Patterns in Catch Per Unit Effort of Native Prey Fish and Alien Piscivorous Fish in 7 Pacific Northwest USA Rivers

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ABSTRACT: *Nonnative or alien invasive species are commonly accorded threats to native biological assemblages; however, it is difficult to separate the effects of aliens from other covarying disturbances. We evaluated the effect of alien piscivorous fish on native prey species in seven Pacific Northwest rivers through the use of a spatially balanced random sample of 20 sites on each river. The rivers lacked large main-stem dams, and point sources, if any, met state and federal water quality standards. Individual sample sites were electrofished a distance equal to 50 times their mean wetted channel widths, and all fish were identified to species, measured, and returned to the rivers alive (except for museum voucher specimens). At nearly all sites in all seven rivers, we found that the catch per unit effort (CPUE) of native prey species varied inversely with the CPUE of alien piscivores. In the two rivers most dominated by alien piscivores, we collected native prey at only 20%–25% of the sites. We conclude that piscivorous alien fish are associated with reduced population sizes of native prey species, at least during the summer low-flow period, and are potential threats to prey species persistence.*

Patrones en la captura por unidad de esfuerzo de peces nativos y peces piscívoros foráneos en siete ríos del Pacífico Noroeste de los Estados Unidos de Norteamérica

RESUMEN: *es comúnmente aceptado que las especies no nativas o foráneas constituyen una amenaza para las comunidades biológicas locales; no obstante, resulta complicado separar el efecto que tienen estas especies invasoras frente a otras perturbaciones co-variantes. Se evaluó el efecto de los peces piscívoros foráneos sobre especies nativas en siete ríos del Pacífico Noroeste de los Estados Unidos de Norteamérica, mediante un muestreo al azar espacialmente balanceado en 20 localidades dentro de cada río. Los ríos carecían de drenajes importantes y los existentes, de haber alguno, cumplían con los estándares federales en cuanto a calidad del agua. En cada localidad de muestreo se llevó a cabo una colecta por medios eléctricos (electro-pesca) a una distancia equivalente a 50 veces el ancho del canal de inundación; todos los peces fueron identificados a nivel especie, medidos y devueltos vivos a los ríos (excepto aquellos especímenes destinados a museos). En casi todas las localidades de los siete ríos, se encontró que la captura por unidad de esfuerzo (CPUE) de las especies nativas de peces, varió de manera inversa con respecto a la CPUE de los peces piscívoros foráneos. En los dos ríos que estaban dominados mayormente por especies piscívoras, se colectaron especies nativas sólo en el 20-25% de las localidades. Se concluye que, al menos durante los periodos de flujo reducido en el verano, los peces piscívoros foráneos se relacionan con reducciones poblacionales de las especies nativas y constituyen una amenaza potencial a la persistencia de las especies locales.mentos relacionados a la liberación y los derechos de los animales, pueden tener consecuencias muy importantes para las pesquerías recreativas.*

INTRODUCTION

Because alien fish introductions affect species and ecosystems inconsistently, there are conflicting views on their consequences (Baltz and Moyle 1993; Moyle and Light 1996). Based on patterns in site and basin diversity, Oberdorff et al. (1998), Gido and Brown (1999), Rathert et al. (1999), and Tejerina-Garro et al. (2005) reported that alien fish species could be added without affecting native species richness at the basin scale. However, Ross (1991) concluded that native fish populations of three continents declined 77% of the time following introduction of aliens. Leprieur et al. (2008) reported that alien invasive fishes were associated with altered fish assemblage composition at the basin scale globally. Lassuy (1995), Rose (2005), Reed and Czech (2005), and Dextrase and Mandrak (2006) concluded that invasive alien species are a major factor in fish endangerment, and Miller et al. (1989) listed them as major causes of fish extinctions. Hughes et al. (2005) concluded that alien species altered native fish assemblages in Southwestern U.S. rivers and Sanderson et al. (2009) considered them major threats to endangered salmon populations in the Pacific Northwest. However, in most of the preceding cases, aliens were associated with additional major pressures, such as habitat alteration or major main-stem dams, and those covarying disturbances cloud conclusions.

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Regardless of their potential effects, alien fish introductions are widespread. Leprieur et al. (2008) identified regions on six continents where alien invasive fish represented more than 25% of all fish species. Lomnicky et al. (2007) found that alien vertebrates represented more than 50% of individuals in 22% of the stream length in the conterminous Western United States. Aliens also occurred in more than 50% of the stream length and appeared in more than 80% of the length represented by large rivers.

