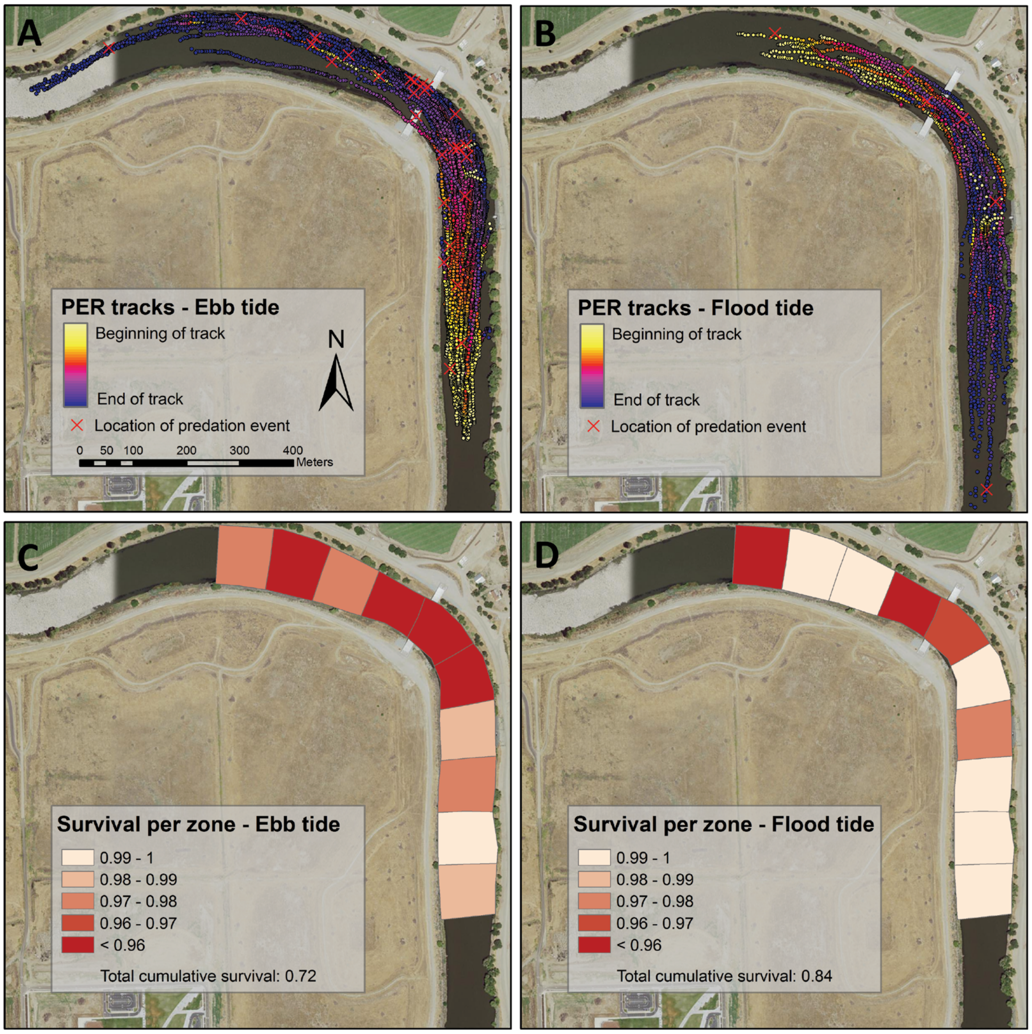


Figure 2

Multipanel aerial photograph of the study site. (**A**) Individual PER tracks during ebb tide conditions. Red ×'s denote individual locations of predation. (**B**) Individual PER tracks during flood tide conditions. Red ×'s denote individual locations of predation. (**C**) Study site segmented into 100-m sections. Color coding denotes survival per 100-m sections during ebb tide conditions. (**D**) Study site segmented into 100-m sections. Color-coding denotes survival per 100 m sections during flood-tide conditions.

test of the null hypothesis that the β's are zero was rejected (LR=11.3, 2 df, P=0.004). The estimated distribution of survival times was calculated at the mean values of the covariates (Fig. 3). These indicated that the proportion of salmon that were preyed upon increased sharply from 20 to 30 minutes of exposure to predators. We plotted the distribution of survival times as they varied from the minimum (negative) to the maximum (positive) water velocities by 0.1 m/s increments (Fig. 4). Predation was greatest with increasing positive water velocities and was lowest at the more negative water velocities.

