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Improved Status of the Endangered Oregon Chub in the Willamette River, Oregon

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ABSTRACT Status and trends in the abundance of populations of federally endangered Oregon chub *Oregonichthys crameri*, small floodplain minnows endemic to the Willamette Valley of western Oregon, were investigated by estimating fish abundance and from extensive fish surveys of 650 off-channel habitats from 1991 through 2004. The recent discovery of previously unknown populations of Oregon chub, some occurring in subbasins where they were presumed extinct, combined with successful reintroductions into suitable habitats have resulted in the improved status of this species. In 1991, eight populations of Oregon chub were known to exist. In 2004, we identified 33 populations of Oregon chub in the Willamette River basin. Ten of these populations, including the two most abundant populations, were introduced. The status of Oregon chub is approaching the recovery plan goal for downlisting the species to threatened. Nonnative fishes, which were found to be widespread in off-channel habitats preferred by Oregon chub, are the largest threat to full recovery and delisting of this species.

Oregon chub *Oregonichthys crameri* (Snyder 1908) are small floodplain minnows endemic to the Willamette Valley of western Oregon (Markle et al. 1991). Historically, this species was widely distributed throughout the Willamette Valley (Markle et al. 1991). Studies conducted in the 1970s and 1980s (Bond 1974; Bond and Long 1984; Markle et al. 1991) found the distribution of Oregon chub to be severely restricted. The loss of habitat and their restricted range led to their listing as endangered under the Endangered Species Act in 1993 (U.S. Fish and Wildlife Service 1993).

Oregon chub are small cyprinids that grow to 75–80 mm total length (TL), mature at age 2 (>40 mm) and are relatively long-lived (up to 9 years). Oregon chub prefer off-channel habitats with minimal or no current velocity, an abundance of vegetation, and depositional substrate (Pearsons 1989; Scheerer 2002). They spawn in aquatic vegetation from May to July when water temperatures exceed 15°C (Scheerer and McDonald 2003).

The Willamette River originates in the Calapooya Mountains of southwestern Oregon and flows in a northerly direction through the Willamette Valley to the Columbia River, a distance of 474 km (Sedell and Froggatt 1984). It is a ninth-order channel, drains an area of 29,728 km^2, and is the tenth largest river in the continental United States in terms of total discharge. The climate in the Willamette Valley is humid temperate with an annual precipitation of 127 cm.

Historically, Oregon chub thrived in an unconstrained Willamette River under a hydrologic regime that featured frequent flood events (Benner and Sedell 1997), which continually created and destroyed off-channel habitats (Lewin 1978; Dykaar and Wigington 2000). Floods provided the mechanism of dispersal and genetic exchange among isolated off-channel habitats for Oregon chub populations.

Today, the Willamette River is a highly altered system. In the past 150 years, the channel length and complexity of the Willamette River has been drastically reduced by the construction of 13 major flood control dams, large scale removal of large woody debris for navigation, channelization and revetments, and the drainage of wetlands to

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increase the land available for river bottomland agriculture (Sedell and Froggatt 1984; Benner and Sedell 1997). Floods in the winter and spring months were common prior to the construction of the dams (1941–1969), averaging 14 floods above bank-full per decade from about 1884 through 1969 (Corps of Engineers 1970). What was considered a 10-year flood event prior to construction of the dams now has a 100-year return interval (Benner and Sedell 1997). Channelization and the construction of flood control dams restricts or eliminates many of the linkages and interactions between the river and its floodplain (Gabriel 1993) and has been detrimental to native fishes that rely on floodplain habitats (Bayley 1991; Osmundson and Burnham 1998; Modde et al. 2001).

Introduction of nonnative fishes in Willamette River began in the late 1800s (Dimick and Merryfield 1945; Lampman 1946; McIntosh et al. 1989). Nonnative centrarchids and bullhead catfishes *Ameiurus* spp. have been widely implicated in the decline of native fishes (Moyle 1976; Lemly 1985; Rinne and Minckley 1991; Newman 1993; Simon and Markle 1999), are common in the Willamette River basin and are considered to be the greatest current threat to the recovery of Oregon chub (U.S. Fish and Wildlife Service 1998; Scheerer 2002).