Some alien piscivores, such as smallmouth bass *Micropterus dolomieu*, have been considered potentially important predators of hatchery and wild Pacific salmonids (Fritts and Pearsons 2004, 2006) and endangered Yampa River fishes (Johnson et al. 2008), but they remain protected, popular, and widespread sport fish in Oregon and Washington coolwater rivers. Fishery management agencies justify those protections because salmonid smolt out-migrations largely occur during high, cold flows when smallmouth bass and other warmwater alien piscivores are assumed to be unable to effectively feed on salmonids (Shrader and Gray 1999; Jahns and Nass 2010). Additionally, the lower reaches of such rivers are now too warm during the summer to support rearing salmonids. However, such assumptions about salmonids may be irrelevant for native coolwater petromyzontids, cyprinids, catostomids, percopsids, and cottids that reproduce or rear in those lower reaches and are potential prey for alien piscivores. For example, Fritts and Pearsons (2008) reported that smallmouth bass preyed heavily on dace (*Rhinichthys*) and mountain whitefish (*Prosopium williamsoni*) in the Yakima River, Washington. Scott and Crossman (1973) described smallmouth bass as a generalist predator on crayfish as well as benthic and water column fishes once the bass are 5 cm long, and Wydoski and Whitney (1979) attributed the rapid growth of smallmouth bass in the Columbia River to the abundance of cyprinids, catostomids, and cottids there.

To evaluate the effect of alien piscivores on *all* resident coolwater native fish (not only salmonids) that might serve as prey, we sampled seven rivers in Oregon and Washington. All seven rivers lacked major main-stem dams, and point source dischargers, if any, met state and federal water quality standards. Our objective was to compare patterns in catch per unit effort (CPUE) of native prey against the CPUE of alien predators. We hypothesized that the CPUE of native prey fish would decline as the CPUE of alien piscivorous fish increased within a river and among rivers.

METHODS

Study Rivers

We sampled fish assemblages of seven large rivers during the summer low-flow periods of 2006–2008 when flows and temperatures are relatively stable and fish migrations minimal (Figure 1). We randomly selected 20 sites on each river so that they were unequally dispersed but were not overlapping (Stevens and Olsen 2004). The three rivers on the west side of the Cascade Mountains had largely forested catchments and the four on the east side of the Cascades had largely steppe catchments. The rivers ranged in size from the Malheur (27.8-m mean width, 1.0-m mean thalweg depth, 7,847-km^2 catchment area) to the Willamette (126-m mean width, 2.9-m mean thalweg depth, 13,554-km^2 catchment area). Main-stem distances sampled ranged from 87 to 254 km for the Chehalis and Willamette, respectively (Figure 1). Except for temporary low-head irrigation diversions on the lower Malheur River, the rivers and their tributaries were accessible to fishes for spawning, rearing, and migration. We used information from Wydoski and Whitney (1979), Scott and Crossman (1973), Bond (1994), and Rathert et al. (1999) to estimate expected native prey species based on their ranges and life histories.

Sampling and Data Analyses

The length of each of the 20 sites was 50 times the mean wetted channel width (MWCW), which was divided into 10 equidistant subsites (each 5 MWCW long; Hughes and Peck 2008). This site length was found sufficient for collecting all species except those captured only once or twice in sites 100 MWCW long (Hughes et al. 2002; Hughes and Herlihy 2007; Kanno et al. 2009), and 50 MWCW produced nearly twice as many species in the Willamette River as did fixed site lengths of 500–1,000 m (LaVigne, Hughes, Wildman, et al. 2008). We sampled fish by daytime raft electrofishing along alternating shorelines for two subsites (10 MWCW) or we fished the thalweg when rapids or other obstacles necessitated it. Due to its effectiveness in collecting nearly all species and size classes present with minimal bias, nearshore electrofishing was adopted as the standard fish sampling method in rivers by the European Union, U.S. Environmental Protection Agency, and U.S. Geological Survey (Meador et al. 1993; Comité Européen de Normalisation [CEN] 2003; Hughes and McCormick, in press). One netter collected all fish possible as the rower maneuvered the raft downstream at a slightly greater velocity than the river; total operating time of the electrofisher averaged one hour per site but varied with current velocity. The electrofisher was a Smith-Root GPP 2.5 (Smith-Root, Vancouver, Washington) operated at 30–60 pps pulsed DC and 400–1,000 V depending on conductivity. The collected fish were identified, measured, and returned to the river alive at the end of each subsite.

Data were entered on computer scan forms and voucher specimens were confirmed at the Oregon State University Museum of Ichthyology (Corvallis, Oregon). Fish collected were classified as young or adult, native prey, alien piscivore, or other (Table 1). Salmonids *Oncorhynchus* and *Prosopium*, chiselmouth *Acrocheilus alutaceus*, chub *Gila*, and peamouth *Mylocheilus caurensis* less than 100 mm in total length were classified as native prey; all sizes of bass *Micropterus* and yellow perch *Perca flavescens* were considered alien predators. We examined the data in two ways. In separate graphs for each river, we plotted the CPUE of native prey and the CPUE of alien predators of each site against relative river distance (we used relative distance to standardize the varying lengths of the seven main stems sampled). This aided us in detecting predator–prey patterns in the seven rivers. In addition, we plotted

