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Using Mark-Recapture Methods to Estimate Fish Abundance in Small Mountain Lakes

Abstract

The majority of lacustrine fish populations in the western USA are located far from the nearest road. Although mark-recapture techniques are widely accepted for estimating population abundance, these techniques have been broadly ignored for fisheries surveys in remote mountain lakes because of restricted access and associated logistical constraints. In this study, mark-recapture experiments were used to estimate fish population abundance in nine small (< 7 ha) lakes of the North Cascades National Park Service Complex. Fish in the mark sample were collected by angling, fin-clipped, and immediately released; fish were recaptured with variable mesh monofilament gill nets. A single-census Petersen estimator was used to calculate abundance in each lake, and assumptions for unbiased estimates appeared to be satisfied in most cases. Post-release mortality of angler-captured fish was low. The small size of these lakes in conjunction with the brief period of time allotted for each individual experiment apparently reduced the probability of unequal vulnerability and mortality for marked and unmarked fish. Single-census mark-recapture experiments appeared to provide reasonable estimates of population abundance in these mountain lakes. Resulting estimates furnish a substantial increase in information when compared to more ubiquitous assessments of relative abundance, but the logistical requirements are modest. We believe that this technique may useful for survey purposes in other small, remote lakes.

Introduction

Estimates of trout population abundance are often difficult to obtain in lakes located in remote, high elevation areas of the western USA. Fishery managers are frequently required to survey numerous lakes with limited personnel over a relatively short field season. An individual sampling visit to a lake is often of short duration, and there are considerable logistical problems in transporting cumbersome sampling gear. Typically, the status of fish populations in mountain lakes is assessed by gillnetting to obtain estimates of age and size structure and growth, and to provide an index of relative abundance. Although mark-recapture techniques are widely accepted for estimating population abundance, these techniques have been broadly ignored for fisheries surveys in remote mountain lakes because of restricted access and associated logistical constraints.

The purpose of this paper is to describe an application of mark-recapture techniques for assessing trout abundance in small lakes and discuss the general suitability of the method in isolated mountain environments. Angling and gill nets were used to collect fish for mark and recapture samples, and therefore, the method requires a limited number of personnel, an abbreviated sampling period, and easily transported sampling gear.

Methods

Fish population abundance was estimated in nine lakes of the North Cascades National Park Service Complex (NOCA) located in northern Washington, USA. All of the study lakes are relatively small (< 7 ha) and shallow (maximum depth < 10 m). Seven of the study lakes supported reproducing populations of cutthroat trout (*Oncorhynchus clarki*) or rainbow trout (*Oncorhynchus mykiss*). Trout in the other two lakes did not reproduce naturally, and the lakes were stocked with cutthroat trout fry (Liss et al. 1995).

Population abundance was estimated by mark-and-recapture. Fish in the mark sample were collected by angling with barbless lures and flies. Sampling was *direct* (i.e., governed by fishing success; Ricker 1975). Prior to release, individuals were marked by removing the adipose fin or part of the caudal fin (upper or lower tip). To reduce handling time, fish in the mark sample were not measured prior to release. Angling occurred from the shore along the entire perimeter of most lakes and from an inflatable boat; this procedure helped

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to insure mixing of marked and unmarked fish throughout the lake. Injured fish (e.g., those bleeding from gills or tongue) were either released unmarked or sacrificed. Two groups (12 fish in each) were held overnight in enclosures to estimate post-release mortality due to capture and marking.

Fish were recaptured with variable-mesh monofilament gill nets. With one exception, nets were 42 m long with 10.5 m panels of 12.5, 18.5, 25, and 33 mm bar mesh; at Upper Triplet Lake (1991) nets were 34 m long with 11.3 m panels of 13.5, 18.5 and 25 mm bar mesh. Nets were usually set at random locations the day after marking was completed. To minimize reduction in capture efficiency, nets were checked frequently so that fish did not accumulate. Overnight sets were checked the following morning. During recapture sampling net locations were changed often.

Because size-selectivity often varies depending on sampling gear (Ricker 1975), a comparison of mean lengths from fish captured by angling and in gill nets was desired. Results were used to determine the segment of the population to which the abundance estimate applied. Marked fish were not measured prior to release, and therefore, the length distribution of *marked fish* in a pooled recapture sample (from all lakes) was used to represent size distribution for fish captured by angling. Subsequently, recapture samples for individual lakes were partitioned by fish length, and population estimates were limited to size categories encompassed by the pooled sample of marked fish.

