Matthew G. Mitro
Alexander V. Zale

Use of Distance Sampling to Estimate Rainbow Trout Redd Abundances in the Henry's Fork of the Snake River, Idaho

Abstract

Distance sampling was used, as an alternative to a traditional census, to sample large-scale areas of the Henry's Fork of the Snake River, Idaho, for rainbow trout (Oncorhynchus mykiss) *redds. Replicate transects perpendicular to flow were traversed by a combination of wading and snorkeling. Perpendicular distances from transects to detected redds were "sampled" and these data were analyzed using the computer program DISTANCE to estimate redd detectability and density. Distance sampling provided an unbiased approach to sampling large-scale areas in a river for redds and was robust to changes in detectability. As discharge in the Henry's Fork increased between sampling dates, detectability of redds decreased, and most observations were closer to the transects. The effective area sampled was smaller, but an increase in redd density was observed, indicating increased spawning activity and demonstrating the robustness of distance sampling to changes in detectability. Spawning activity in the Henry's Fork prior to the installation of the Buffalo River fish ladder in October 1996 was concentrated in the area between Island Park Dam and the United States Geological Survey gauging station; only one redd was detected in Last Chance, and no spawning activity was detected in Box Canyon and Harriman State Park. Relatively little spawning activity was detected in the Henry's Fork in 1997, when spawning fish had access to the Buffalo River.*

Key words: Distance sampling, Henry's Fork, rainbow trout, redds, spawning.

Introduction

Redds are spawning nests of salmonids constructed by digging a depression in gravel substrate, depositing eggs, and covering the eggs with loose gravel. Redd counts are typically conducted to identify spawning areas, to confirm that spawning has occurred, and to count the total number of redds present in an area. Redd counts are usually obtained by censusing an area or stream, and it is generally assumed that all redds are detected. A redd census may be conducted on foot or by canoe in small streams (e.g., Beland 1996) or by aerial observation in larger streams (e.g., Heggberget *et al.* 1986). However, it may be unreasonable to assume that all redds can be detected, especially when searching large areas. Censusing may yield biased results if some redds remain undetected.

Distance sampling (Buckland *et al.* 1993) can be used to systematically search a large area of interest and to obtain an abundance estimate of objects within that area. Distance sampling theory allows for the detectability of objects to decrease as the distance of the

Matthew G. Mitro, Montana Cooperative Fishery Research Unit, U.S. Geological Survey, Department of Ecology, Montana State University, Bozeman, MT 59717
Alexander V. Zale, Montana Cooperative Fishery Research Unit, U.S. Geological Survey, Department of Ecology, Montana State University, Bozeman, MT 59717

object from a line transect increases (Buckland *et al.* 1993). Therefore, objects can remain undetected without undermining the validity of the estimate. Perpendicular distances from a transect to a detected object are "sampled," and the distances are modeled so that detectability and density can be estimated. As distance from the transect increases, detectability decreases, allowing estimation of the effective area sampled. The use of distance sampling has received little attention in the study of fish populations (for exceptions see Bergstedt and Anderson 1990, Ensign *et al.* 1995). Distance sampling has not been used in the estimation of redd abundance, although it appears to be well suited to this problem. Three assumptions necessary for reliable estimation from line transect sampling are: 1) objects on a transect are detected with certainty; 2) objects are detected at their initial location before any movement in response to the observer; and 3) distances between objects and the transect are measured accurately (Buckland *et al.* 1993). It is reasonable to assume that redds on a transect will be detected with certainty. Redds are immobile objects; therefore, redds detected off a transect will be detected in their initial location, and the distance from a transect to a redd can be measured accurately. We used distance sampling to identify rainbow trout (*Oncorhynchus mykiss*) spawning areas in study sections of the Henry's Fork of the Snake River, Idaho, and to quantify spawning activity therein.

Study Area

We divided the Henry's Fork from Island Park Dam to Osborne Bridge into the following five sections for sampling rainbow trout redds: 1) Island Park Dam to the United States Geological Survey (USGS) gauging station (length [L] = 250 m, mean width [$\overline{w}$] = 56 m); 2) USGS gauging station to the Buffalo River (L = 350 m, $\overline{w}$ = 42 m); 3) Box Canyon (L = 4 km, $\overline{w}$ = 70 m); 4) Last Chance (L = 4 km, $\overline{w}$ = 95 m); and 5) Harriman State Park (L = 8 km, $\overline{w}$ = 125 m) (Fig. 1).