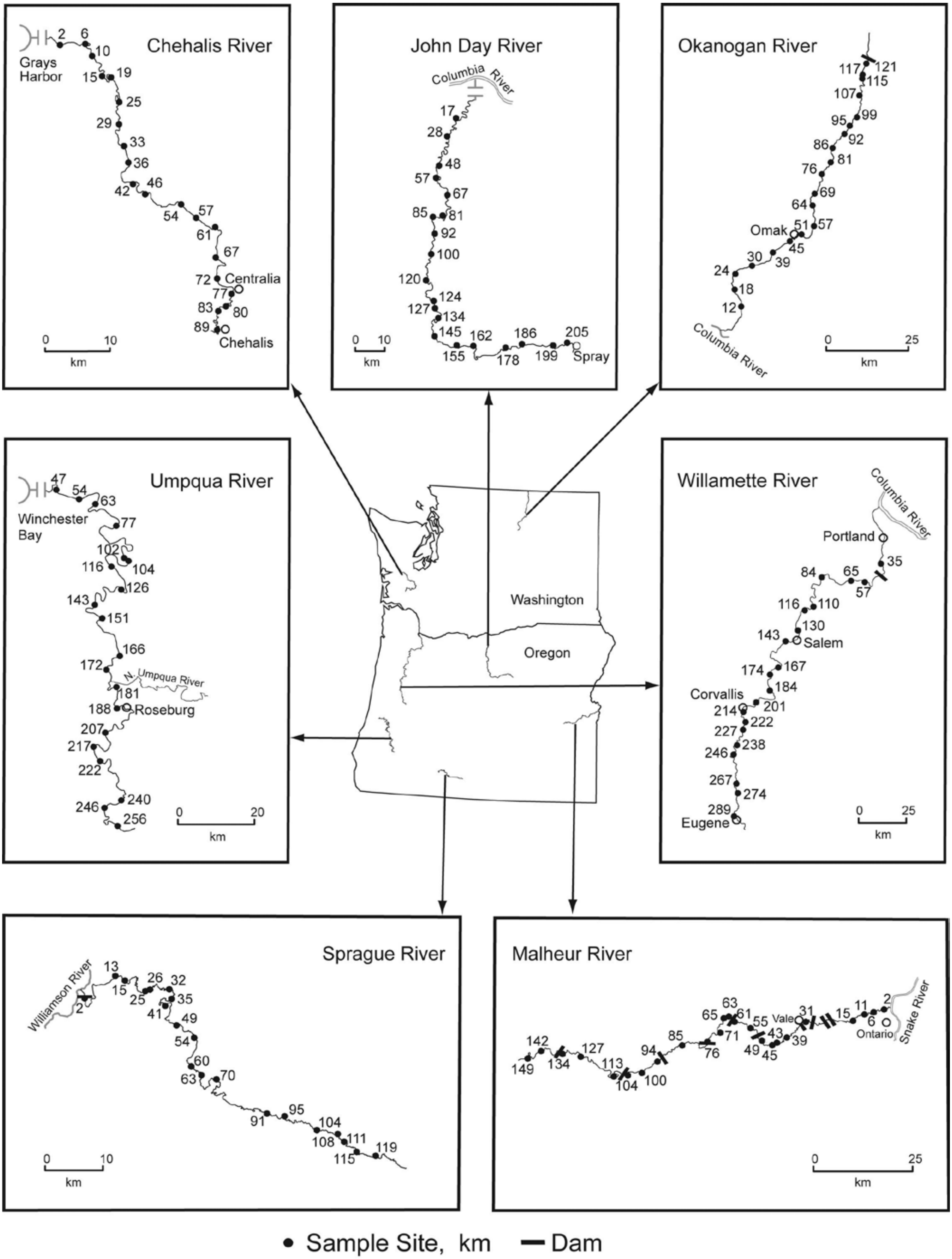

Figure 1. Locations and spatially balanced random sampling design of seven study rivers in the Pacific Northwest. Solid bars are low-head dams or waterfalls.

TABLE 1. Fish species collected from seven Pacific Northwest rivers.

