2014 Deschutes River Fisheries Monitoring Report:

Occupancy and Closed-Capture Modeling of Salmonids Using Boat Electrofishing in the Middle and Upper Deschutes River

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Abstract
The middle and upper Deschutes River has experienced changes to its fish assemblage, flow regime, habitat quality, and habitat connectivity since the river was harnessed for irrigation and other human uses. These alterations to the river, as well as empirical and anecdotal data suggesting a substantial decrease in redband trout abundance have led to management concern about the status of this native species and highlighted the need for a current status assessment and monitoring protocol. Ideally, the monitoring protocol would have the ability to track population changes in response to regional development or management actions that impact the river and recreational fisheries. To assess status and evaluate potential monitoring protocols, closed-capture and occupancy modeling was used to estimate detectability of species and individuals, species occupancy, and abundance of three salmonid species in the middle and upper segments of the Deschutes River in 2014. Using a cataraft-mounted electrofisher, 43 sites (300-m long) were surveyed 4 times each from July through August in the middle segment and from March through April in the upper segment. Redband trout were distributed throughout the middle segment and 76% of the upper segment, composing 25% of the catch in the middle segment and only 1% in the upper segment. Mountain whitefish were ubiquitous in the Deschutes River and accounted for a majority of the catch in both segments. Brown trout were also captured in all sample sites, composing 13% and 5% of the catch in the middle and upper segments, respectively. To estimate abundance based on individually marked fish, 1355 salmonids (≥150 mm TL) were PIT tagged during sampling visits among site and only 38 PIT-tagged individuals were recaptured. Closed-capture modeling was conducted separately by segment and species and three basic models involving initial (p) and recapture (c) probabilities and time (i.e., visit) were tested. The top closed-capture model for each species suggested that p and c were equal and p varied by visit for redband trout, but not for brown trout or mountain whitefish. Capture probabilities for individuals were extremely low for all species (range, 0-3.2%) in both segments and led to high uncertainty (range in CVs, 0.46-0.85) in the abundance estimates. In occupancy modeling, size class (<205 and ≥205 mm TL) and segment were evaluated as factors and each species was modeled separately. Detection probabilities were moderate to high (p=0.45-0.93) for all species and size classes except for redband trout in the upper segment, which was low (p=0.18). For redband trout, species detection differed between the segments and by size class. Naïve occupancy was high for most species and size classes, except for redband trout in the upper segment and modeled occupancy probability was high ($\psi \geq 0.92$) in the cases in which it was estimable (range in CVs, 0.01-0.33). Low capture probability and high imprecision of abundance estimates suggest that closed-capture methods used in this study are not likely to provide a reliable monitoring protocol for tracking trend in redband trout abundance in the middle and upper Deschutes River. If abundance estimation is desired by managers in future monitoring, substantial changes to the protocol used in this study will be needed to improve precision of the estimates. These include a greater number of sample sites, larger sample sites and more visits during a survey season, using alternative or additional gear types to which the target species or size class is more vulnerable, improve gear efficiency using radio-tagged fish as guides, or test emerging monitoring tools.

Introduction
The middle and upper Deschutes River, Oregon, have been dramatically altered by humans beginning in the early 1900s. Some of these alterations include irrigation diversion that turned

historically steady flows into a managed flow regime of seasonal extremes, construction of dams that restrict access to historical habitat by fishes and altered flow of sediment and organic matter, and stocking of hatchery rainbow trout (*Oncorhynchus mykiss ssp.*) and other nonnative fishes that may have adversely affected native fishes (for a more detailed summary, see Starcevich et al. 2015). These alterations led to the extirpation of bull trout (*Salvelinus confluentus*) in the 1950s and a perception among local biologists and anglers of a decline in redband trout (*O. m. gairdneri*) in both the middle and upper Deschutes River (Fies et al. 1996, NPCC 2004). This perceived decline in redband trout abundance has led to management concern about the status of this species and highlighted the need to accurately assess status and to develop a monitoring protocol that can track population response to water management changes and other management actions impacting recreational fisheries in the middle and upper Deschutes River.

In response to this management concern, the Deschutes Watershed District of the Oregon Department of Fish and Wildlife (ODFW), in collaboration with the Upper Deschutes Watershed Council (UWDC) and Mitigation and Enhancement Board (M&E) began a field study in 2012 designed to obtain baseline information on the status of native redband trout and mountain whitefish (*Prosopium williamsoni*) and nonnative brown trout (*Salmo trutta*) and initiate development of a monitoring protocol that will enable managers to monitor these species and guide research and management actions in the middle and upper Deschutes River.

The project in 2012 and 2013 provided information on salmonid occupancy, distribution, and relative abundance as well as recommendations about sampling timing. In both segments, all three salmonid species generally had high probability of occupancy in any given sample site with the exception of large redband trout (>250 mm TL), which were estimated to have low site abundance and occupancy relative to large brown trout (Carrasco and Moberly 2014; Starcevich et al. 2015). The work done in 2014 summarized by this report is a continuation of the previous two years but with a new focus on exploring the usefulness of closed-capture modeling to estimate capture probabilities and abundance using cataraft electrofishing. The specific objectives for 2014 were as follows:

1) Determine current distribution and relative abundance of all salmonids, with a focus on two size classes of redband trout, brown trout, and mountain whitefish.
2) Evaluate occupancy and closed-capture sampling designs and sampling timing for feasibility and effectiveness as an approach to monitoring trends in status in large river habitats.

Study Area

The study area comprised two segments, the middle and upper Deschutes River, which differ substantially in their fluvial geomorphology and managed flow regime. The middle Deschutes River was defined as extending from Steelhead Falls (RK 206) to the North Canal Dam (RK 265) in Bend. Tumalo Creek is the only major tributary in this segment, with annual mean daily discharge of 1.9 cubic meters per second [c^3/s]. Artificial and natural barriers in this segment that affect upstream movement of fishes include Steelhead Falls, Big Falls (RK 213), Odin Falls (RK 225), Cline Falls (RK 233), Awbrey Falls (RK 246), and the North Canal Dam. Maximum water temperatures in the middle Deschutes River range from 18-24˚C during the summer and 0-7˚C in the winter. The middle Deschutes River is characterized by relatively high channel gradient (mean, ~6.4%) and the river channel is largely constrained by canyon geology. Historical daily mean discharge prior to irrigation development varied annually between 28.3-39.6 c^3/s (estimated at Benham Falls, U.S. Bureau of Reclamation). In 2014, mean daily discharge was 10.6 c^3/s, with minimum discharge of 2.1 c^3/s when water was diverted away from the middle Deschutes River at irrigation diversions upstream of Bend.