Markle et al. (1991) found that nonnative fishes were common in historic Oregon chub habitats that no longer contained Oregon chub. Scheerer (2002) found that Oregon chub were absent, or in low in abundance, when nonnative fishes were present in off-channel habitats and described several Oregon chub populations that declined or were extirpated when their habitats were invaded by nonnative fishes following flood events or when nonnative fishes were illegally stocked.

This paper describes (1) the current known distribution, status, and trends of Oregon chub populations and their habitats in the Willamette River, (2) the status of reintroductions, and (3) progress towards the initial goal of downlisting this species from endangered to threatened status.

Methods

Oregon chub distributional surveys were conducted by the Oregon Department of Fish and Wildlife throughout the Willamette Valley from 1991 through 2004. A total of 650 off-channel habitats and small tributaries were sampled in the Willamette River basin.

Fish sampling was conducted using a combination of gear types. A minimum of 20% of the surface area of each site was sampled within the range of habitat types present at each location. Most habitats were sampled using a 1 x 5 m seine (64-mm mesh). In deep sites (greater than 1.5 m maximum depth) and/or sites where seining was inefficient because of large amounts of woody debris, baited minnow traps and dip nets (32-mm mesh) were used. Dipnetting was conducted in shallow shoreline areas and around woody debris. A gill net (four panels measuring 7.6 m long x 1.8 m deep, with square mesh sizes of 127, 191, 254, and 381 mm) was also used at certain locations to capture larger, mostly nonnative fishes. The gill net was set for a minimum of 2 h and extended from the shore into deeper water. All fish captured were identified, counted, and their length recorded within 25-mm increments.

Population estimates were obtained for adult Oregon chub (greater than 35 mm TL) at selected locations between 1992 and 2004. When catch rates were very low, attempts to estimate abundance were abandoned. Low numbers of centrarchid fishes were captured during our sampling efforts compared to visual observations of their abundance. No population estimates were obtained for these species. Minnow traps measuring 23 by 46 cm with 64-mm mesh were used to capture fish for marking. The traps were baited with a half of a slice of bread. Minnow traps were regularly spaced at a density of one trap per 100–250 m^2 of surface area, up to 60 traps per site, to ensure that fish were marked from all locations within the pond or slough. Traps were typically fished for 3–4 h during the day. If catch rates were low during the day set, traps were set overnight (up to 18 h). All fish were given a partial caudal fin clip before returning them to the water. Marked fish were distributed throughout the pond to promote mixing with the unmarked population. Population size was estimated using an adjusted Peterson mark–recapture procedure (Ricker 1975) from the total number of marked fish, and the catch and recaptures from the last sample date, if more than 1 d of marking was required. The last sample date was separated by a minimum of 2 d from the last date of marking, to allow time for adequate mixing of the marked and unmarked segments of the population. Confidence intervals were calculated using a Poisson approximation (Ricker 1975). No estimates were made for age-0 fish (less than 35 mm), which were too small to be efficiently captured in the minnow traps (Scheerer and McDonald 2003). Regeneration of caudal fins was rapid following marking, with substantial regeneration noted as early as 3–4 weeks postmarking. In subsequent years, caudal fin clips from the previous years' marking were almost completely regenerated and easily distinguished from new fin clips.

The connectivity of a habitat to the river or reservoir was described for sites containing Oregon chub, based on the degree of isolation of the off-channel habitat from the adjacent water body. Sites with high connectivity had year-round connection, had yearly influx of water during the winter and/or spring months, or were connected by a culvert to the adjacent river or reservoir. Sites with low connectivity were isolated from the adjacent river by impassable culverts, high beaver dams, and/or regulated flows. All sites characterized with low connectivity remained isolated during two 1996 flood events (approximate 20-year recurrence interval postdams).