Scientific name	Common name	Trophic classification	River occurrence
Petromyzontidae			
Lampetra richardsoni	Western brook lamprey y, a	NP	W
Lampetra tridentata	Pacific lamprey y	NP	C, J, U, W
Lampetra sp.	Unknown lamprey species y	NP	S
Clupeidae			
*Alosa sapidissima**	American shad y	O	C, U, W
Clupea pallassi	Pacific herring y	NP	W
Salmonidae[a]			
Oncorhynchus clarkii	Cutthroat trout y, a	NP	C, W
Oncorhynchus mykiss	Rainbow trout y, a	NP	J, M, O, S, U, W
Oncorhnchus tshawytscha	Chinook salmon y	NP	C, O, W
Prosopium williamsoni	Mountain whitefish y, a	NP	C, O, W
*Salmo trutta**	Brown trout a	AP	S
Cyprinidae[a]			
Acrocheilus alutaceus	Chiselmouth y, a	NP	J, M, O, W
*Ctenopharyngodon idella**	Grass carp a	O	W
*Cyprinus carpio**	Common carp a	O	J, M, O, W
Gila bicolor	Tui chub y, a	NP	S
Gila coerula	Blue chub y, a	NP	S
Mylocheilus caurensis	Peamouth y, a	NP	C, O, W
*Notemigonus chrysoleucus**	Golden shiner a	O	U
*Pimephales promelas**	Fathead minnow a	O	M, S
Ptychocheilus oregonensis	Northern pikeminnow a[b]	O	C, J, M, O, W
Ptychocheilus umpquae	Umpqua pikeminnow a[b]	O	U
Rhinichthys cataractae	Longnose dace y, a	NP	C, J, M, O, W
Rhinichthys evermanni	Umpqua dace y, a	NP	U
Rhinichthys falcata	Leopard dace y, a	NP	M, W
Rhinichthys osculus	Speckled dace y, a	NP	C, M, S, U, W
Richardsonius balteatus	Redside shiner y, a	NP	C, M, O, U, W
Fundulidae			
*Fundulus diaphanous**	Banded killifish a	O	W
Catostomidae			
Catostomus columbianus	Bridgelip sucker a	O	J, M, O
Catostomus macrocheilus	Largescale sucker a	O	C, J, M, O, W
Catostomus platyrhynchus	Mountain sucker y, a	NP	J, M, W
Catostomus rimiculus	Klamath smallscale sucker a	O	S
Catostomus snyderi	Klamath largescale sucker a	O	S
Catostomus tsiltcoosensis	Tyee sucker a	O	U
Percopsidae			
Percopsis transmontana	Sand roller y, a	NP	W
Poeciliidae			
*Gambusia affinis**	Western mosquitofish a	O	M
Ictaluridae			
*Ameiurus melas**	Black bullhead a	AP	J, M, O, W
*Ameiurus natalis**	Yellow bullhead a	AP	O, U, W
*Ameiurus nebulosus**	Brown bullhead a	AP	J, O, S, U
*Ictalurus punctatus**	Channel catfish a	AP	J, M

TABLE 1. (continued)

Scientific name	Common name	Trophic classification	River occurrence
*Noturus gyrinus**	Tadpole madtom a	O	M
*Pylodictus oliverus**	Flathead catfish a	AP	M
Centrarchidae			
*Ambloplites rupestris**	Rock bass a	AP	C
*Lepomis gibbosus**	Pumpkinseed y	O	C, M, O, S, U, W
*Lepomis macrocheilus**	Bluegill y	O	C, O, U, W
*Micropterus dolomieu**	Smallmouth bass y, a	AP	C, J, M, O, U, W
*Micropterus salmoides**	Largemouth bass y, a	AP	C, M, O, S, U, W
*Pomoxis annularis**	White crappie a	AP	M, O, W
*Pomoxis nigrum**	Black crappie a	AP	U, W
Gasterosteidae			
Gasterosteus aculeatus	Three-spined stickleback y, a	NP	C
Cottidae			
Cottus aleuticus	Coastrange sculpin y, a	NP	U
Cottus asper	Prickly sculpin y	NP	C, O, U, W
Cottus beldingi	Paiute sculpin y, a	NP	W
Cottus gulosus	Riffle sculpin y, a	NP	C, W
Cottus klamathensis	Marbled sculpin y, a	NP	S
Cottus perplexus	Reticulate sculpin y, a	NP	O, U, W
Cottus rhotheus	Torrent sculpin y, a	NP	C, O, W
Cottus tenuis	Slender sculpin y, a	NP	S
Percidae			
*Perca flavescens**	Yellow perch y, a	AP	C, M, O, S, U, W

* = alien; y = young; a = adult; NP = native prey; AP = alien predator; O = other. Rivers: C = Chehalis; J = John Day; M = Malheur; O = Okanogan; S = Sprague; U = Umpqua; W = Willamette.

[a]Adult Acrocheilus, Gila, Mylocheilus, and native salmonids classified as other.
[b]Native piscivore.

the CPUE of native prey versus the CPUE of alien predators in a single graph so that we could assess the composite predator–prey pattern of the seven rivers. In the latter graph, we used 90th percentile quantile regression and a lognormal curve to separate the predator–prey pattern from other measured factors (e.g., water body size, water quality, substrate, fish cover, anthropogenic disturbance; Hughes et al. 2011) that may limit prey CPUE. Others have also used quantile regression for assessing the effects of suspected limiting factors on fish assemblages (Terrell et al. 1996; Dunham et al. 2002; Mebane et al. 2003; Bryce et al. 2010).