A single-census Petersen estimator ($N = (M+1)(C+1)/(R+1)$; Ricker 1975) was used to estimate abundance in each lake. Sampling variance was estimated using Chapman's approximation ($V(N) = N^2(C-R)/(C+1)(R+2)$; Ricker 1975), and coefficient of variation was estimated according to Seber (1982) ($C(N)= 1/(((M*C)/N)^{1/2})$). Upper and lower confidence limits were calculated with Poisson approximations to the hypergeometric distribution (Ricker 1975). Procedures assumed that the proportion of recaptured fish was binomially distributed (equivalent to Poisson distribution of recaptured fish for a given number marked). Individual fish were assumed to behave independently with a constant probability of capture. Equal probability of capture was also assumed for marked and unmarked fish.

Results

Because fish captured by angling were not measured prior to release, the lengths of recaptured fish (R) were used to estimate the size range of fish in the mark sample. Differences were evident in the length-frequency distributions of all fish in the recapture sample and recaptured fish (R) alone (Figure 1). Mean lengths were 209 and 235 mm for all fish sampled and recaptured fish, respectively; the difference was statistically significant (ANOVA; $p < 0.01$). Apparently, angling selected for larger fish than gillnetting, and therefore, abundance estimates were partitioned by fish length so that the assumption of equal probability of capture for marked and unmarked fish would not be violated. Few fish < 170 mm were recaptured in any lake (Figure 1), and in lakes without fish reproduction, fish < 200 mm were infrequent; therefore, estimates for all fish, fish > 170 mm, and fish > 200 mm were calculated separately and compared.

In many lakes estimates for all fish in the population and those restricted to fish > 170 mm (Table 1) did not differ substantially. Smaller fish were apparently underrepresented in both gill-net and angling samples, and thus, mark-recapture estimates underestimated abundance of all fish in reproducing populations. Limiting comparisons to fish > 200 mm substantially reduced abundance estimates when compared to estimates for all fish and for fish > 170 mm. Although confidence intervals were smaller when population estimates were restricted by fish length, statistical bias (because of small sample size; Robson and Regier 1964) occurred in estimates of fish > 200 mm, and sampling variation (as measured by coefficient of variation) increased (Table 1). Therefore, using estimates for fish > 170 mm appeared to provide the most appropriate comparisons of fish abundance among lakes in this study.

Post-release mortality in the two overnight experiments was low. Only 1 of 24 fish died, and that individual was bleeding from the gills when placed in the holding area. Injured fish were not marked at any of the lakes in this study.

Discussion

Using angling and gill-net collections for mark-recapture estimates of fish in remote small lakes had several advantages. At each lake, sampling