Abundance estimates were used to determine the status of Oregon chub in relation to recovery criteria set forth in the Oregon Chub Recovery Plan (U.S. Fish and Wildlife Service 1998). The recovery plan adopted the following criteria for downlisting the species from endangered to threatened: (1) establish and manage 10 populations of at least 500 adults each; (2) all populations must exhibit stable or increasing trends for 5 years; and (3) ensure that at least three populations are located in each of the three major recovery areas (Middle Fork Willamette, Santiam, and main-stem Willamette subbasins). Delisting will occur when there are 20 populations totaling 500 or more adults, which maintain a stable or increasing trend for 7 years. At least four populations must be located in each of the three recovery areas. Management of these populations must be guaranteed in perpetuity. Abundance trends were defined quantitatively as increasing, declining, stable, not declining, or unknown. A linear regression of abundance over time was calculated for each population for the past 5 years (2000–2004). When the slope of this regression was negative and significantly different from zero ($P < 0.10$), the population was defined as exhibiting a declining trend in abundance. When the slope was positive and significantly different from zero ($P < 0.10$), the population was defined as exhibiting an increasing trend in abundance. When the slope was not significantly different from zero ($P > 0.10$), then the coefficient of variation was calculated for the abundance estimates for the past 5 years. When this coefficient of variation was less than 1.0 then the population was defined as stable. Otherwise, the population was defined as not declining in abundance. At locations with fewer than 5 years of data or where no abundance estimates were obtained due to low catch rates, the abundance trend was defined as unknown.

Results

In 2004, 33 locations were identified that contained Oregon chub in the Willamette basin (Table 1; Figure 1). Eight of these were on the list of 29 historical sites in Oregon State University fish museum records, 10 were locations where populations were introduced between 1988 and 2004, and 15 were new populations discovered since 1991 (Figure 2). Distribution included populations located in the Santiam River (6 sites), McKenzie River (3 sites), Coast Fork Willamette River (2 sites), mid-Willamette River (9 sites), and the Middle Fork Willamette River (13 sites) (Figures 1 and 2).

Known chub distribution and status has improved substantially since the listing in 1998 (Table 2). This change in distribution and status of Oregon chub is likely the result of increased sampling effort, rather than range expansion, since many of the newly discovered populations were found in isolated habitats. The number of chub populations known in 1998 was 18, compared to 33 in 2004. The number of abundant chub populations (500 or more fish) increased from 9 in 1998 to 15 in 2004. The number of populations that meet the recovery plan criteria (500 or more fish

Table 1.

Oregon chub population abundance, status, 5-year trends, site connectivity, and presence of nonnative fish. Mark–recapture population estimates were obtained at locations when possible. When abundance was low, the total number of fish captured is shown in bold. Numbers in parentheses are the number of fish introduced at the site. In the Oregon Chub Recovery Plan, the McKenzie River subbasin is included in the main-stem Willamette River recovery area. Site locations were assigned a code consisting of one or more letters followed by a number. The larger the population in each subbasin, the smaller the number. Sites in the Middle Fork Willamette River drainage were coded with the letter "M," in the Coast Fork Willamette River basin with the letter "C," in the McKenzie River drainage with the letter "MCK," in the Santiam River drainage with the letter "S," and in the main-stem and mid-Willamette River tributaries with the letter "W."