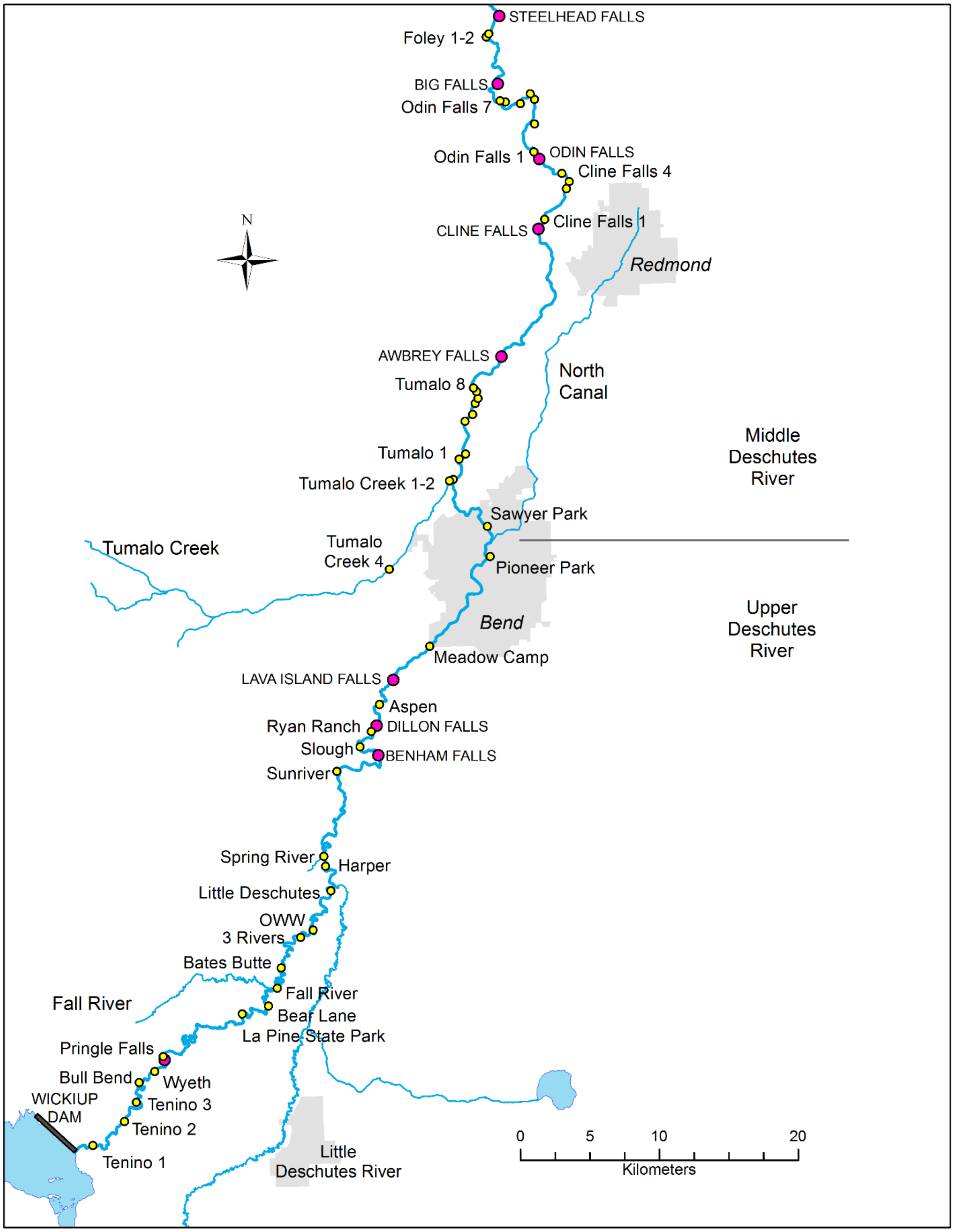

Figure 1. Map of study area, including sample sites (yellow dots), major falls (pink dots) and cities (gray areas), and demarcation (horizontal line) between the middle and upper Deschutes River study reaches.

The upper Deschutes River was defined as extending from the North Canal Dam (RK 265) to Wickiup Dam (RK 365). Three major tributaries enter the Deschutes River in this segment: Spring River (annual mean daily discharge, 4.2 c^3/s, RK 306), Little Deschutes River (10.9 c^3/s; RK 311), and Fall River (4.2 c^3/s; RK 330). Maximum water temperatures range from 10-18˚C in summer and 0-7˚C in winter. From Bend upstream to the Little Deschutes River confluence, the river flows through basalt formations that result in a series of falls and cascades. In this section, the river splits into two channels around Lava Island, one of which is dewatered when flows are reduced at Wickiup Dam for storage in the reservoir. Lava Island Falls (RK 281), Dillon Falls (RK 286), and Benham Falls (RK 291) may be barriers to upstream movement by fish during certain flows. From the Little Deschutes River upstream to Wickiup Dam, the river is sinuous and low gradient, except at Pringle Falls (RK 349), which may be an upstream passage barrier for fish at low flows. Historical daily mean flows ranged from 14.2 to 19.8 c^3/s in winter and 19.8 to 28.3 c^3/s in summer where Wickiup Dam was built. Since the 1990s, flows average 4.0 c^3/s, often drop below 1.4 c^3/s in the winter as Wickiup Reservoir refills, and increases to 38.2 c^3/s in the summer as water is released at the dam for irrigation diversion downriver. Within the study section, only river reaches that were accessible to the electrofishing cataraft, and for which access was granted by private landowners, were considered for sampling. This resulted in a discontinuous study area, from which 22 study sites in the middle segment and 21 sites in the upper segment were randomly selected (Figure 1).

Methods

Fish sampling

Fish were captured using a 4.3 m cataraft equipped with a Smith-Root (Vancouver, Washington, USA) 2.5 GPP Electrofisher with 0.8 m array droppers, except in Tumalo Creek, in which a Smith-Root backpack electrofishing unit was used. The raft crew consisted of two netters at the bow of the raft and a rower. The electrofishing unit was set for direct current (DC) with a pulse rate of 120 pulses/s and 60% power. Sample sites were generally 300 m long except for sites in Tumalo Creek (100-m sites) and the Foley 2 site (200-m sample site). This represents an increase in site length compared to previous studies [i.e., 200-m sample sites (Starcevich et al. 2015)] in an attempt to reduce the probability of temporary emigration during the study (Gwinn et al. 2011). Each site was visited four times, except for Tumalo Creek sites (one visit), and 3 Rivers, Fall River, OWW, Pringle, and Sunriver sites (three visits), which were sampled fewer times because of a lack of time. At each visit, usually one sampling transect per site was conducted in the middle segment and three sampling transects per site in the upper segment. A transect consisted of a longitudinal downstream pass of the cataraft electrofisher through the site. Higher stream gradient in the middle Deschutes River usually precluded returning upstream for additional passes. Captured fish were held in a live well until the final transect for each site was completed. All fish were identified to species and measured for total length [mm TL]. In the first visit, large salmonids (i.e., ≥150 mm TL) were injected intraperitoneally with 12 mm half-duplex passive integrated transponder [PIT] tags. In subsequent visits, large salmonids were scanned for PIT tags; if a tagged individual was recaptured, the tag code was recorded and the fish released; if no tag was found, the large salmonid was PIT-tagged prior to release. After each site visit, all fish were released at the downstream end of the sample site. The survey season in the middle Deschutes River was from July 1 to August 21, 2014; during sampling, mean daily discharge ranged from 3.5 to 6.4 c^3/s and water temperature ranged from 15.0 to 21.1˚C. Upper Deschutes River survey season was from March 4 to April 17, 2014; during sampling, mean daily discharge ranged from 25.3 to 41.1 c^3/s and water temperature ranged from 5.5 to 12.8˚C at Benham Falls and 3.9 to 23.7 c^3/s and 3.9 to 10.6˚C at Wickiup Dam.