The Buffalo River joins the Henry's Fork about 0.6 km downstream of Island Park Dam (Fig. 1). A dam at the mouth of the Buffalo River prevented upstream migration of rainbow trout, except during spring runoff, prior to the installation of a fish ladder in October 1996. The river section from Island Park Dam to the Buffalo River has a gradient of 0.3 percent, with boulder substrate in the thalweg and gravel substrate in the adjacent shallow areas; a larger gravel-substrate area lies upstream of the USGS gauging station. Box Canyon has a high gradient (0.45%) with cobble-boulder substrate and Last Chance has an intermediate gradient (0.3%) with cobble substrate. Harriman State Park has a low gradient (0.1%) with a highly embedded sand-gravel substrate.

Methods

The first spawning activity of each spring season in each river section was verified by digging into suspected redds until eggs were found. Thereafter, we identified depressions in the substrate as redds based on characteristics that included a decreasing gravel size-gradient from the redd pit through the redd tail, gravel in a redd that was cleaned of periphyton compared to surrounding gravel, and gravel in a redd pit-area that was loose to the touch.

We searched for redds along multiple transects in each river section. Transects were parallel to one another and perpendicular to flow. A grid of equally-spaced transects was randomly positioned in each river section, thereby constituting a systematic sample design (Buckland *et al.* 1993). We recorded each transect length (m) and the locations of redds on either side of each transect to estimate the effective area sampled and the density of redds. Locations of redds

Figure 1. *Study sections of the Henry's Fork searched for rainbow trout redds: 1) Island Park Dam to the U.S. Geological Survey (USGS) gauging station; 2) USGS gauging station to the Buffalo River; 3) Box Canyon; 4) Last Chance; and 5) Harriman State Park. Lines with end-caps represent dams, dashed lines represent river-section boundaries, and parallel lines denote a bridge.*

were identified by perpendicular distance (m) from the transect to the redd center.

We estimated redd densities from distance sampling data using the computer program DISTANCE (Laake *et al.* 1994). Density (D) is equal to the number of redds observed (n) divided by the area searched (a) when sampling strips of known width $2w$ and length L, i.e., $a=2wL$; thus,

$$\hat{D} = n / 2wL$$

(Buckland *et al.* 1993). An unknown proportion P_a of redds was detected in a given area in our study using distance sampling. If P_a is estimated from the distance data, then

$$\hat{D} = n / 2wL\hat{P}_a.$$

The product $w\hat{P}_a$ equals the effective strip width, where w equals the distance to the furthest observed redd. The expected value of the number of objects—all detected—out to the effective strip width on either side of the transect equals the number of objects detected in an actual survey with no predefined strip width. The unconditional probability P_a of detecting a redd is estimated by

$$\hat{P}_a = \frac{\int_0^w g(x)dx}{w},$$

where $g(x)$ is a function of the distance data. By substitution, the estimator for density then becomes

$$\hat{D} = \frac{n}{2L\int_0^w g(x)dx}.$$

The integral is related to the probability density function, $f(x)$, of the distance data by

$$f(x) = \frac{g(x)}{\int_0^w g(x)dx}.$$

The density function $f(x)$ is identical in shape to the detection function $g(x)$. The integral is then estimated by rescaling under the assumption of certainty of detection on the line (i.e., $g(0)=1$) so that

$$f(0) = \frac{1}{\int_0^w g(x)dx}.$$

Therefore, the density estimator is expressed in terms of an estimated probability density function evaluated at zero. The estimator for density is now

$$\hat{D} = \frac{n \cdot \hat{f}(0)}{2L} = \frac{n}{2L\int_0^w \hat{g}(x)dx}$$

(Buckland *et al.* 1993). An estimate of the total number of redds in a section was obtained by extrapolating the estimate of density across the total area within the section.

The detection function $g(x)$ was selected from a series of models comprising a key function and a series expansion (Buckland *et al.* 1993). The key function may be uniform (no parameters), half-normal (one parameter), or hazard-rate (two parameters). The series expansion adds one or two parameters to the model and is used to adjust the key function to improve the fit of the model to the distance data. Series expansions include cosine series, simple polynomials, and Hermite polynomials. For small sample sizes, the key function alone may be adequate (Buckland *et al.* 1993). We selected the key function and series expansion using a combination of likelihood ratio tests, goodness of fit tests, and Akaike's information criteria.