RESULTS

The CPUEs of alien piscivores were low, and the CPUEs of native prey were high at nearly all sites on the Chehalis, Malheur, Sprague, and Willamette rivers, although at two or more sites on each river increased alien piscivore CPUE was associated with lowered native prey CPUE (Figure 2). On the John Day and Okanogan rivers, alien piscivore CPUE was consistently greater than native prey CPUE at all or nearly all sites (Figure 3). The pattern was intermediate on the Umpqua River, where alien piscivore CPUE was greater than native prey CPUE at 15 sites (Figure 3). At most Umpqua sites where alien piscivore CPUE was low, native prey CPUE was higher than the alien piscivore CPUE; however, at one site, the CPUE of piscivores and prey were equivalent. Native prey were not collected from one or more sites in the Malheur, Willamette, John Day, Okanogan, and Umpqua rivers, but they simply may have been rare in those locations. Uncollected native prey species that were expected based on their ranges and life histories (Scott and Crossman 1973; Wydoski and Whitney 1979; Bond 1994; Rathert et al. 1999) varied from 1 (Sprague) to 10 (John Day; Table 2). In each river the average proportion of sites where listed native prey species were observed ranged from 20% to 66%, with the lowest average proportions in the John Day and Okanogan rivers (Table 2).

When alien predator CPUE was plotted against native prey CPUE in a single plot, a decline in prey with increased predators is evident; however, the steepness of that decline is less for the Sprague River than for the others (Figure 4). In no case is native prey CPUE high when alien predator CPUE is high (upper right quadrat of figure); however, there are many cases of low prey CPUE and low predator CPUE (lower left quadrat), indicating that additional environmental factors may limit populations at those sites.

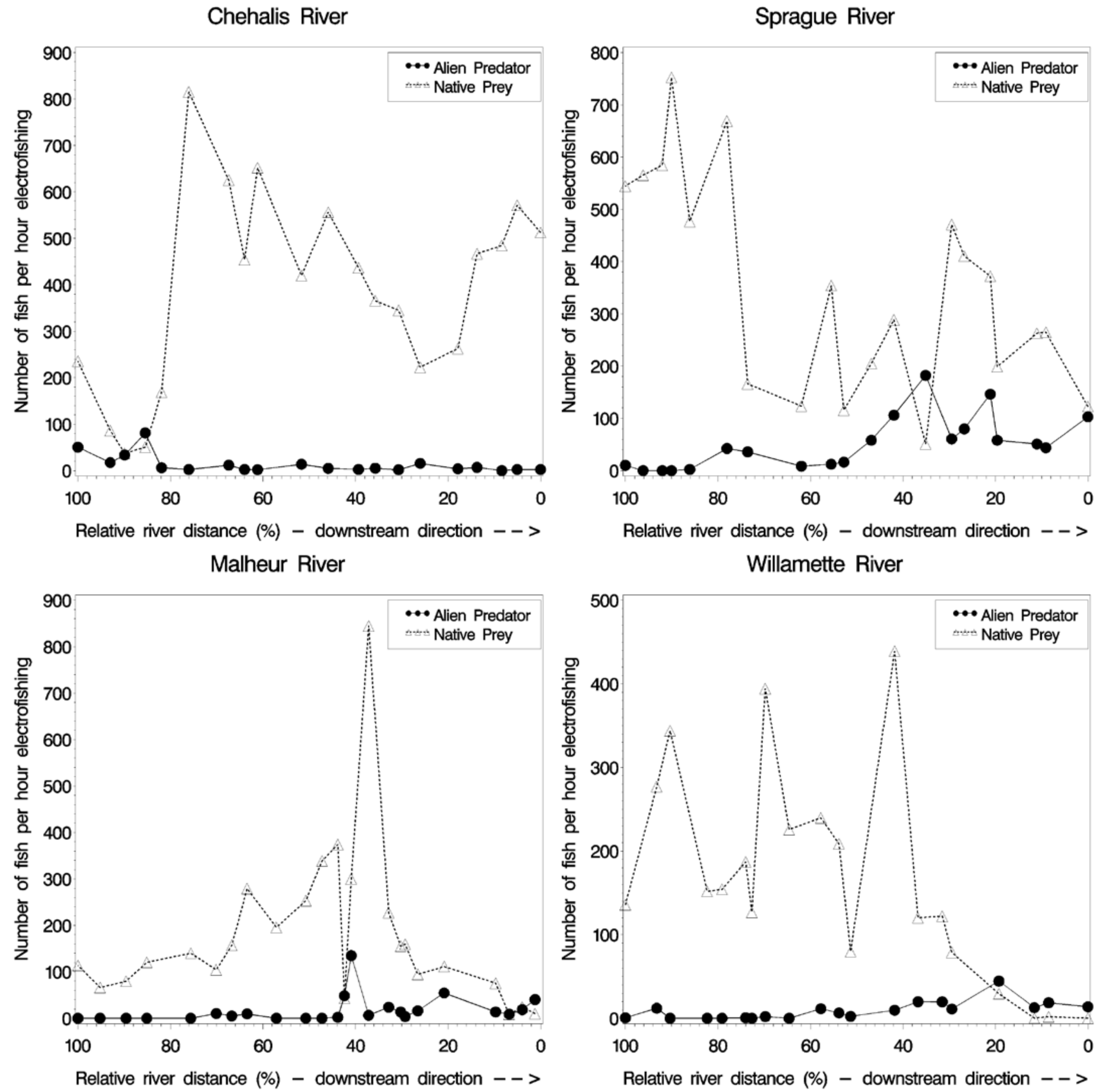

Figure 2. Four rivers in which the catch per unit effort of native prey species almost always exceeded that of alien piscivorous species.