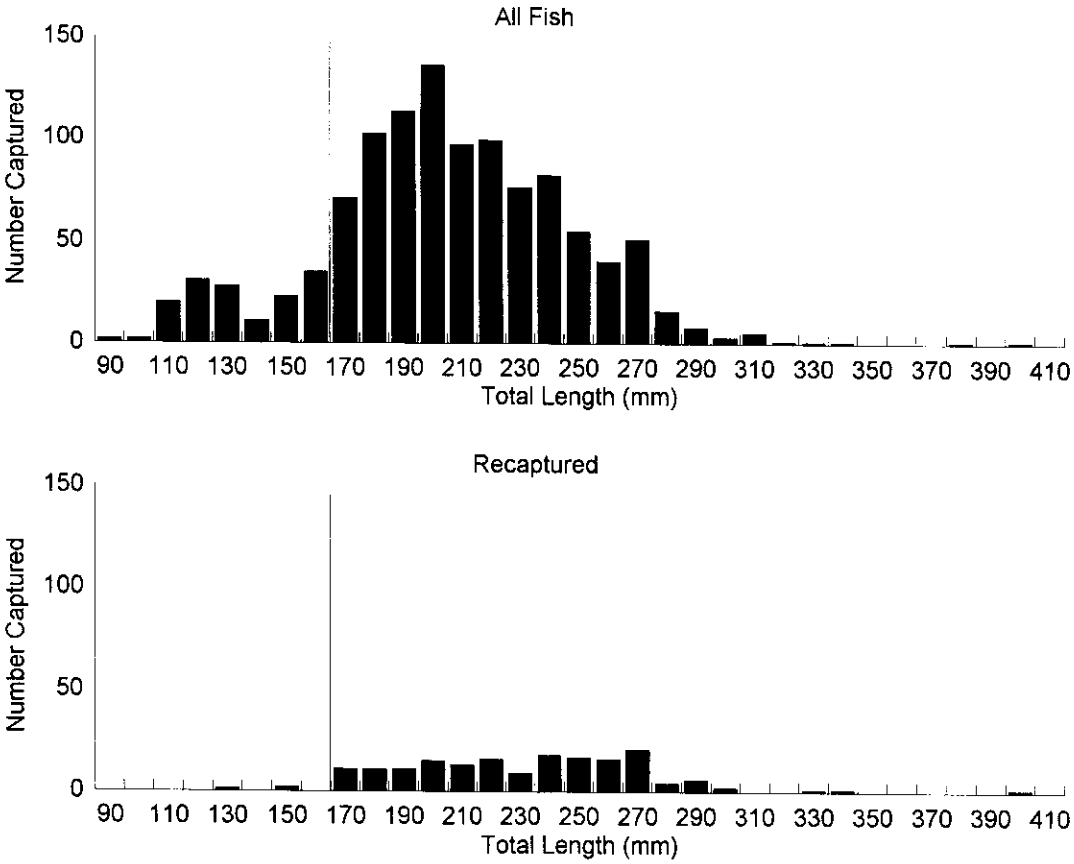

Figure 1. Histograms for lengths (total length) of all fish captured by gillnetting from recapture-samples in lakes of the North Cascades National Park Service Complex, 1991-1993, and for lengths of recaptured fish (R) in the same samples.

gear requirements were limited to several fishing rods and gill nets, an important factor in areas where access is difficult. Initial capture by angling was effective in most lakes, and tests suggested that post-release mortality of marked fish was low. In most cases three people could conduct the survey within 3 d. Precision of population estimates for fish > 170 mm was suitable for long-monitoring studies (White et al. 1982), and estimates appeared to be reasonable for the nine small lakes in this study.

Assumptions associated with the single-census Petersen estimate include equal mortality and vulnerability to capture for marked and unmarked fish. Marks must be retained and remain recognizable throughout the period. Distribution of marked and unmarked fish is assumed to be independent and random, or if not random, subsequent sampling is proportional to the number of fish in different areas. Finally, recruitment should be negligible during the sample period (Ricker 1975).

Previous research suggests that neither of the marks used in this study (adipose and partial caudal fin clips) has adverse effects on survival (Wydoski and Emery 1983), and post-release mortality of marked fish in our enclosure experiments was low. The short period of time between marking and recapture should have reduced the probability of unequal mortality among marked and unmarked fish. It was assumed that no growth or recruitment occurred during this period. Distribution of marked and unmarked fish in the study lakes was unknown; however, all of the lakes were relatively small, and observations suggested that fish moved throughout individual lakes. Gill nets were

Lake	Species[a]	Year	Area (ha)	All Fish M	C	R	N	CV	N/ha	LCL	UCL	>170mm M	C	R	N	CV	N/ha	LCL	UCL	>200 mm M	C	R	N	CV	N/ha	LCL	UCL
Reproducing fish																											
LS2	CTT	1992	1.0	101	70	9	724	32	724	402	1448	79	63	7	640	36	640	332	1347	56	47	5	456	42	456	215	1052
MR16	CTT	1993	1.0	50	47	24	98	20	98	67	149	50	44	24	92	20	92	63	140	43	36	21	74	22	74	49	116
Upper Triplet	CTT	1991	1.0	150	77	23	491	21	491	333	755	150	72	23	459	21	459	311	707	150	67	23	428	21	428	290	658
Dagger	CTT	1993	3.6	181	198	14	2415	26	671	411	1156	181	189	14	2305	26	640	392	1104	181	174	14	2123	26	590	361	1017
Kettling	RBT	1993	4.0	310	316	73	1332	12	333	266	417	284	248	69	1014	12	254	201	320	231	107	61	404	13	101	79	129
McAlester	CTT	1992	5.0	210	134	10	2590	30	518	294	999	210	125	10	2417	30	483	274	933	117	45	6	775	38	155	77	339
Rainbow	RBT	1992	6.3	145	208	5	5086	41	807	381	1863	145	167	5	4088	41	649	307	960	116	109	4	2574	45	409	182	1021
Non-reproducing fish[b]																											
LS1	CTT	1992	0.4	34	24	8	97	35	243	130	498	34	24	8	97	35	243	130	498	17	16	4	61[c]	47	152	68	383
Lower Panther	CTT	1992	0.2	28	30	13	64	28	320	195	570	28	30	13	64	28	320	195	570	28	30	13	64	28	320	195	570

[a]CTT = cutthroat trout (*Oncorhynchus clarki*); RBT = rainbow trout (*Oncorhynchus mykiss*)

[b]Fish were removed by intensive gillnetting and angling during 1990, and lakes were restocked with fry in fall 1990 at a density of 313 fry/ha in LS1 and 750 fry/ha in Lower Panther Lake (Liss et al. 1995).