Data analysis
Salmonid distribution and relative abundance was displayed graphically by site using maximum single-visit counts. Closed capture modeling (Otis et al. 1978) was used to estimate capture probability of individually marked salmonids and abundance across sites sampled. Modeling was conducted by segment and species. Three basic closed-capture models were evaluated: 1) Initial capture (p) and recapture (c) probabilities equal and constant across visits; 2) initial capture and recapture probabilities equal but vary by visit; and 3) initial capture and recapture probabilities differ, suggesting a behavioral response by individual animals after initial capture (i.e., attraction to or avoidance of cataraft electrofishing). For each species in each segment, abundance ($\widehat{N}$), standard error (SE), and 95% confidence intervals were estimated through model-averaging. Precision of an estimate, represented by the coefficient of variation (CV), was calculated for each closed-capture abundance estimate, using the equation: $CV = SE/\widehat{N}$ (Gerrodette 1993). Single-season occupancy modeling (MacKenzie et al. 2006) was used to estimate species occupancy (ψ = "psi") and detection (p) probabilities for two size classes of redband trout, brown trout, and mountain whitefish. The two size classes were ≤205 and >205 mm TL, with the large size class representing legally "catchable" trout as defined by Oregon state fishing regulations (i.e., >8 inches). Each species was modeled separately. Segment (i.e., middle and upper) and size class were used as factors to evaluate differences in occupancy and detection. Linear regression was used to evaluate the relationship of total electrofishing seconds per visit to the product of site length and the number of transects per visit; there was a significant positive relationship (R^2=0.83, $p < 0.001$), suggesting total electrofishing seconds was representative of sampling effort. The influence of sampling effort on detection was evaluated separately through Pearson correlation analysis of two site visit characteristics: total electrofishing seconds and the number of salmonids captured.

Akaike information criterion model selection procedures were used with a correction factor for low sample size [AICc] to select the models of best fit. Models were ranked by AICc values and evaluated using the ΔAIC (i.e., the difference in AICc values between a given model and the highest ranked model) and Akaike weight, which is a relative measure of the weight of evidence for a model given the data (Burnham and Anderson 2002). The best fitting model had the lowest AICc value and the greatest weight. Tumalo Creek sites were not included in the analysis because there was only one visit to each site and detection probabilities could not be estimated. Modeling and estimating species occupancy and detection, closed-capture capture probability and abundance, model-averaging, and model selection procedures were conducted using Program MARK via the RMark package in Program R.

To obtain unbiased estimates (i.e., p, c, ψ, $\widehat{N}$), both occupancy and closed-capture modeling require that certain sampling assumptions are met (Otis et al. 1978). For occupancy modeling the assumptions are that sample sites are closed to changes in occupancy over the survey season, the probability of detection and occupancy is constant across sites or differences are modeled by covariates, and species detection is independent at each survey location (McKenzie et al. 2006). The closure assumption for closed-capture modeling further requires the site be closed to any demographic change (i.e., no birth, death, immigration, or emigration of individuals) over the

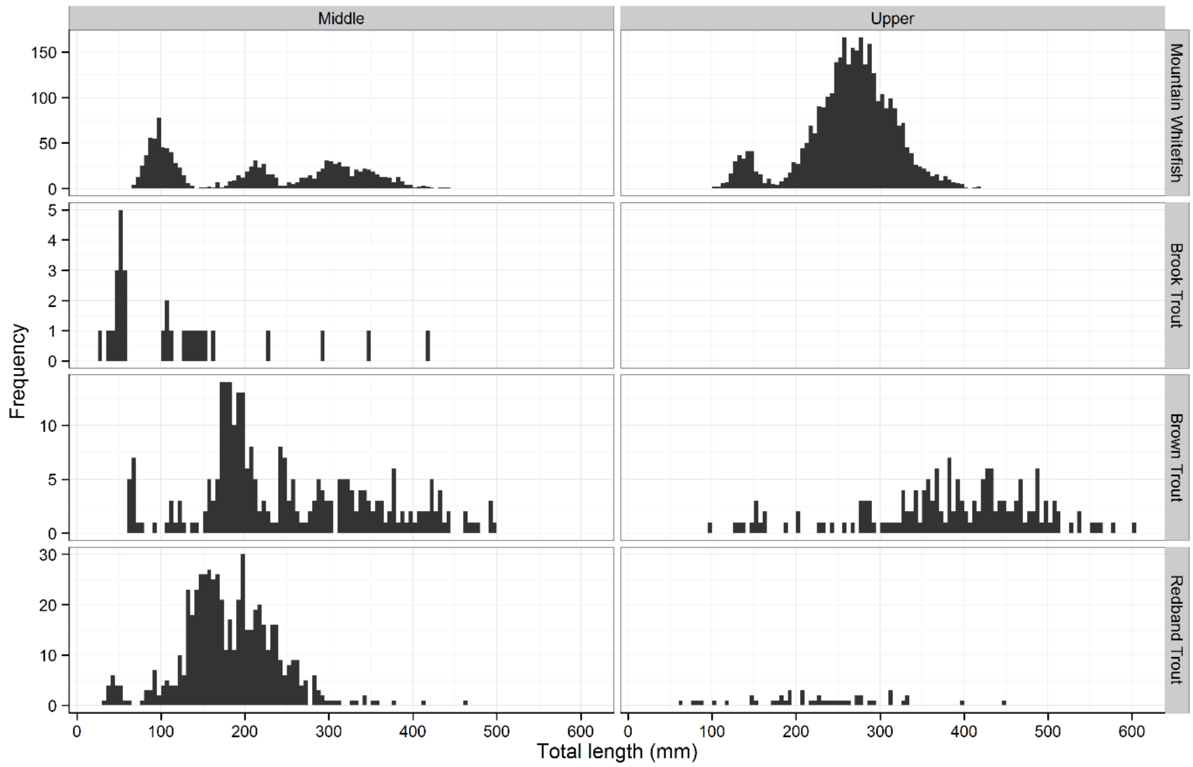

Figure 2. Frequency distributions by total length for all salmonids captured during cataraft electrofishing in 20 sites in the Middle Deschutes River (left column), which included 3 sites in Tumalo Creek, and 21 sites in the Upper Deschutes River (right column) in 2014.

survey season. Channel width, discharge, and flow velocity were too great to allow site closure; therefore, it was assumed that sampling over a short time period precluded site-level demographic changes (Pine et al. 2003). Two additional assumptions (Otis et al. 1978) are required for closed-capture modeling: 1) fish do not lose their tags and 2) all tagged fish are correctly noted and recorded during each sampling visit.