DISCUSSION

Lomnicky et al. (2007) found aliens in 80% of the large river length in the Western United States and we found alien piscivores in all seven of the large rivers we sampled and in the vast majority of our sample reaches (Figures 2–4). Like their study, ours was a random sample, meaning that we can infer with confidence that alien piscivores are also present in 40% of the main-stem Chehalis, 55% of the main-stem Willamette and Malheur, 80% of the main-stem Sprague, and 100% of the main-stem Umpqua, Okanogan, and John Day river lengths.

Although we have no concrete evidence of local extinctions or extirpations, several native prey species whose reported ranges and life histories include our study rivers (Scott and Crossman 1973; Wydoski and Whitney 1979; Bond 1994; Rathert et al. 1999) were not collected from some of the rivers (Table 2). Mountain whitefish *Prosopium williamsoni* was missing from all of our Malheur River collections, despite being recorded there historically (LaVigne, Hughes, and Herlihy 2008). In addition, the average proportions of sites with native prey species were one third to two thirds lower in the three rivers (John Day, Okanogan, Umpqua) in which alien predator CPUE was markedly greater than native prey CPUE (Figure 3,

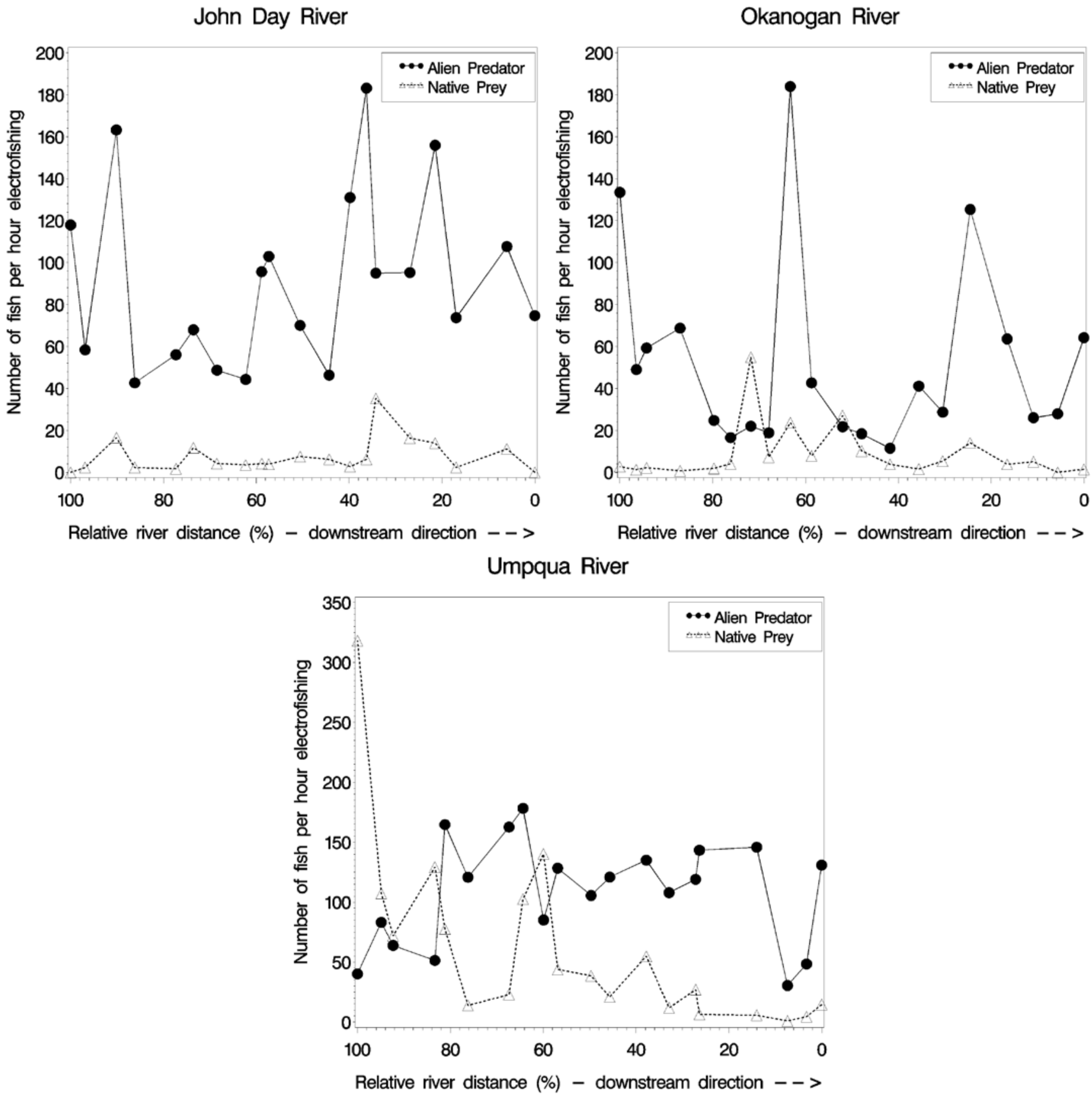

Figure 3. Three rivers in which the catch per unit effort of alien piscivorous species almost always exceeded that of native prey species.