From the PERs that were outfitted with cameras, we obtained 48 complete videos of individual deployments (22% of total) that resulted in approximately 800 gigabytes of raw data. Of these, tripped timers in combination with missing smolts indicated that 12 were predation events. Video analysis confirmed the predation and a fish was seen preying upon the smolt in each instance. Three of the events captured on video were confirmed to be predation by striped bass (*Morone saxatilis*), and the remaining 8 predators were not identifiable to species. Analysis of the video data revealed that if the timer was activated and the

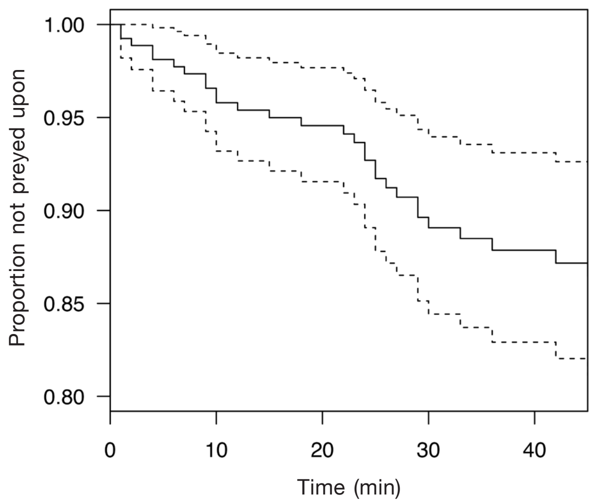


Figure 3

Estimated survival function for the Cox regression of time to predation on water velocity and median depth. Broken lines indicate a point-wise 95% confidence interval about the survival function.

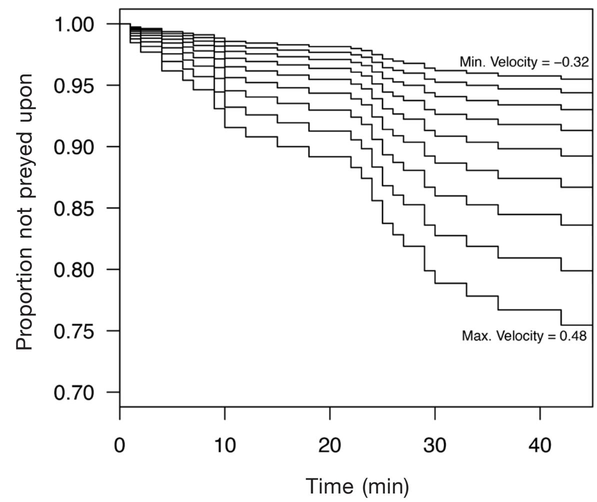


Figure 4

Estimated survival function for the Cox regression of time to predation over a series of water velocities from the minimum (negative) to the maximum (positive) water velocities by increments of 0.1 m/s.

smolt was missing, it was a confirmed predation event. Video analysis also indicated that the tethered smolts remained in an upright and active swimming position during deployments.

Discussion

Predation upon juvenile Chinook salmon in the Sacramento–San Joaquin Delta and resulting effects on population level has been a topic of debate. The presumption that predation may play a significant role in survival was investigated with the use of statistical models on winter-run Chinook salmon by Lindley and Mohr (2003) and Hendrix.[4] Neither analysis implied a substantial link between striped bass predation and Chinook salmon survival. However, the quality of the data used in statistical analyses is a major determinant of the strength of the results, and diet data for many piscine predators in the delta is lacking (Grossman et al.[2]). The addition of robust data from new methods for quantifying predation may help fill this crucial gap for future modeling efforts. Our results, that predation was greatest at maximum positive water velocities (outgoing tide) and lowest at more negative water velocities (incoming tide), are in contrast with those of Anderson et al. (2005), who found that survival of juvenile salmon was influenced more by travel distance than travel time or velocity. However, there are some important differences between studies. First, we conducted our study on a much smaller spatial and temporal scale that quantified individual predation events and therefore characterized more proximate, short-term processes. Secondly, our study system was strongly tidally influenced, to the extent that tidal water movements may have substantially affected predator behavior.

Acoustic tag technology for basin-scale studies has become the standard for assessing movement and survival of fish, particularly in salmonids (Perry et al., 2010; Michel et al., 2013). However, these studies are often expensive and do not reveal the mechanisms or locations of mortality. Although researchers are developing acoustic tags that report predation events through a change in tag ID code, it may be hours to days before the digestion-based processes trigger the predation event to be detected by a receiver (Afentoulis and Schultz, 2014). Furthermore, acoustic tags designed to report predation events do not identify predator species or distinguish the difference between predation events and the scavenging of tagged fish after some other cause of mortality. As such, alternative methods and instrumentation, such as PERs are needed to complement acoustic tagging studies to evaluate predation mortality.