To evaluate the statistical power of closed-capture abundance estimates to detect either a decreasing or increasing trend (i.e., a one-tailed test) in the population, four annual rates of population trend (i.e., +5%, +25%, -5%, and -25%) and two levels of statistical variation were specified. To describe statistical variation, the coefficients of variation (CVs) of 0.46 and 0.85, which was the range in closed-capture abundance estimates, were used. To determine the power of this monitoring protocol to detect a directional trend, we used one-tailed tests and set $\alpha = 0.2$ and $\beta=0.2$, which could be considered the lowest significance level for "high power" to detect change (Peterman 1990). The statistical power of these scenarios were simulated with the software program Trends (Gerrodette 1993).

Results

Sampling effort

Mean electrofishing time per visit was 258 seconds (range, 100-631) in the middle Deschutes River and 603 seconds (range, 159-981) in the upper Deschutes River. Electrofishing seconds was not recorded in Tumalo Creek sites. There was no significant correlation between sampling

Table 1. Cataraft electrofishing counts (*N*) of all species captured and as a percentage of the total catch within the study segment (%) in the middle and upper Deschutes River and Tumalo Creek in 2014.

				Length (mm)			
Study segment	Species	*N*	%	Mean	SD	Min	Max
Middle Deschutes River	Mountain whitefish	1199	59.7	212	104	65	442
	Redband trout (wild)	511	25.4	192	48	104	462
	Brown trout	255	12.7	264	94	60	495
	Sculpin species[1]	14	0.7	85	8	71	98
	Tui chub[2]	12	0.6	115	36	66	191
	Bridgelip sucker[3]	8	0.4	181	144	70	390
	Brook trout	5	0.2	289	99	160	415
	Kokanee[4]	2	0.1	110	0	110	110
	Three-spined stickleback[5]	2	0.1	31	1	30	31
	Brown bullhead[6]	1	0.0	189	NA	189	189
Tumalo Creek	Redband trout (wild)	66	57.9	93	41	32	196
	Brown trout	24	21.1	101	39	60	199
	Brook trout	24	21.1	81	41	26	150
Upper Deschutes River	Mountain whitefish	3340	94.0	263	53	100	417
	Brown trout	159	4.5	382	102	99	603
	Redband trout (wild)	39	1.1	213	79	62	446
	Redband trout (hatchery)	6	0.2	304	66	205	395
	Brown bullhead	4	0.1	166	14	151	183
	Sculpin species	4	0.1	53	8	42	60

[1]*Cottus ssp*, [2]*Gila bicolor*, [3]*Catostomus columbianus*, [4]*O. nerka*, [5]*Gasterosteus aculeatus*, [6]*Ameiurus nebulosus*

effort (i.e., total electrofishing seconds) and the total number of individuals captured during a visit for an individual species in either segment or size class (R=-0.19 to +0.21, P=0.07-0.86). Therefore, sampling effort was not included as a variable in the occupancy and closed-capture analyses.

Fish assemblage, distribution, and relative abundance

Mountain whitefish was the dominant species captured (size range, 65-442 mm TL) in the Deschutes River, accounting for 60% of the catch in the middle segment and 94% in the upper segment (Figure 2, Table 1). Both size classes of mountain whitefish were distributed throughout both study segments; large whitefish were relatively more abundant in the upper Deschutes River (Figure 3). Redband trout (size range, 62-462 mm TL) accounted for 25% of catch in the middle segment and only 1% in the upper segment (Figure 2, Table 1). Redband trout were distributed throughout the middle segment and in 76% of the sample sites in the upper Deschutes River, where they were also in lower relative abundance (Figure 3). Brown trout (size range, 60-603 mm TL) composed 13% of the catch in the middle and 4.5% in the upper Deschutes River. Brown trout were distributed throughout the Deschutes River sample sites (Figure 3). Brook trout (*S. fontinalis*; size range, 160-415 mm TL) were captured in very low numbers in the Deschutes River, only in the middle segment (Figure 2-3, Table 1). Six other fish species were

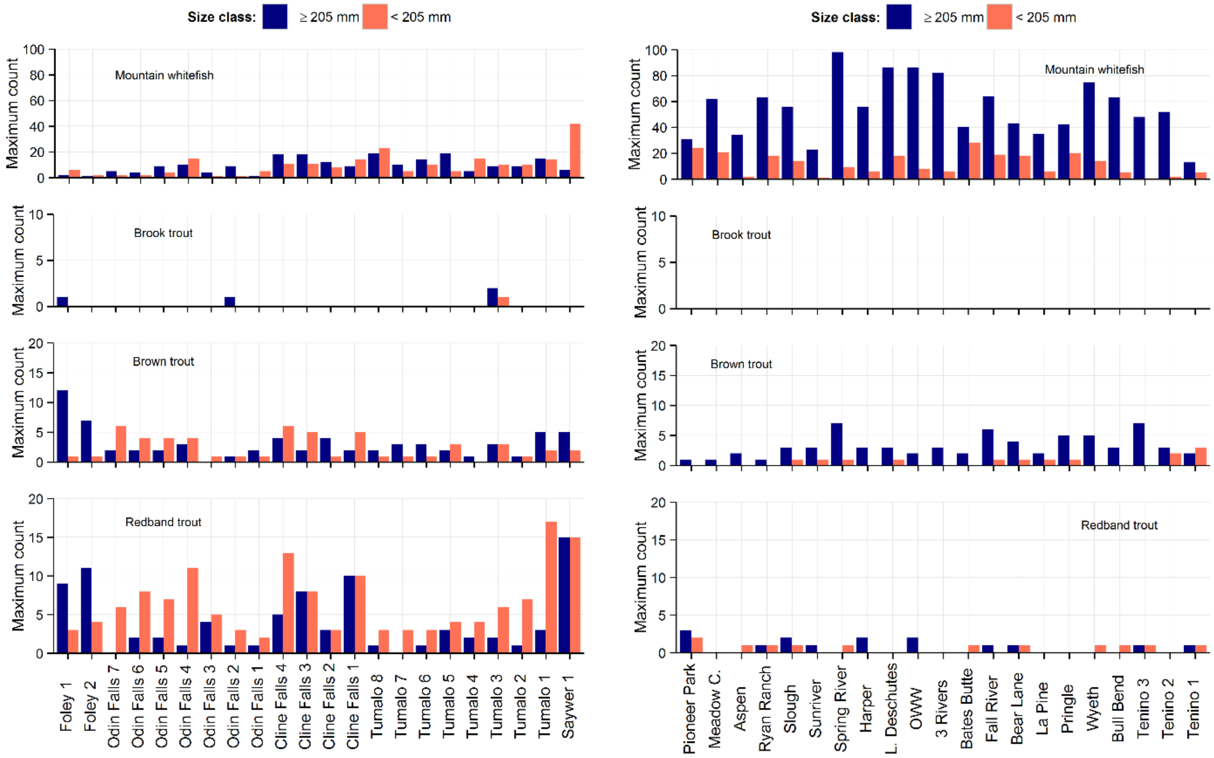

Figure 3. Distribution and relative abundance (using maximum count by size class) of salmonids captured in the Deschutes River basin in 2014. Fish were captured during cataraft electrofishing of 22 sites in July and August in the Middle Deschutes River (left panel) and of 21 sample sites in March and April in the upper Deschutes River (right panel). Sites were 200-300 m long, surveyed 3-4 times over the sample period, and consisted of 1-3 longitudinal survey transects. Maximum count, partially correcting for this range in sampling effort among the sites, represents the greatest number of each species and size class captured during an individual survey of a site.

captured during cataraft electrofishing in the Deschutes River (Table 1). In Tumalo Creek, redband trout was the most abundant species captured; brown trout and brook trout were also present (Table 1).