Table 2). Hiram Li (Department of Fisheries and Wildlife, Oregon State University, personal communication) found redside shiner *Richardsonius balteatus* and speckled dace *Rhinichthys osculus* common throughout the John Day River Basin in the mid-1980s, and Torgersen et al. (2006) reported that both species were common in the middle and north forks of the John Day River in 1996 and 1997, but they were missing from all of our 20 sites on the John Day main stem. Simon and Markle (1999) reported that smallmouth bass displaced Umpqua chub *Oregonichthys kalawatseti* from the main-stem Umpqua River. However, some of the other expected native prey species are naturally uncommon, making it difficult to assess their declines (Kanno et al. 2009). Repeated sampling of these rivers with the same sampling designs and methods would aid trend detection. For example, LaVigne, Hughes, and Herlihy (2008) and LaVigne, Hughes, Wildman, et al. (2008) documented range expansions of several alien species in the Malheur and Willamette rivers but indicated that the apparent expansions may have resulted from more effective sampling designs and methods. Decreased CPUE of native prey species is likely to depress index of biological integrity (IBI) scores by reducing IBI metric scores that are based on species richness (Dolph et al. 2010; Wan et al. 2010). Thus, lower IBI scores may also serve as indicators of biological pollution by alien piscivores (Whittier, Hughes, Stoddard, et al. 2007; Oliviera et al. 2009).

TABLE 2. Proportion of sites in each river where the listed native prey species were observed. Proportions based only on species collected from main-stem rivers in this study. Mean prey occurrence for each river was calculated by adding the frequency of occurrence of all native prey species then dividing by the number of native prey species.

Scientific name	Chehalis	John Day	Malheur	Okanogan	Sprague	Umpqua	Willamette
Petromyzontidae							
Lampetra richardsoni	0.05						
Lampetra tridentata	0.45	0.15		E		0.7	0.15
Lampetra sp.					0.25		
Clupeidae							
Clupea pallassi							0.05
Salmonidae							
Oncorhynchus clarkii	0.1					E	0.4
Oncorhynchus mykiss		0.1	0.15	0.05	0.85	0.35	0.45
Oncorhnchus tshawytscha	0.2	E		0.25		0.05	0.7
Prosopium williamsoni	0.5	E	E	0.6			0.9
Cyprinidae							
Acrocheilus alutaceus	E	0.2	0.95	0.15			0.85
Gila bicolor					1.0		
Gila coerula					0.4		
Mylocheilus caurensis	0.15	E	E	0.05			0.7
Rhinichthys cataractae	0.7	0.75	0.8	0.2			0.7
Rhinichthys evermanni						0.75	
Rhinichthys falcata	E	E	0.15	E			0.65
Rhinichthys osculus	0.85	E	0.85	E	0.95	0.35	0.8
Richardsonius balteatus	1.0	E	0.95	0.05	E	0.3	0.85
Catostomidae							
Catostomus platyrhynchus		0.05	0.55	E			0.8
Percopsidae							
Percopsis transmontana		E	E	E			0.3
Gasterosteidae							
Gasterosteus aculeatus	0.5					E	E
Cottidae							
Cottus aleuticus	E					0.55	
Cottus asper	0.9	E		0.2		0.15	0.85
Cottus beldingi		E					0.6
Cottus gulosus	1.0					0.05	E
Cottus klamathensis					0.95		
Cottus perplexus	E			0.35		0.5	0.9
Cottus rhotheus	0.85	E		0.3			0.8
Cottus tenuis					0.2		
Number native prey species	12	5	7	10	7	10	19
Mean prey occurrence	0.60	0.25	0.63	0.22	0.66	0.38	0.60

E = expected but not found.