Distance sampling was conducted once in 1995 from Island Park Dam to the Buffalo River, in Box Canyon, and in Last Chance. The section between Island Park Dam and the USGS gauging station was sampled on four dates in 1996 and on six dates in 1997. Last Chance and Harriman State Park were each sampled once in 1997. We sampled 10-15 transects on each date in sections between the dam and the Buffalo River and 20 transects on each date in the remaining sections. We also searched for redds along alternating sides of the river between transects on each sampling date in Box Canyon, Last Chance, and Harriman State Park to verify that near the banks, transects were representative of sections, i.e., that near the banks, there were not many more or many less redds between transects than on or near the transects.

Results

Rainbow trout spawning activity was concentrated in the section between Island Park Dam and the USGS gauging station on sampling dates in 1995 and 1996 and was limited in other sections. Spawning was limited in all sections of the Henry's Fork on sampling dates in 1997.

Twenty-two redds were observed on 27 April 1995 between the dam and the

USGS gauging station, yielding an estimate of 28 redds (95% confidence interval (CI), 12-67; Table 1). Detection function model specification, encounter rate, and effective strip width appear in Appendix A. The discharge was 17.0 m^3/s. Redds were scattered throughout the shallow areas adjacent to the thalweg. There was an insufficient number of redd observations in the other sampled sections to estimate redd density using program DISTANCE (Table 2). One redd was observed near the west bank between the USGS gauging station and the Buffalo River on 27 April and one redd was observed near the east bank in Last Chance on 18 April. No redds were observed in Box Canyon on 17 April and no redds were observed along alternating sides of the river between transects in Box Canyon and Last Chance.

Table 1. *Estimates of redd abundance ($\hat{N}$) and 95 percent confidence intervals (CI) in the Henry's Fork from Island Park Dam to the United States Geological Survey gauging station (13,750 m^2) in 1995, 1996, and 1997. Estimates were obtained using the computer program DISTANCE; effort equaled the sum of transect lengths; ne = no estimate.*

Date	Transects	Effort (m)	Observed redds	$\hat{N}$	95% CI
		1995			
27 Apr	13	716.7	22	28	[12, 67]
		1996			
30 Mar	10	537.5	2	ne	ne
9 Apr	10	520.6	6	12	[3, 44]
14 Apr	10	551.0	11	11	[4, 30]
21 Apr	10	575.0	9	16	[6, 42]
		1997			
11 Mar	10	565.0	0	ne	ne
31 Mar	10	579.0	1	ne	ne
6 Apr	10	608.5	1	ne	ne
13 Apr	15	839.0	0	ne	ne
18 Apr	11	660.5	1	ne	ne
19 Apr	11	606.0	1	ne	ne

There was an increasing trend in the total number of redds between Island Park Dam and the USGS gauging station between 30 March and 21 April 1996 (Table 1). An estimate could not be obtained for 30 March because only two redds were observed. The maximum number of redds observed was 11 on 14 April, yielding an estimate of 11 redds (95% CI, 4-30). Visibility was reduced by 21 April because of an increase in discharge to 19.7 m^3/s from 16.0 m^3/s on 14 April; 9 redds were observed, yielding an estimate of 16 redds (95% CI, 6-42) (Table A.1). Thereafter, it was not feasible to wade or snorkel to sample redds because of an additional increase in discharge.

Table 2. *Summary statistics for sampling of redds in the Henry's Fork from the United States Geological Survey (USGS) gauging station to Harriman State Park. Effort equaled the sum of transect lengths; additional effort included the section length for observations made along banks between transects.*

Section	Date	Area (m^2)	Transects	Effort (m) (additional)	Observed redds
USGS gauging station to Buffalo River	27 Apr 1995	14,700	10	421.5	1
				(350)	(0)
Box Canyon	17 Apr 1995	270,000	20	1,394	0
				(4,000)	(0)
Last Chance	18 Apr 1995	336,800	20	1,946	1
				(4,000)	(0)
	20-21 Apr 1997		20	1,820	0
				(4,000)	(0)
Harriman State Park	21 Apr 1997	1,013,000	20	2,532	0
				(8,000)	(0)

An increasing trend in the total number of redds between Island Park Dam and the USGS gauging station was not observed between 11 March and 19 April 1997 (Table 1). Discharge was 26.2 m^3/s on 11 March and about 21.3 m^3/s from 31 March to 19 April. One redd was first observed on 31 March and no additional redds were identified thereafter. No redds were observed in Last Chance on 20-21 April or in Harriman State Park on 21 April (Table 2); no redds were observed along alternating sides of the river between transects. Visibility was reduced because of an increased discharge by the last week of April 1997, and wading or snorkeling to sample redds thereafter was not feasible.