Site	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*Trend (5-year)*	*Connectivity*	*Nonnative fishes*
W1[a]			(200)	(373)460	4,860	14,090	26,240	19,270	28,740	25,810	stable	low	no			
M1[a]			(500)	480	1,420	6,310	5,030	7,770	6,370	5,620	5,850	stable	low	no		
M2	690	780	3,160	3,030	3,020	2,980	2,700	2,130	1,600	4,940	stable		low	no		
M3[a]	3		0	1	9	25	160	4,580	4,080	2,410	4,100	4,780	stable	low		no
M4	1,630	4,770	3,770	4,240	3,790	3,650	2,860	3,830	2,280	2,420	2,330	4,210	stable	low	no	
M5				3,010	3,570	7,140	4,080	2,830	3,600	stable	low	no				
M6	8,770	7,540	7,130	4,470	4,020	4,440	4,780	5,050	3,380	3,270	3,650	3,140		declining	low	no
M7	4,010	1,910	2,010	5,350	2,720	1,190	3,970	4,910	2,140	2,950	stable	low	no			
S1			8,340	8,660	1,830	860	360	760	740	1,590	2,290	increasing	lowb	no		
M8				1,060	1,170	1,090	940	610	1,340	stable		low	no			
MCK1						120	650	1,050	unknown	low	no					
M9[c]	59		15	1,330	830	50	880	1,950	2,270	870	790	stable		high	yes	
MCK2[a]					(350)	(150)470	450	720	unknown	low	no					
S2[a]				(85)	(20)80	(75)210	(50)320	(158)640	(112)570	increasing	low	no				
W2	370	600	460	470	520	620	510	730	630	290	230	520	stable		high	yes
W3[a]							(500)	unknown	low	no						
W4[a]							(500)	unknown	low	no						
M10						2,780	420	unknown	high	yes						
C1[a]						(400)	420	350	unknown	low	no					
S3		2	3	2	0	13	4	2	12	270	340	increasing	high	yes		
S4			5	2	3	13	13	350	220	320	increasing	high	yes			
MCK3						940	620	310	unknown	high	no					
W5[a]						(50)	50	220	unknown	low	no					

(continued)

Table 1. (continued)

Site	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*Trend (5-year)*	*Connectivity*	*Nonnative fishes*
C2						16	130	190	unknown	high	yes					
M11[c]	780		140	40	920	450	1,130	1,440	800	460	390	70	declining	high	yes	
W6[a]	(60)		(45)360	1,750	(49)670	500	130	70	stable		low	no				
S5				3	4	1	0	0	0	21	unknown	high	yes			
W7									5	unknown	high	yes				
M12	0				3	7	2	1	2	unknown	high	no				
W8[d]		26		2					22	1	unknown	high	no			
M13		4	8	2	21	480	140	140	9	1	1	declining	high	no		
S6		1,250	830	320	250	13	4	12	2	0	1	declining	high	yes		
M14						13	0	extinct?		high	yes					
S7			2	0	0	2	9	4	6		0	extinct?	high	no		
S8	5		2	5	0	2	0	3	2	4	0	extinct?	high	yes		
M15	7		6		1	2	2	2	2	0	extinct?		high	yes		
M16	3		0		7	0	0	0	8	2	0	extinct?		high	yes	
S9[a]					(15)	7	(26)29	0	0	extinct?		low	no			
M17	31		0		22	0	0	0	0	0	0	extinct?	high	yes		
M18		6	0	1	0	1	0	0	0	0	0	extinct?	high	yes		
M19[a]		(576)	3,520	5,610	7,160	3,490	60	0	0	0	0	0	extinct?	high	yes	
M20			3	0	0	0	0	0	0	0	extinct?	high	yes			
M21	40		0	0	0	0	0	0	0	0	extinct?	high	no			
M22		3	0	0	0	0	0	0	0	0	extinct?	high	yes			
C3	1	2	0	0		0	0	0	0	0	0	extinct?	high	yes		
S10[e]			2		0					extinct?	high	no				
W9[f]	5		5							unknown	high	yes				
M23[a]	3	(525)	2	0	0	0	0					extinct?	high	yes		

[a] Oregon chub reintroduction sites.
[b] Connectivity changed from high to low in 2001 when a portion of this habitat was isolated (screened) to exclude nonnative fishes. Nonnative fishes were not collected in 2001–2004.
[c] Nonnative fishes have access to these sites through a culvert connected to a reservoir. Nonnative fish were collected from site M9 in 1999, 2003, and 2004. Nonnative fish were collected from site M11 in 1996, 2002, and 2004.
[d] Access was denied 1998–2002.
[e] Site was destroyed by 1996 floods and no longer exists.
[f] Access was denied 1997–2004.