Closed-capture modeling of individual capture probability and abundance

Overall, 1355 salmonids were PIT-tagged over the 4 visits to the Deschutes River sample sites and only 38 fish were recaptured on a subsequent visit (Table 2). Mean lengths of tagged fish by species ranged from 205-390 mm TL; all tagged fish (except two) were ≥ 150 mm TL (Table 2). In the middle Deschutes River, the best fitting closed-capture model for redband trout suggested that initial capture (p) and recapture (c) probabilities did not differ and overall capture probability varied by visit (Table 3). For brown trout and mountain whitefish, the top models suggested capture and recapture probabilities were equal and did not vary by visit. In the upper Deschutes River, for brown trout and whitefish, the top model suggested that p and c were equal, but varied by visit (Table 3). Only 31 redband trout were tagged in the upper Deschutes River and none were recaptured (Table 2), which precluded closed-capture modeling in this segment (Table 3). Overall, capture probabilities for each species and visit were extremely low, ranging from 0.008 to 0.032 (Table 4). Therefore, the chance of capturing a salmonid (≥150 mm TL) present in a site was equal to the chance of recapturing a tagged salmonid in a site, and the chance of capture was estimated at about 1% for redband trout and 1% to 3% for brown trout and mountain whitefish. These low capture probabilities led to high uncertainty in the abundance estimates for each species (Table 5); therefore, the abundance estimates should be interpreted with caution. The estimated abundance of large fish (≥150 mm TL) within the sample sites was 6805 (CV=0.85) for redband trout in the middle segment, and ranged from 1317-4289 (CVs, 0.46-0.73) for the other species and segments (Table 4). There was direct evidence that the site-closure assumption was violated: One mountain whitefish was tagged in site Tumalo 7 and recaptured on the same day in the downstream adjacent site Tumalo 8; and one brown trout was tagged in Foley 1 site and recaptured two days later in the downstream adjacent Foley 2 site.

Table 2. PIT tagging results for salmonids (generally ≥150 mm) in the Deschutes River in 2014.

		Tagged	Recapped	Tagged Length (mm)			
Segment	Species	(N)	(N)	Mean	SD	Max	Min
Middle	Redband trout	407	7	205	44	462	140
	Brown trout	247	10	268	92	495	152
	Mountain whitefish	240	9	297	61	442	165
	Brook trout	5	0	289	99	415	160
Upper	Redband trout	31	0	241	60	446	154
	Brown trout	135	4	390	87	560	152
	Mountain whitefish	330	8	277	38	416	152

Table 3. Closed-capture models evaluated using Akaike's Information Criterion with a correction for small sample size (AICc) for three salmonid species in two segments of the Deschutes River. The best fitting model, determined by its Akaike weight, is described. No tagged redband trout were recaptured in the upper Deschutes River, which precluded modeling.

Segment	Species	Rank	Model	k	AICc	ΔAICc	Weight	Deviance	Description
Middle	Redband trout	1	p(~visit)c()	5	-2809.5	0.0	0.61	25.18	Initial capture and recapture probabilities were equal and varied by visit
		2	p(~1)c(~1)	3	-2808.4	1.0	0.36	30.25	
		3	p(~1)c()	2	-2803.7	5.7	0.03	36.95	
	Brown trout	1	p(~1)c()	2	-1350.4	0.0	0.45	19.67	Initial capture and recapture probability were equal and did not vary
		2	p(~1)c(~1)	3	-1350.1	0.3	0.38	18.00	
		3	p(~visit)c()	5	-1348.5	1.9	0.17	15.55	
	Mountain whitefish	1	p(~1)c()	2	-1324.3	0.0	0.66	17.19	Initial capture and recapture probability were equal and did not vary
		2	p(~1)c(~1)	3	-1322.8	1.6	0.30	16.76	
		3	p(~visit)c()	5	-1319.1	5.3	0.05	16.43	
Upper	Redband trout	NA	NA	NA	NA	NA	NA	NA	Small sample size and no recaptures precluded modeling
	Brown trout	1	p(~visit)c()	2	-1350.4	0.0	0.45	19.67	Initial capture and recapture probabilities were equal and varied by visit
		2	p(~1)c(~1)	3	-1350.1	0.3	0.38	18.00	
		3	p(~1)c()	5	-1348.5	1.9	0.17	15.55	
	Mountain whitefish	1	p(~visit)c()	5	-2082.8	0.0	0.8	23.06	Initial capture and recapture probabilities were equal and varied by visit
		2	p(~1)c()	2	-2079.7	3.1	0.2	32.21	
		3	p(~1)c(~1)	3	-2077.9	5.0	0.1	32.05	

Table 4. Capture probability and model averaged abundance estimates from the top closed-capture models for each salmonid species, listed by Deschutes River segment and capture occasion. No tagged redband trout were recaptured in the upper segment, which precluded estimating capture probability and abundance.

		Middle Deschutes River				Upper Deschutes River			
Species	Parameter	Estimate	SE	L: 95%	U: 95%	Estimate	SE	L: 95%	U: 95%
Redband trout	Capture occasion 1	0.012	0.005	0.006	0.028	NA	NA	NA	NA
	Capture occasion 2	0.009	0.004	0.004	0.020	NA	NA	NA	NA
	Capture occasion 3	0.011	0.005	0.005	0.024	NA	NA	NA	NA
	Capture occasion 4	0.008	0.003	0.004	0.018	NA	NA	NA	NA
	Model averaged N	6805	5814	1621	33987	NA	NA	NA	NA
Brown trout	Capture occasion 1	0.030	0.009	0.017	0.054	0.024	0.012	0.009	0.065
	Capture occasion 2	0.030	0.009	0.017	0.054	0.032	0.016	0.012	0.084
	Capture occasion 3	0.030	0.009	0.017	0.054	0.017	0.009	0.006	0.046
	Capture occasion 4	0.030	0.009	0.017	0.054	0.011	0.006	0.004	0.032
	Model averaged N	1517	1052	603	4703	1371	1003	443	5053
Mountain whitefish	Capture occasion 1	0.026	0.008	0.013	0.048	0.016	0.006	0.008	0.031
	Capture occasion 2	0.026	0.008	0.013	0.048	0.023	0.008	0.012	0.045
	Capture occasion 3	0.026	0.008	0.013	0.048	0.020	0.007	0.010	0.038
	Capture occasion 4	0.026	0.008	0.013	0.048	0.016	0.005	0.008	0.030
	Model averaged N	1952	1213	794	5496	4289	1955	2091	9215

Power simulations showed that when there is a relatively slow annual change in abundance (5%), moderately low precision in the abundance estimate (CV=0.46, as observed for mountain whitefish in the upper segment), and abundance is estimated annually, the closed-capture protocol used in this study reaches 80% power to detect a trend after 16 years of annual sampling and a cumulative population decline of 54% (Figure 4, top panel); with low precision (CV=0.85, as estimated for redband trout in the middle segment) and slow rate of change in abundance (5%), this protocol would not attain 80% power to detect a trend in the population after more than 20 years of annual abundance estimation (Figure 4, top panel). If the population were experiencing rapid annual change in abundance (20%), at moderately low and low imprecision, this protocol would achieve 80% power to detect an increasing or decreasing trend after a 74% and 89% change to the population and 7 to 11 years of annual abundance estimation, respectively (Figure 4, bottom panel).