Fishery and water managers often call for investigations of predator control along with predator habitat manipulation as a management tool, and some predator-reduction studies have been implemented (e.g., Porter, 2011). Evaluations of predator control and preda-

[4] Hendrix, N. 2008. A statistical model of Central Valley Chinook incorporating uncertainty: description of *Oncorhynchus* Bayesian analysis (OBAN) for winter run Chinook, 18 p. R2 Resource Consultants Inc., Redmond, WA. [Available at website, accessed November 2014.]

tor habitat manipulation require estimates of pretreatment predation rates and of how predation rates fluctuate with changes in predator abundance and habitat condition. These predation rates may be estimated in various ways. One method involves conducting coordinated studies of predator and prey distribution and abundance, in combination with predator diet studies (Rieman et al., 1991). However, this approach is labor intensive and time consuming, making it difficult to replicate in several different areas at once. Considering that the Sacramento–San Joaquin Delta has a complex suite of hydrological processes and geography (the south delta is especially affected by municipal and freshwater export processes), there is potential for substantial spatial heterogeneity in fish predation rates, thus requiring replication of predation rate studies in many different areas and habitats.

Diet-based predation studies lack statistical power when prey species of concern are rare and make up only a small part of a predator's diet. Predation-event recorders (PER) provide an alternative that has the advantage of being relatively inexpensive and also capable of being implemented over a broad spatial and temporal scale. The intent of this method is not to quantify absolute predation rates, but rather to provide a relative comparison of predation rates among study areas to substantiate predator density and environmental covariate hypotheses. Additionally, the identification of predation "hotspots" gives us insight into the underlying physical and biological mechanisms that contribute to observed mortality. By simultaneously collecting environmental data, we were able to construct and select appropriate statistical models to describe the contributing factors that affect predation.

Fish ecologists have used stationary tethers to study predation on fishes (Linehan et al., 2001; Adams et al., 2004; Chittaro et al., 2005). However, our free drifting PERs have features that are more useful in free-flowing rivers. Drifting PERs may be the preferred design under conditions where movements through a habitat feature are favored, resulting in a more natural presentation and larger area sampled. This is especially important when assessing interactive effects of variables such as water exports, flow rate, total discharge and tidal mechanics on the movement and survival of young fish. Alternatively, anchored PERs enable targeted sampling around specific habitat features like the lower water column in deeper river sections, littoral habitats, or around fixed structures. The PER design has the advantage that it may be altered (size, shape etc.) for sampling in different conditions. Owing to the tidal nature and relatively low current velocities in our study site, we designed our PERs to maximize the effect of subsurface current forces in order to counteract the effect of wind. PERs may also be adapted to study predation on other fish species, such as delta smelt (*Hypomesus transpacificus*) or steelhead (*Oncorhynchus mykiss*) that also occur in the Sacramento–San Joaquin Delta, and it may be modified for use in rivers, lakes, estuaries and coastal ocean environments.

Acknowledgments

We would like to thank the many people who assisted with fieldwork, particularly M. Sabal, V. Lo, T. Brown, B. Lehman, and M. Miller. In addition, M. Henderson and F. Cordoleani provided insightful comments on early drafts and three anonymous reviewers provided helpful suggestions during the review process. The California Department of Water Resources funded this work under agreement no. 46-10100 with the National Marine Fisheries Service. Material and logistical support was also provided by The National Marine Fisheries Service Southwest Fisheries Science Center, Santa Cruz, CA.

Literature cited

Adams, A. J., J. V. Locascio, and B. D Robbins.
2004. Microhabitat use by a post-settlement stage estuarine fish: evidence from relative abundance and predation among habitats. J. Exp. Mar. Biol. Ecol. 299:17–33. Article

Afentoulis, V., and A. Schultz.
2014. Efficacy test of a tag designed to signal when a fish has been consumed. *In* Challenges, collaboration, solutions. California-Nevada Chapter of the American Fisheries Society 48th Annual Conference; Sacramento, CA, 27–29 March, p. 29. Calif.-Nev. Chapter Am. Fish. Soc., Davis, CA. [Available at website.]