Discussion

Distance sampling was particularly useful for sampling large-scale areas such as Box Canyon, Last Chance, and Harriman State Park, where a traditional census was not feasible. This method provided an objective approach to searching large-scale areas for spawning activity and quantifying spawning activity therein. Distance sampling is not useful for sampling redds in small tributaries and streams because of their narrow width. For example, a stream 5-m wide can usually be adequately searched from the bank and a census taken while walking along the stream length would be more efficient and likely more accurate than a distance-sampling approach.

A ground-based method of searching for redds in the Henry's Fork was necessary because trumpeter swans (*Cygnus buccinator*) left depressions in the substrate after feeding on macrophytes, and the depressions could be mistaken for redds when viewed from far away, e.g., from an airplane. Distance sampling provided an unbiased approach to identifying spawning areas and to quantifying spawning activity therein. Traditional redd counts are not robust to changes in detectability and therein lies the advantage of distance sampling: detectability can change without affecting the validity of the estimates.

The robustness of distance sampling to changes in detectability was demonstrated when sampling the river section between Island Park Dam and the USGS gauging station on multiple dates in 1996. As discharge increased between sampling dates, the distance at which redds could be detected from a transect decreased. Consequently, fewer redds were detected for a given number of transects. However, the shorter distances of detected redds from transects indicated an increase in redd density and hence an increase in spawning activity. A traditional redd count would have required more effort to detect an increase in spawning activity given the decrease in detectability, and the increase in spawning activity may not have been observed if redds remained undetected.

The detectability of redds may depend on stream discharge and light conditions. Increased discharge may decrease the distance at which redds can be detected from a transect. Distance sampling is robust to this situation provided that redds on a transect are still detected with certainty (Buckland *et al.* 1993). Light may affect visibility by creating a glare on the water surface. If a glare occurs on one side of the transects, observations will be asymmetric about the transects, but estimation will not be adversely affected (Buckland *et al.* 1993). If a glare occurs in the direction a transect is being traversed, the observer can turn around and look back to make observations (Buckland *et al.* 1993).

A random and independent distribution of redds is not required for distance sampling if the transects are randomly located in a river section or if a systematic grid of transects in a river section begins with a random first start (Buckland *et al.* 1993). Therefore, it is important that transects extend from bank to bank perpendicular to the current such that transects are representative of river habitat across a channel. If redds are clustered along a bank, transects that follow the bank will overestimate redd abundance when used to make inference on the river as a whole. However, we do think it is useful to search for redds while moving along the bank from one transect to the next. This additional information cannot be used to calculate redd density, but it can be used to judge the effectiveness of a systematic sampling grid at representing a river section. For example, no redds were observed between transects in Box Canyon, thereby supporting the assumption that the transects were representative of Box Canyon where no redds were observed on or near the transects.

An estimation problem encountered in this study was small sample size, which led to large confidence intervals on abundance estimates. Buckland *et al.* (1993) suggest a minimum sample size of 60 to 80 detected objects; our largest sample was 22 redds. However, the distance sampling assumptions were satisfied and the approach to estimation was valid. Confidence intervals for abundance estimates also had lower bounds less than the actual number of distinct redds observed. Program DISTANCE computes confidence intervals based on the $\log_e$ approach of Burnham *et al.* (1987), but unlike the $\log_e$ approach used to construct intervals for mark-recapture and removal estimates of abundance, intervals constructed in DISTANCE do not guarantee lower bounds equal to or greater than the number of objects observed.

There was an increasing trend in spawning activity in the river section between Island Park Dam and the USGS gauging station from 30 March to 21 April 1996. This trend was not observed in 1997. Installation of the Buffalo River fish ladder in October 1996 provided access to spawning areas in the Buffalo River in spring 1997 that were previously inaccessible to rainbow trout in the Henry's Fork prior to spring runoff. Spawning rainbow trout that may have formerly used the area near Island Park Dam could have spawned in the Buffalo River instead. Van Kirk and Giese (1999) reported that 224 rainbow trout greater than 400 mm total length migrated upstream through the fish ladder during spring 1997 prior to runoff. Access to the Buffalo River via the fish ladder could change long-term trends in redd numbers in the Henry's Fork. Future studies should investigate the use of the Buffalo River by rainbow trout for spawning. The distance sampling approach evaluated in this study is suited for identifying spawning areas in the Buffalo River and quantifying spawning activity therein.