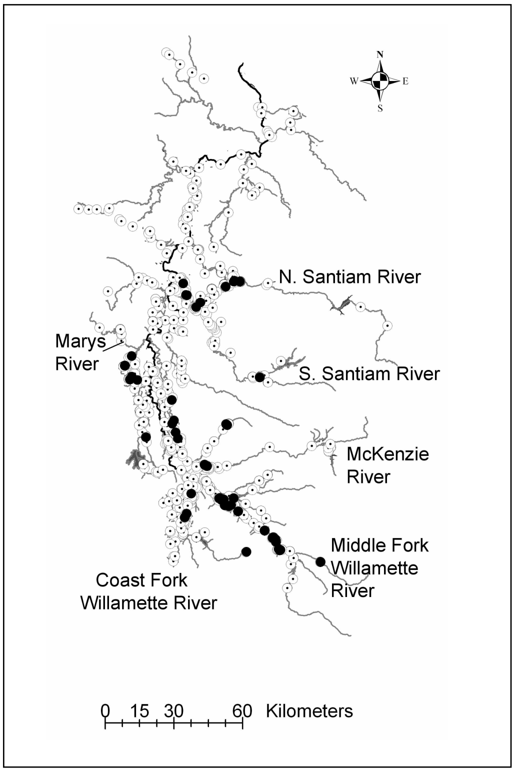

Figure 1. Distribution of sampling effort during 1991–2004 surveys in the Willamette River basin. Circles with center dots indicate sites where sampling occurred. Solid circles indicate the current distribution of Oregon chub.

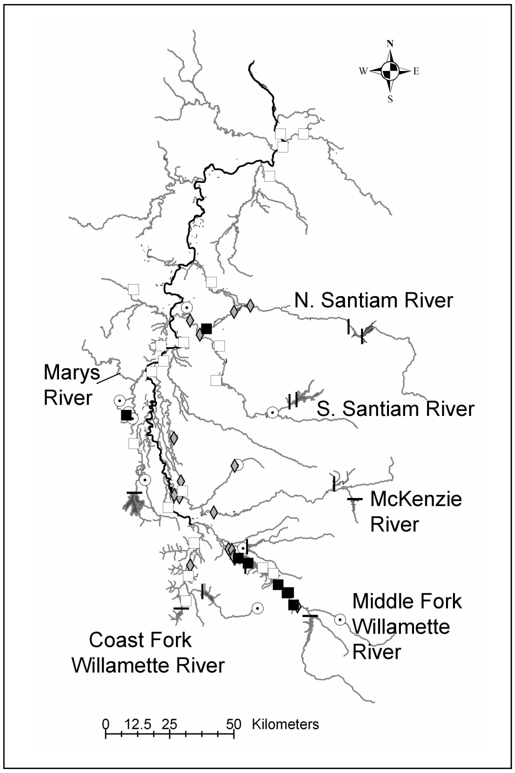

Figure 2. Distribution of Oregon chub populations in the Willamette River basin in 2004. Open squares represent historical Oregon chub locations where no Oregon chub currently exist. Closed squares represent historical Oregon chub locations where Oregon chub currently exist. Diamonds represent newly discovered Oregon chub populations (since 1991). Circles with center dots represent introduced Oregon chub populations. Bold dashes represent the locations of major flood control dams.

and stable or increasing in abundance for 5 years) increased from 2 to 12 over this same period. Four of the 12 populations that meet recovery plan criteria were reintroductions, and four were populations known to exist historically. In addition, the known distribution expanded from three to five major subbasins from 1998 to 2004, including recent collections in the McKenzie River subbasin and the Coast Fork Willamette River subbasin, last collected in 1899 and 1993, respectively.

Oregon chub population abundance estimates and 5-year trends are shown in Table 1. Abundance estimates ranged from 40 fish to more than 28,000 fish per population. The lower 95% confidence limits for the estimates were fairly tight, averaging 75% of the estimate (95% confidence interval: 73–77%; range: 50–94%). Oregon chub were more widespread and abundant in the Middle Fork Willamette River drainage than in the other Willamette River subbasins. Nine of the 15 largest populations (500 or more fish) were found in the Middle Fork Willamette River drainage. Of the 12 populations that met the recovery plan criteria in 2004 (stable or increasing in abundance for 5 years), eight were located in the Middle Fork Willamette River subbasin, two were located in the Santiam River subbasin, and two were located in the mid-Willamette subbasin.