In short-term observational studies of natural ecosystems such as ours, it is difficult to attribute causation; instead, one must take a weight-of-evidence approach and consider the (1) strength of the association, (2) ecological mechanism, (3) measurement or sampling error, and (4) strength of alternative explanations. (1) The consistent declines in prey CPUE associated with increases in alien predator CPUE in this study suggest that alien predators limit native prey (Figures 2–4). (2) Predation by alien predators is a well-established mechanism for limiting or extirpating native prey fish (Miller et al. 1989; Moyle and Light 1996; Cucherousset and Olden 2011), and several expected prey species that we collected elsewhere were not collected from other study rivers, despite our use of the same sampling methodologies. (3) Our survey design was unusually thorough: we electrofished nearly 50% of the main-stem length of each river, passed species richness asymptotes after sampling 12–16 sites, and collected 90% of the species collected from 20 sites in 2–11 of those sites, depending on the river being sampled (Hughes et al. 2011). Although CPUE is not a measure of true abundance, it is an established fishery indicator of relative abundance (Bonar et al. 2009). There is error in our 100-mm cutoff of designating prey for species that attain greater lengths, but that may result in an overestimate or underestimate of prey depending on the sizes of the predators present. (4) Alternative mechanisms for reducing native prey or increasing alien predators include differing effects on the two groups following changes in water quality and physical habitat structure. We found no consistent correlations between environmental variables and vertebrate species richness in previous studies on the same seven rivers (Hughes et al. 2011) or on a set of 45 reaches on 25 Oregon rivers (Hughes et al. 2002). Although most of the alien predators in this study are more tolerant than the native prey species of physical and chemical habitat degradation, not all of the prey species are intolerant and not all the predator species are tolerant of such degradation (Whittier, Hughes, Lomnicky, et al. 2007).

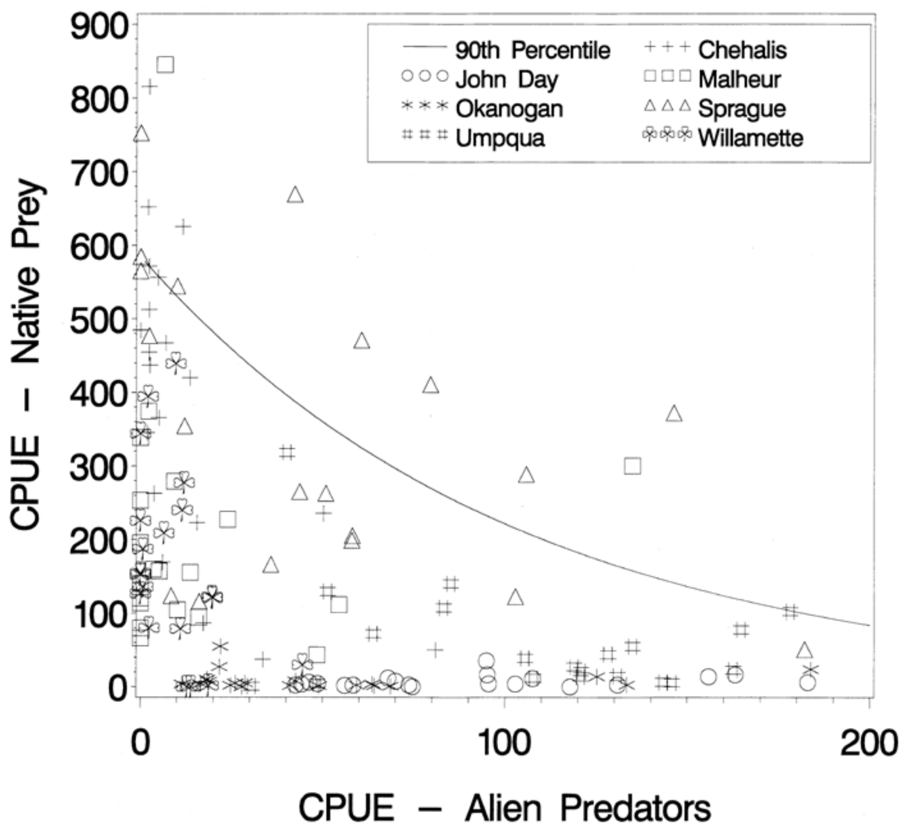

Figure 4. Alien predator catch per unit effort versus native prey catch per unit effort for all seven rivers.

CONCLUSIONS

We conclude that alien piscivores are associated with substantial alterations in the fish assemblages of two rivers (John Day, Okanogan) and major portions of one other (Umpqua). Unlike the other study rivers, those three systems support abundant and extensive populations of smallmouth bass. We suspect that some previous failures to detect the effects of alien piscivores on native prey (Oberdorff et al. 1998; Gido and Brown 1999; Rathert et al. 1999; Tejerina-Garro et al. 2005) were partly the result of previously inadequate survey designs, sampling methods, indicators, data analyses, and trend studies (Independent Multidisciplinary Science Team 2007). Our survey design, sampling protocol, and indicators—if implemented broadly through use of a rotating panel design—offer a cost-effective mechanism for assessing status and trends in fish assemblages and physical and chemical habitat of main-stem rivers across the regions and basins being managed.

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From the Archives

Sport fishing in India is practiced only by the privileged class. To quote Radcliffe, "the angler, pure and simple for the mere love of sport is hardly represented in the people of India." The best known fresh-water sport fish in India is the mahaseer which experienced anglers believe affords more sport than the salmon. The fish is tough to land and weighs on an average between 80 and 100 pounds.

H. D. R. Iyengar, p. 93, Seventy-Eighth Annual Meeting, Transaction of The American Fisheries Society