Species occupancy modeling

The best fitting occupancy model varied among the salmonid species; for redband trout, detection varied by river segment and occupancy varied by size class (Table 5). Redband trout detection probability was 0.83 in the middle and 0.18 in upper Deschutes River (Table 6). Therefore, there was an 83% chance of detecting the species at an occupied site in the middle segment and a much lower 18% chance of detecting the species even when occupying a site in the upper segment. Even though naïve occupancy (i.e., number of occupied sites divided by number of sites sampled) of large redband trout differed between segments, taking into account sample size and imperfect detection, the modeling results suggest no statistically significant difference in the occupancy probability estimated for large redband trout (ψ=0.92, Table 6).

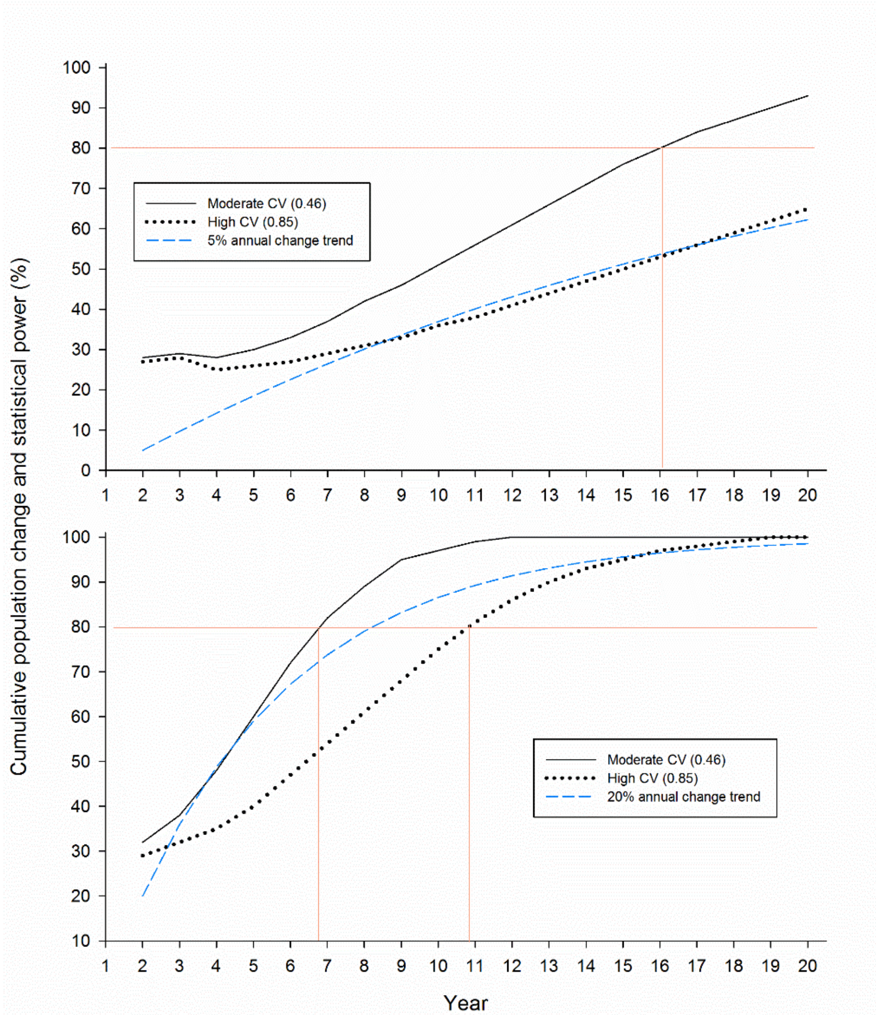

Figure 4. Simulated statistical power of the closed-capture abundance estimates to detect slow (5%, top panel) and rapid (20%, bottom panel) annual population change at moderately high (0.46) and high (0.85) coefficients of variation (CVs). CV is a relative measure of the precision of the estimated abundance; a high CV suggests a highly imprecise estimate, large confidence intervals, and low power to detect change. The effectiveness of the sampling method to detect was evaluated at 80% power (pink lines; β=0.20, Power=1-β), which is a recommended minimum in conservation monitoring.

There was an estimated 92% chance that any sample site in the Deschutes River was occupied by large redband trout. When occupancy probability is high (i.e., high naïve occupancy), there is little need to use occupancy analysis and occupancy estimates often do not converge (which is represented by NAs in Table 6), especially when sample size is small. This was the case for small redband trout, and all brown trout and mountain whitefish. For brown trout, the best fitting model suggested that detection varied by size class and occupancy varied by both size class and segment (Table 5). Detection probabilities were 0.45 and 0.72 for small and large brown trout, respectively, and naïve occupancy was high for each size class, which results in non-convergence of occupancy estimates (Table 6). Similarly, for mountain whitefish, detection and occupancy probabilities were high and occupancy estimates did not converge (Table 6). For brook trout in the middle Deschutes River, detection was very low (p=0.02) and the data were very sparse (i.e., low naïve occupancy), and model estimates did not converge to estimate occupancy (Table 6).

Table 5. Single season occupancy models evaluated using Akaike's Information Criterion with a correction for small sample size (AICc) for three salmonid species in the Deschutes River. Size class and river segment were factors. The best fitting model is determined by its Akaike weight and described.

Species	Rank	Model	k	AICc	ΔAICc	Weight	Description
Redband trout	1	p(~segment)Psi(~size)	4	321.1	0.0	0.29	Detection varied by segment; occupancy varied by size class
	2	p(~segment)Psi(~1)	3	321.9	0.8	0.19	
	3	p(~size + segment)Psi(~size)	5	322.5	1.4	0.15	
	4	p(~size + segment)Psi(~1)	4	322.9	1.8	0.12	
Brown trout	1	p(~size)Psi(~size + segment)	5	413.1	0.0	0.62	Detection varied by size class; occupancy varied by size class and segment
Mountain whitefish	1	p(~size)Psi(~1)	3	264.7	0.0	0.25	Detection varied by size class; occupancy did not vary
	2	p(~size)Psi(~segment)	4	265.5	0.8	0.17	
	3	p(~size)Psi(~size)	4	265.6	0.9	0.16	
	4	p(~size + segment)Psi(~1)	4	266.4	1.7	0.11	
	5	p(~size)Psi(~size + segment)	5	266.4	1.7	0.11	
Brook trout	1	p(~1)Psi(~1)	2	42.8	0.0	0.45	Detection and occupancy did not vary by size
	2	p(~size)Psi(~1)	3	44.0	1.2	0.24	
	3	p(~1)Psi(~size)	3	44.1	1.3	0.24	

Table 6. Detection and occupancy probabilities for each salmonid species, listed by small (<205) and large (>205) size class and middle and upper Deschutes River segments.