Oregon chub were more abundant at sites where nonnative fishes were absent (Table 1). In 2004, only 2 of the 15 locations that supported large populations of Oregon chub (500 or more fish) contained nonnative fishes. Conversely, nonnative fish-

Table 2.

Status of Oregon chub populations by subbasin in 1998 and 2004. The number of populations includes the total number known in each subbasin, the number of large populations (500 or more adults), the number of viable populations (i.e., those that meet the criteria in the recovery plan [500 or more adults and exhibiting a stable or increasing trend for five years]), the number of introduced populations (included in the total number of populations), and the number of populations presumed extinct. The Oregon chub recovery plan includes the McKenzie River subbasin in mid-Willamette River subbasin. The totals listed for the mid-Willamette subbasin do not include totals for the McKenzie subbasin.

Number of populations	*Santiam*		*Mid-Willamette*		*McKenzie*		*Middle Fork Willamette*		*Coast Fork Willamette*		*All subbasins*	
	1998	*2004*	*1998*	*2004*	*1998*	*2004*	*1998*	*2004*	*1998*	*2004*	*1998*	*2004*
Total	4	6	2	9	0	3	12	13	0	2	18	33
Large	1	2	1	2	0	2	7	9	0	0	9	15
Viable	0	2	1	2	0	0	1	8	0	0	2	12
Introduced[a]	0	1	2	5	0	1	4	2	0	1	6	10
Extinct[b]	0	3	0	0	0	0	4	9	1	1	5	13

[a] Three introductions failed (sites M19, M23, and S9) and are not included in totals. Total attempted reintroductions is 13.

[b] Failed introductions were not included in the number of presumed extinct populations listed.

es were present in many of the locations where Oregon chub abundance was low or where chub are presumed extinct. Eight of the 15 sites supporting small chub populations (fewer than 500 fish) contained nonnative fishes (53%), and 11 of the 15 sites where chub are presumed to be extinct contained nonnative fishes (73%). Sites with low connectivity ($n = 8$) supported larger naturally occurring populations of Oregon chub ($P < 0.001$) and contained fewer species of nonnative fishes ($P < 0.001$) than sites with high connectivity ($n = 24$).

Forty-two percent of all locations sampled in the Willamette River drainage, and 53% of the locations where any fish were present contained nonnative fishes (Table 3). Nonnative fishes were collected most frequently from off-channel habitats in the main-stem Willamette River (59%), the Coast Fork Willamette River drainage (55%), mid-Willamette River tributaries (43%), Santiam River drainage (42%), and the lower Willamette River tributaries (37%). In these subbasins, naturally occurring chub populations frequently occurred in lower abundance and/or were in decline. The Middle Fork Willamette River drainage, which contained the largest concentration of abundant chub populations, and the McKenzie River drainage, where two populations were discovered in 2002, had the lowest occurrence of nonnative fishes in off-channel habitats (28% and 22%, respectively).

Nonnative fishes invaded several Oregon chub locations during the course of this study. These include two Santiam River locations (sites S1 and S7) that were invaded during flooding in 1996 and one Middle Fork Willamette River location (site M19), which was illegally stocked with largemouth bass *Micropterus salmoides* in 1997 (Table 1). The Oregon chub populations subsequently declined at these locations. At one Santiam location (S1), we were successful in isolating a portion of the habitat by screening in 2000 and 2001. No centrarchids were captured from this isolated habitat in 2001 through 2004, and the chub population has since increased in abundance (Table 1).

Discussion

Oregon chub status and the known distribution has improved over the past 13 years, resulting from the discovery of new populations through extensive surveys of off-channel habitats and from the establishment of new populations through successful reintroductions within their historical range.