[c]Statistically biased (Robson and Regier 1964)

relocated often during the recapture sample. Furthermore, fish were generally marked and released along the entire shoreline in order to promote mixing of marked and unmarked fish.

Although the use of different types of gear to catch fish for marking and recapture samples may ameliorate non-random distribution of marks or fishing effort (Seber 1982), gear selectivity can introduce systematic bias in mark-recapture estimates (Ricker 1975). Size selectivity occurs with all types of sampling gear, both passive and active (Hayes 1983; Hubert 1983; Reynolds 1983). Although size selectivity is difficult to avoid, effects of this source of systematic bias can be minimized by dividing estimates among two or more size groups or excluding fish near the limits of a given fishing gear (Seber 1982) as we did for lakes in NOCA.

The effects of sampling gear on size distribution can be detected by comparing size distribution of fish in capture and recapture samples. In this study, fish that were captured by angling were not measured prior to release; however, length frequency of fish in the recapture sample suggested differential vulnerability to angling and gillnetting for different length groups in the population. Angling tended to select for larger fish than gill nets. Because smaller fish were underrepresented by both techniques, abundance estimates appeared to be more meaningful when limited to larger fish (e.g., > 170 mm). Fish > 170 mm corresponded to the catchable portion of the fish populations in these lakes, however, and because managers generally focus on the availability of fish to anglers, using angling to mark fish appeared to be appropriate for estimates of the catchable population.

Success of the mark-recapture procedure described here depends on the vulnerability of fish to capture by angling and gillnetting. Dwyer (1990) found that different strains of cutthroat trout could be differentiated by susceptibility to angling. In NOCA, cutthroat trout and rainbow trout initially stocked several decades ago were more vulnerable to both angling and gillnetting than Mt. Whitney rainbow trout that have been stocked in these lakes in recent years. In 1992 attempts to estimate density in two lakes that had been stocked with the Mt. Whitney strain in 1990 failed because a sufficient number of fish could not be captured by angling (W. J. Liss, Oregon State University, unpublished data).

Other methods used to estimate abundance in small lakes have yielded poor results. Kelso and Shuter (1989) employed the removal method (with three different estimators) to estimate total abundance of brook trout (*Salvelinus fontinalis*), lake trout (*Salvelinus namaycush*), and rainbow trout in a small lake (11.7 ha) in north-central Ontario, but variation in catchability throughout the removal period resulted in significant underestimates. The authors cast doubt on the usefulness of the removal technique for lake populations. Cone et al. (1988) used the Jolly-Seber multiple mark-recapture method, but three and possibly four of the six assumptions for this method were violated, and the results were inaccurate.

Bernard et al. (1993) compared direct estimates of abundance of burbot (*Lota lota*) from mark-recapture to an index of abundance based on catch per unit effort in small and moderate-size lakes. If populations of burbot were dense (> 1 adult burbot/ha) and catch rates were high, direct estimates of abundance using mark-recapture experiments yielded more precise estimates than when sampling effort was low, a distinct advantage over using mean catch per unit effort as an index.

Single census mark-recapture experiments appeared to provide reasonable estimates of population abundance in this study, and it may useful for survey purposes in other remote small lakes. In contrast to relative abundance approximations, using a population estimator provides the means to establish confidence limits and promotes among-lake comparisons and temporal trend analysis. Additionally, abundance estimates from mark-recapture experiments provide a level of accuracy and precision suitable for research. The small size of the lakes in this study, in conjunction with the brief period of time allotted for each individual experiment, apparently reduced the probability of unequal vulnerability and mortality for marked and unmarked fish, two important assumptions of the Petersen estimator. Partitioning estimates by size groups is recommended, especially with the combination of angling and gillnetting for collecting fish. Although we were able to accomplish partitioned estimates by crudely approximating the size of fish captured by angling, measuring fish in both the marking and recapture samples is strongly recommended.

Acknowledgements

P. B. Bayley, J. D. Hall, J. Lukas, and B. Roper reviewed an earlier draft of this paper, and J. H. Meyer and E. P. Pister contributed insightful comments that were incorporated into the final manuscript. M. Kiss assisted in data collection. The US National Park Service and the National Biological Service provided financial support to Oregon State University for the research upon which the paper is based through cooperative agreement CA-9000-3-0003, Subagreement 21 and cooperative agreement CA-9000-8-006, Subagreement 11. The opinions expressed are those of the authors and do not necessarily reflect those of the acknowledged individuals, institutions, or agencies.

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Received 1 June 1996
Accepted for publication 2 November 1996