Anderson, J. J., E. Gurarie, and R. W. Zabel.
2005. Mean free-path length theory of predator–prey interactions: application to juvenile salmon migration. Ecol. Model. 186:196–211. Article

Bennett, W. A., and P. B. Moyle.
1996. Where have all the fishes gone: interactive factors producing fish declines in the Sacramento-San Joaquin estuary. *In* San Francisco Bay: the ecosystem, vol. 1 (J. T. Hollingbaugh, ed.), p. 519–542. Pacific Division, American Association for the Advancement of Science, San Francisco, CA

Buchanan, R. A., J. R. Skalski, P. L. Brandes, and A. Fuller.
2013. Route use and survival of juvenile Chinook salmon through the San Joaquin River Delta. North Am. J. Fish. Manage. 33:216–229. Article

Burnham, K. P., and D. R. Anderson.
2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd ed., 488 p. Springer, New York.

Brandes, P. L., and J. S. McLain.
2001. Juvenile Chinook salmon abundance, distribution and survival in the Sacramento-San Joaquin estuary. *In* Contributions to the biology of Central Valley salmonids, vol 2. Calif. Dep. Fish Game, Fish. Bull. 179 (R. L. Brown, ed.), p. 39–136. Calif. Dep. Fish Game, Sacramento, CA.

Chittaro, P. M., P. Usseglio, and P. F. Sale.
2005. Variation in fish density, assemblage composition and relative rates of predation among mangrove, seagrass and coral reef habitats. Environ. Biol. Fish. 72:175–187. Article

Cox, D. R.
1972. Regression models and life-tables. J. R. Stat. Soc., Ser. B 34:187–220.

Dormann, C. F., J. Elith, S. Bacher, S. Bachmann, G. Carl, G. Carré, J. R. García Marquéz, B. Gruber, B. Lafourcade, P. J. Leitão, T. Münkemüller, C. McClean, P. E. Osborne, B. Reineking, A. K. Skidmore, D. Zurell, and S. Lautenbach.
2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36(1):27–46. Article

Diez, D. M.
2013. OIsurv: survival analysis supplement to OpenIntro guide. [Available at website, accessed June 2015.]

Lindley, S. T., and M. S. Mohr.
2003. Modeling the effect of striped bass (*Morone saxatalis*) on the population viability of Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*). Fish. Bull. 101:321–331.

Linehan, J. E., R. S. Gregory, and D. C. Schneider.
2001. Predation risk of age-0 cod (*Gadus*) relative to depth and substrate in coastal waters. J. Exp. Mar. Biol. Ecol. 263:25–44. Article

Michel, C. J., A. J. Ammann, E. D. Chapman, P. T. Sandstrom, H. E. Fish, M. J. Thomas, G. P. Singer, S. T. Lindley, A. P. Klimeley, and R. B. MacFarlane.
2013. The effects of environmental factors on the migratory movement patterns of Sacramento River yearling late-fall run Chinook salmon (*Onchorhynchus tshawytscha*). Environ. Biol. Fish. 96:257–2571. Article

Mueller, J. E.
1968. An introduction to the hydraulic and topographic sinuosity indexes. Ann. Assoc. Am. Geogr. 58:371–385.

Mount, J., W. Bennett, J. Durand, W. Fleenor, E. Hanak,. J. Lund, and P. Moyle.
2012. Aquatic ecosystem stressors in the Sacramento–San Joaquin Delta, 22 p. Public Policy Inst. California, San Francisco. [Available from website, accessed October 2014.]

Newman, K. B.
2003. Modelling paired release-recovery data in the presence of survival and capture heterogeneity with application to marked juvenile salmon. Stat. Model. 3:157–177. Article

Newman, K. B., and J. Rice.
2002. Modeling the survival of Chinook salmon smolts outmigrating through the lower Sacramento River system. J. Am. Stat. Assoc. 97:983–993. Article

Perry, R. W., J. R. Skalski, P. L. Brandes, P. L. Sandstrom, A. P. Klimley, A. Ammann, and B. MacFarlane.
2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento-San Joaquin River Delta. North Am. J. Fish. Manage. 30:142–156. Article

Porter, R.
2011. Report on the predation index, predator control fisheries, and program evaluation for the Columbia River Basin Experimental Northern Pikeminnow Management Program, 124 p. U.S. Dep. Energy, Bonneville Power Administration, Portland, OR. [Available at website, accessed October 2014.]

Pyper, B. T., Garrison, and S. Cramer.
2013. Analysis of trawl efficiency at Chipps Island using coded-wire-tagged releases of juvenile Chinook salmon, 97 p.. Cramer Fish Sciences, Gresham, OR. [Available at website, accessed October 2014.]

R Core Team.
2015. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. [Available at website, accessed March 2015.]

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 the John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120:448–458. website

Somerton, D. A., B. S. Kikkawa, and C. D. Wilson.
1988. Hook timers to measure the capture time of individual fish. Mar. Fish. Rev. 50(2):1–5.

Document Content(s)