Determining the distribution of a small cyprinid, Oregon chub, in large river basin such as

Table 3.
The number of locations sampled in subbasins of the Willamette River and the number and percentage of these locations that contained nonnative fishes. Lower Willamette tributaries include all tributaries downstream of the Santiam River. Main-stem Willamette River locations include side channels and backwaters to the main stem. Mid-Willamette tributaries include all tributaries to the Willamette River between the confluence of the Coast and Middle Forks and the Santiam River, except for the McKenzie River. The total number of sites with fish excludes sites where no fish were collected that likely desiccate annually (isolated wetlands).

Subbasin	*Number of locations*	*Locations containing nonnative fishes*	
		Number	*Percentage*
Lower Willamette tributaries	51	19	37
Main-stem Willamette River	99	58	59
Mid-Willamette tributaries	115	49	43
Santiam River	122	51	42
McKenzie River	54	12	22
Coast Fork Willamette River	84	46	55
Middle Fork Willamette River	125	35	28
All subbasins	650	270	42
Sites with fish	508	270	53

the Willamette River, has been a challenge considering that 64% of the watershed is in private ownership (Hulse et al. 2002) and historic species records are sparse (29 records from 1894 to 1979) (Markle et al. 1991). In 1990, when the species was petitioned for listing, only three populations, restricted to 30 km of the Middle Fork Willamette River, were known to exist (Markle and Pearsons 1990). In 1998, 12 naturally occurring populations were identified, distributed over three major subbasins. Six years later in 2004, 23 naturally occurring populations were identified, distributed over five major subbasins. These data illustrate the importance of extensive sampling efforts to determine the distribution of small rare fishes in large watersheds.

Reintroduction is a common management action for endangered species recovery (IUCN 1995). We have established 10 introduced populations of Oregon chub in suitable habitats within their current range; 4 have been quite successful. We chose locations that had suitable chub habitat with low connectivity to reduce the risk of invasion by nonnative fishes (U.S. Fish and Wildlife Service 1998; Scheerer 2002). To minimize the potential genetic consequences of our activities (genetic drift, bottlenecks, and inbreeding) in the absence of genetic data, we transferred a minimum of 500 fish when we conducted introductions to establish a large effective population size and we used multiple donor populations when possible (Scheerer 2002). When possible, we chose donor populations that were large (more than 1,000 fish) and always limited the number of fish transferred from the donor site to 10% of the estimated adult population abundance. Successive annual transfers were sometimes needed to achieve the minimum stocking target of 500 fish.

Metapopulation theory states that the probability of extinction of local populations decreases with increased population size (Hanski and Gilpin 1997). A goal in recovery of threatened and endangered fish species is to increase the population size enough to withstand stochastic fluctuations and maintain sufficient genetic diversity (Li et al. 1995; Fagan 2002). Oregon chub expand rapidly in suitable habitats, as evidenced by successful reintroductions, achieve large population size at most isolated sites, and tend to be the numerically dominant fish species in these habitats. These species characteristics act to reduce the risk of extinction and facilitate the recovery of Oregon chub.

Fragmentation disrupts patterns of immigration and emigration, which can restrict recolonization of habitats and reduce gene flow among populations (Lafferty et al. 1999). Habitat alteration in the Willamette River has resulted in fragmentation of Oregon chub habitat. Since nonnative fishes are common in habitats preferred by Oregon chub, large chub populations tend to be found in isolated habitats with low connectivity. Exchange among populations is likely minimal or nonexistent because the hydrology of the Willamette River has been severely altered. Consequently, reduced gene flow may be a significant impediment to Oregon chub recovery. Genetic investigations are currently being conducted to determine the levels of genetic diversity within and among Oregon chub populations and to help determine the genetic relationships among populations relative to their spatial distribution.