We identified the area between Island Park Dam and the USGS gauging station as the primary rainbow trout spawning site in the Henry's Fork proper. It was not possible to quantify the number of redds produced in the Henry's Fork during the entire spawning season because spawning coincided with spring runoff, thereby making it difficult to find redds. Although relatively few redds were observed in the Henry's Fork, estimates of age-0 rainbow trout abundance indicated that spawning and production were not limiting factors in recruitment (Mitro 1999).

Acknowledgements

This study was supported by a grant from the Idaho Department of Fish and Game. We thank Mark Gamblin and Bruce Rich of the Idaho Department of Fish and Game for their logistic support and general facilitation of this study. We thank the following individuals for their field assistance: Richard Dykstra, James Gregory, Richard Henderson, Gregory Pavellas, Stan Van Sickle, Brian Vaughn, and

Eldon Volk. The Montana Cooperative Fishery Research Unit is jointly sponsored by the U.S. Geological Survey, Montana State University, and the Montana Department of Fish, Wildlife, and Parks. The senior author's current address is: U. S. Environmental Protection Agency, Atlantic Ecology Division, 27 Tarzwell Dr., Narragansett, RI 02882.

Literature Cited

Beland, K. F. 1996. The relation between redd counts and Atlantic salmon (*Salmo salar*) parr populations in the Dennys River, Maine. Can. J. Fish. Aquat. Sci. 53:513-519.

Bergstedt, R. A., and D. R. Anderson. 1990. Evaluation of line transect sampling based on remotely sensed data from underwater video. Trans. Am. Fish. Soc. 119:86-91.

Buckland, S. T., D. R. Anderson, K. P. Burnham, and J. L. Laake. 1993. Distance sampling: estimating abundance of biological populations. Chapman and Hall, London.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society, Monograph 5, Bethesda, MD.

Ensign, W. E., P. L. Angermeier, and C. A. Dolloff. 1995. Use of line transect methods to estimate abundance of benthic stream fishes. Can. J. Fish. Aquat. Sci. 52:213-222.

Heggberget, T. G., T. Haukebo, and B. Veie-Rosvoll. 1986. An aerial method of assessing spawning activity of Atlantic salmon, *Salmo salar* L., and brown trout, *Salmo trutta* L., in Norwegian streams. J. Fish Biol. 28:335-342.

Laake, J. L., S. T. Buckland, D. R. Anderson, and K. P. Burnham. 1994. DISTANCE User's Guide V2.1. Colorado Fish and Wildlife Research Unit, Colorado State University, Fort Collins.

Mitro, M. G. 1999. Sampling and analysis techniques and their application for estimating recruitment of juvenile rainbow trout in the Henry's Fork of the Snake River, Idaho. Dissertation, Montana State University, Bozeman.

Van Kirk, R., and K. Giese. 1999. Angler effort and catch on the Buffalo River during 1998 and effects of the Buffalo River fish ladder on the Box Canyon rainbow trout population. Report to Idaho Fish and Wildlife Foundation, Boise, ID. Department of Biological Sciences, Idaho State University, Pocatello.

Appendix A

Table A.1. *Detection function model, value of probability distribution function at 0 for the detection function* (f(0))*, probability of observing a redd in a river section* (p)*, effective strip width (ESW), and redd encounter rate* (n/L *or number per total length of transects sampled) for 1995 and 1996 sampling in the river section between Island Park Dam and the United States Geological Survey gauging station.*

	Mean	95% Confidence interval
	27 April 1995	
Model	Half-normal/no series expansion	
f(0)	0.133	[0.086—0.204]
p	0.660	[0.429—1]
ESW	7.5 m	[4.9—11.6]
n/L	0.031	[0.014—0.068]
	9 April 1996	
Model	Half-normal/no series expansion	
f(0)	0.150	[0.068—0.333]
p	0.803	[0.362—1]
ESW	6.7 m	[3.0—14.8]
n/L	0.012	[0.003—0.040]
	14 April 1996	
Model	Half-normal/no series expansion	
f(0)	0.080	[0.042—0.153]
p	1	[0.523—1]
ESW	12.5 m	[6.5—23.9]
n/L	0.020	[0.008—0.050]
	21 April 1996	
Model	Half-normal/no series expansion	
f(0)	0.150	[0.072—0.314]
p	0.900	[0.430—1]
ESW	6.7 m	[3.2—13.9]
n/L	0.016	[0.007—0.033]