		Detection					Occupancy						
Species	Segment	Size	p	SE	L: 95%	U: 95%	Segment	Size	Naïve	ψ	SE	L: 95%	U: 95%
Mountain whitefish	Middle	Small	0.80	0.03	0.73	0.86	Middle	Small	1.00	NA	NA	NA	NA
		Large	0.93	0.02	0.88	0.96		Large	1.00	NA	NA	NA	NA
	Upper	Small	0.80	0.03	0.73	0.86	Upper	Small	0.95	0.99	0.01	0.91	1.00
		Large	0.93	0.02	0.88	0.96		Large	1.00	NA	NA	NA	NA
Redband trout	Middle	Small	0.83	0.03	0.77	0.88	Middle	Small	1.00	NA	NA	NA	NA
		Large	0.83	0.03	0.77	0.88		Large	0.91	0.92	0.06	0.72	0.98
	Upper	Small	0.18	0.03	0.12	0.25	Upper	Small	0.55	NA	NA	NA	NA
		Large	0.18	0.03	0.12	0.25		Large	0.50	0.92	0.06	0.72	0.98
Brown trout	Middle	Small	0.45	0.05	0.36	0.54	Middle	Small	0.91	NA	NA	NA	NA
		Large	0.72	0.03	0.65	0.78		Large	0.96	NA	NA	NA	NA
	Upper	Small	0.45	0.05	0.36	0.54	Upper	Small	0.50	NA	NA	NA	NA
		Large	0.72	0.03	0.65	0.78		Large	1.00	NA	NA	NA	NA
Brook trout	Middle (only)	Small	0.02	0.01	0.01	0.06	Middle (only)	Small	0.04	NA	NA	NA	NA
		Large	0.02	0.01	0.01	0.06		Large	0.13	NA	NA	NA	NA

Discussion

In 2014, cataraft electrofishing was used in sample sites that had also been surveyed in 2012 and 2013 in the middle and upper Deschutes River to determine current status of redband trout and other salmonids and to evaluate the effectiveness of closed-capture abundance estimation and occupancy estimation for monitoring redband trout. Sampling timing and counts of redband trout and brown trout in 2014 differed substantially between middle and upper Deschutes River segments. Despite these differences, the capture probability of large (i.e., >150 mm TL) PIT-tagged salmonids was extremely low and abundance estimates were imprecise between segments and among species. These results suggest that closed-capture abundance estimation in the large river habitats of this study area, and using this field protocol without substantial improvements, is not likely to provide a reliable monitoring protocol for tracking trend in salmonid abundance in the middle and upper Deschutes River. In contrast, occupancy estimation from 2012-2014 in the middle and upper Deschutes River resulted in more precise estimates of occupancy probability for different size classes of redband trout. This suggests that with improvements in the sampling plan and protocol, occupancy estimation may be useful to managers as a long-term monitoring protocol in tracking trends in occupancy and relative abundance of redband trout and other salmonids in the middle and upper Deschutes River.

Closed-capture abundance estimation

The capture probabilities estimated for salmonids using closed-capture methodology (0%-3.2%; i.e., p=0-0.032) were low relative to previous pilot studies conducted in the middle Deschutes River and extremely low relative to other closed capture studies of fishes in a range of fluvial habitats. In 2010 and 2012, two-visit and three-visit cataraft electrofishing was used in closed-capture pilot studies to estimate abundance of redband trout in the Foley Waters sites (Jacobsen and Jacobs 2010, Carrasco et al. 2012). These pilot studies also experienced higher but still relatively low capture probabilities, estimating that they had a 3% to 7% chance (p=0.030-0.070) of capturing or recapturing individual redband trout and resulting in imprecise abundances estimates. Monitoring studies using closed-capture methods to estimate rainbow trout abundance in larger rivers have ranged from 9% capture probability using angling as a capture method in the Kisaralik River (36 m channel width; Harper et al. 1997) to 12% to 15% using driftboat electrofishing in the Spokane River (13.3 c^3/s; Lee 2013). In a multi-year closed-capture study to estimate smallmouth bass abundance in a large river (50 to 165 m channel width) in Virginia, using boat electrofishing in the main channel and backpack electrofishing in the shallow areas, annual capture probability ranged from 11% to 57% (median, 36%; Odenkirk and Smith 2005). When closed-capture methods were used in a brown trout removal study in the relatively smaller Logan River (14 m wetted width, 3 c^3/s baseflows), capture probabilities using a canoe-mounted electrofisher were even greater (range, 29-95%; Saunders et al. 2014).

It is unclear why capture probability was so low in this study and previous closed-capture studies in the Deschutes River. There are at least three competing hypotheses that may contribute to an explanation. First, individual salmonids may be difficult to capture using cataraft electrofishing as the sole capture technique in a river the size of the Deschutes River. If trout use deeper areas and reside near the river bottom during the day, they may be out of reach of the electric field generated by the cataraft electrofisher (Grabow et al 2009). Mean channel depths are largely a function of discharge (Knighton 1998) and habitat greater than 1.5 m deep appeared to be prevalent in the study area. Second, although there was no support for the behavioral response of tagged fish to avoid the cataraft electrofisher on subsequent sampling visits, it is possible that fish were avoiding the cataraft electrofisher equally on all visits, including the initial visit. Third, violating the assumptions of the model may have contributed to estimates of low capture probability. Two tagged fish in the study were recaptured in the site downstream and adjacent to the site where they were initially captured thus violating the closure assumption. Tagged fish may have emigrated from a site for two reasons: 1) At the end of visit, the field crew released all tagged fish at the downstream end of the 300 m sample site and some of the tagged fish may not have returned upstream; and 2) some tagged fish may have had home ranges larger than the sites themselves and had some chance of temporarily emigrating from a site during the survey season (Gwinn et al. 2011). Other assumptions that may have been violated included tag loss (which was not estimated through double-tagging) or missed tags through inadequate scanning of captured fish with the PIT tag reader; both of which would reduce capture probability. One or more of these hypotheses may be at least partially true and they highlight the challenges of using closed-capture methods in areas like the Deschutes River.