Habitat degradation and introduced species, major factors implicated in the decline of Oregon chub (Markle et al. 1991; U.S. Fish and Wildlife Service 1998), have been implicated in the decline of native minnows throughout the western United States (Cross 1976; Kaeding et al. 1990; Blinn et al. 1993; Scoppettone 1993; Meng and Moyle 1995; Marsh and Douglas 1997; Sommer et al. 1997; Osmundson and Burnham 1998; Simon and Markle 1999; Scheerer 2002). Most large western streams have been dammed creating permanent lentic environments (reservoirs) and more stable flow regimes than previously existed. These conditions tend to favor introduced species that were most common in lakes and river backwaters in their native range (Moyle 1986). These introduced fishes may eliminate native fishes directly by predation or indirectly through competition for resources or higher reproductive success (Schoenherr 1981; Taylor et al. 1984). In the western United States, many native minnows are unable to establish populations in reservoirs or other slackwater habitats, likely due to the presence of nonnative centrarchids (Moyle et al. 1986). Rahel (1984) found native cyprinids were absent in lakes that had centrarchid or northern pike *Esox lucius* predators. Moyle (1976) documented the extinction of six native fish species in Clear Lake, California following the introduction of centrarchids. Meng et al. (1994) found native fishes were forced into smaller, dead-end sloughs when nonnative fishes were present in the system, and over time, the natives declined in abundance in these habitats as well. In the Willamette basin, large populations (500 or more fish) of Oregon chub were found primarily in isolated off-channel habitats. Sites with high connectivity frequently contained centrarchids and rarely contained Oregon chub. The frequency of occurrence of nonnative predators was highest in the main-stem Willamette River and in flood control reservoirs and was higher in most downstream subbasins compared to the subbasins in the upper watershed. Conversely, naturally occurring Oregon chub populations were concentrated primarily in the upstream subbasins and in isolated habitats where nonnative fish occurrence was less common. Many of the isolated habitats in the Middle Fork Willamette River basin are located in close proximity to flood control dams. These habitats are less likely to be impacted by flood events that can transport nonnative fishes into these habitats. This isolation may account for the large concentration of abundant Oregon chub populations in this subbasin.

In large alluvial rivers, declines of populations of native floodplain fishes have been attributed to altered river-floodplain connectivity and function as well as impacts from nonnative fishes (Marsh and Brooks 1989; Minckley 1982, Modde et al. 2001; Moyle 1976; Mueller 1995; Tyus 1987). Floodplain habitats increase the productivity and diversity of riverine communities (Bayley 1995; Gutreuter et al. 1999; Junk et al. 1989) and can provide survival and growth advantages to fish (Starrett 1951; Peterson 1982; Tyus 1987; Kwak 1988; Matheney and Rabeni 1995; Osmundson and Burnham 1998; Modde et al. 2001; Sommer et al. 2001). Native fishes are adapted to natural flow regimes in which they evolved. These adaptations provide advantages over nonnative fishes during periodic flooding (Gido et al. 1997; Meffe 1984; Minckley 1981; Minckley and Meffe 1987; Osmundson and Kaeding 1991). Damming of rivers has made them more lake-like, thus eliminating the adaptive advantages of the native fishes and conferring the advantage to nonnative fishes, like centrarchids. However, in certain situations, flooding has resulted in the invasion of habitats by nonnative fishes with subsequent declines in native fishes (Lafferty et al. 1999; Meffe 1983; Scheerer 2002). Schultz et al. (2003) found the abundance of some nonnative species that inhabited reservoirs and creeks increased in the dammed creek following flooding, probably due to the movement of nonnative fishes out of the reservoir. Stanford and Ward (1986) documented the spread of nonnative fishes downstream of impoundments in the Colorado River basin. The 13 large flood control reservoirs in Willamette River basin are both sources of nonnative fishes as well as barriers (physical and biological) to successful migration by Oregon chub.

The discovery of new populations, some in subbasins where they were presumed extinct, and the establishment of additional populations through reintroductions has substantially improved the known status of Oregon chub. Meeting the recovery criteria to downlist Oregon chub to threatened (i.e., maintaining 10 large populations of Oregon chub that exhibit a stable or increasing trend of abundance for 5 years) can likely be achieved within the next 5–7 years. Future introductions and additional surveys in previously unsurveyed habitats will likely assist in meeting this goal.

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