Temporary emigration, as noted above, may have contributed to low capture probability and violated the site-closure assumption, which would lead to a bias toward overestimating abundance. To reduce the probability of temporary emigration occurring or at least minimizing its bias on estimates, occupancy and closed-capture sampling should coincide when the species is phenologically most likely to display sedentary behavior or the shortest home ranges. Even during this part of the species phenology, some individuals may have a home range that extends outside of an individual sample site and some individuals, while moving within their home range, become temporarily invulnerable to sampling when they move out of a site. Increasing the site length can reduce bias from temporary emigration in two ways: 1) It can increase the chance that the home range of more individuals will be encompassed by the sample area, and 2) it can reduce the proportion of edge (i.e., channel width), where fish can move in and out of the sampling area, to interior area (Gwinn et al. 2011). In a simulation using Murray cod (*Maccullochella peelii*) and their known home ranges in a large river in Australia, Gwinn et al. (2011) estimated that to achieve an acceptable abundance estimate using four site visits during a survey season, sample sites would have to be at least 1400 m long. They defined an abundance estimate as acceptable when its coefficient of variation ($CV=100*SE/\widehat{N}$), a measure of the estimate's precision, was ≤25%. Home range length, temporary emigration rates, and the ideal site length are currently not known for redband trout in systems like the Deschutes River. However, to reduce the chance of temporarily losing tagged individuals from a site, sample sites in 2014 were lengthened to 300 m (a 50% increase relative to 2012 and 2013 seasons) in both segments of the Deschutes River. The CVs for close capture abundance estimates in 2014 ranged from 46% for mountain whitefish in the upper Deschutes River to 85% for redband trout in the middle segment. The low precision of the estimates suggest that the sampling protocol used in this study did not produce estimates reliable enough to track trend in abundance in this study area.

This monitoring project has been evaluating the effect of survey timing on capture probability, detection, and occupancy. In 2013, the detection probability of redband trout in the middle Deschutes River was more than four times higher during August sampling than during November sampling, but there was little support for a difference in detection for redband trout between September and October sampling efforts in the upper segment (Starcevich et al. 2015).

In the upper Deschutes River in 2014, sampling was conducted in March and April to evaluate another survey season. The March-April survey season in the upper segment experienced sharp reductions in the number of trout captured relative to both the previous year and the August 2014 survey season in the middle segment. Relative to 2013, counts of wild and hatchery redband trout and brown trout dropped by >80% in the upper segment and mountain whitefish counts remained the same, despite sampling sample sites that were 50% longer in 2014. In contrast, counts in the middle segment in 2014 almost doubled for brown trout and mountain whitefish and more than quadrupled for redband trout, which would be expected given the increase in site length. Relatively low numbers of fish tagged and no redband trout recaptured in the upper Deschutes River may have been related in part to the timing of the sampling, which occurred during the peak of redband trout spawning (NPCC 2004). Adults (≥150 mm TL) may have been more likely to move since they may have been searching for mates and spawning habitat or had already begun spawning. The distribution and abundance of high-quality spawning habitat in the upper Deschutes River is not well known, but these areas are likely rare and patchily distributed because of specific substrate, depth, velocity, and water temperature characteristics needed for redd construction and embryo incubation (Quinn 2005). The study sites encompassed only 6% of the upper Deschutes River; if spawning habitat were indeed rare and patchily distributed, there would be a low probability spawning habitat and adult fish would be present within the area sampled during the spawning season. These results, and results from 2012-2013 sampling, suggest that future closed-capture or occupancy monitoring protocols should limit sampling to July through September in the middle and upper Deschutes River.

Low capture probability and low precision of abundance estimates strongly suggest that, if closed-capture methods are to be used for estimating abundance in future monitoring, substantial changes to the protocol used in this study will be needed to maximize the probability of capturing individual fish present in a given site. These include larger sample sites and more visits during a survey season (Gwinn et al. 2011), using alternative or additional gear types to which the target species or size class is more vulnerable (Grabow et al. 2009), improve capture efficiency using radio-tagged fish as guides (Grabow and Jennings 2009), and limit sampling to July-September. Additionally, logistical constraints prevented cataraft access from long sections of the Deschutes River. This in part led to a sample size that was small and not spatially balanced within the study area, which potentially decreased the representativeness of the study. For greater representativeness, more study sites should be added and different gear types or sampling methods should be used in those areas not accessible to the cataraft. These changes likely imply an increase in time and effort in the field and greater costs of the monitoring protocol.

Occupancy estimation

The extra time and cost required and often imprecise estimates produced by closed-capture methods have led some to suggest shifting the focus of status assessment and monitoring to species occupancy (MacKenzie et al. 2006). In the middle and upper Deschutes River, all three salmonid species were highly likely to occupy any given sample site in the surveys conducted by this project from 2012 to 2014, which generally suggests these species were common in the middle and upper Deschutes River. However, in 2012 and 2013, large redband trout (i.e., >250 mm) were in low abundance and occupancy relative to large brown trout and mountain whitefish (Starcevich et al. 2015), which was a management concern because redband trout were thought to be historically abundant and provided an important recreational fishery in the upper Deschutes

River. In 2014, large redband trout in the upper segment were again low in abundance, low in naïve occupancy, and displayed low detection probabilities relative to large brown trout and mountain whitefish. Sampling timing in 2014 likely affected these results (see discussion above); nevertheless, the 2014 results are consistent with relatively low numbers of large redband trout in the upper segment.

There was relatively high precision of occupancy estimates for redband trout in both the middle and upper Deschutes River (mean CV, 13%; range, 1-33%). This suggests that occupancy estimation may be a useful tool for tracking trend in occupancy of redband trout and other salmonids, thereby alerting managers to concerns such as low occupancy and relative abundance of catchable redband trout in the upper segment. Tracking trend in occupancy as a long-term monitoring protocol is a more difficult endeavor because it requires maximizing precision of the estimate so that there is acceptable power to detect an existing trend. Several improvements have been discussed above for closed-capture abundance estimation that also apply to occupancy estimation. Greater effort (e.g., more sample sites and visits, additional gear types) and sampling from July-September are needed to improve detection probabilities for large salmonids, especially for large redband trout. Improved detection would improve the precision of occupancy estimates and the power to detect trend. There is a need to improve survey access to a greater proportion of the study area so that the results are more likely to be representative of the target study area. Furthermore, the extremely low capture probabilities for large salmonids observed in this study suggests the need for an evaluation of how fish respond to cataraft electrofishing in large river habitats and an assessment of the degree to which the protocol meets the statistical assumption that sample sites are closed to changes in occupancy in repeated visits during the survey season.

Future research

In 2015, the final year of this study, a sampling design and field protocol that differs substantially from those used in 2012-2014 and eliminates the need for active demographic closure or closure to changes in occupancy at sample sites will be evaluated. The 2015 protocol will focus sampling on early rearing areas (e.g., margins, side channels, off-channel habitats) and sampling without replacement (i.e., spatial replicates within a site) to relax the closure requirement and also provide information on spawning and early rearing habitat and distribution (Starcevich et al. 2015). Emerging techniques in genetic assessment and monitoring that focus sampling on more easily-accessed juvenile rearing areas (i.e., river margins and edge habitats: Moore and Gregory 1988a, 1988b; Muhlfeld et al. 2001) have been used to estimate effective population size and effective number of breeders of trout, salmon, and other animals (Waples and Do 2010, Whiteley et al 2011, Allendorf et al. 2013;) and may be useful as a long-term monitoring protocol for redband trout in the middle and upper Deschutes River.

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