ASSESSING RISK OF EXTINCTION FOR WESTSLOPE CUTTHROAT TROUT INHABITING STREAMS WITHIN FEDERALLY MANAGED LANDS IN THE UPPER MISSOURI RIVER BASIN USING THE BayVAM MODEL

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Abstract

Westslope cutthroat trout Oncorhynchus clarki lewisi presently occupy less than 5% of their historically occupied range within the upper Missouri River drainage in Montana. A salmonid population viability assessment model, called the BayVAM model, was parameterized for westslope cutthroat trout and used to assess extinction risk for 144 known populations inhabiting streams within federally managed lands in the upper Missouri River basin. We chose to use the predicted probability of persisting for 100 years or more (p_{100}) as a standard for comparisons among populations. Populations were classified into three risk groups based on their predicted probability of extirpation: very high risk = [$p_{100} \leq 50\%$], high risk = [$50\% < p_{100} \leq 80\%$], moderate risk = [$80\% < p_{100} \leq 95\%$]. None of the assessed populations had a p_{100} value greater than 95%, a criterion proposed by Shaffer and Sampson (1985) for low extirpation risk. Most (103 or 71%) of the 144 populations had a "Very High" predicted risk of extirpation ($p_{100} \leq 50\%$), twenty seven populations (19%) exhibited a "High" risk ($50\% < p_{100} \leq 80\%$), and fourteen (10%) of the populations had a "Moderate" risk ($80 < p_{100} \leq 95\%$). Higher average predictions of p_{100} were consistently associated with those populations which inhabited watersheds with lower levels of management activities. A matrix of information divergence measures indicated that livestock grazing, mineral development, angling, and the presence of non-native fish had the greatest association with assigned likelihood values across all model nodes. Livestock grazing and the presence of non-native salmonids explained significant variation in p_{100} values when entered last in ANOVA models which explored the effects of individual management activity

types. Of 25 major sub-basins within the Upper Missouri, 16 still support at least one known westslope cutthroat trout population on federal lands, and 14 of these 16 support at least one population which has a predicted p_{100} value of 0.5 or greater and a genetic purity of at least 98%. The results from this analysis has led to action by citizens of Montana, and state and federal managers to begin developing a conservation and restoration program for this subspecies in the upper Missouri River basin.

Populations of westslope cutthroat trout (Oncorhynchus clarki lewisi) have declined dramatically from historical levels, both in abundance and distribution, throughout their range (Liknes and Graham 1988; McIntyre and Rieman 1995). Some of the more dramatic declines in their distribution and abundance may be found in the upper Missouri River basin of Montana (Upper Missouri). Historically, westslope cutthroat trout likely occupied the entire Upper Missouri from the Musselshell River upstream (Hanzel 1959; Figure 1). Behnke (1992) identified the historic range of westslope cutthroat trout in Upper Missouri to be the entire basin down to about Fort Benton, as well as the headwaters of the Judith, Milk, Marias, and Musselshell rivers. Behnke's inclusion of the upper Milk River was based on Willock's (1969) distributional list. We suspect that the upper Sun River drainage was probably barren of fish above a natural barrier (presently occupied by an irrigation diversion dam) about 155 km above its mouth at the Missouri River (B. Hill, Montana Department of Fish, Wildlife and Parks, personal communication). Two tributaries in the lower Musselshell drainage (one in the Box Elder drainage and one in the Flatwillow drainage) currently contain genetically pure westslope cutthroat trout (Dr. R. Leary, Salmon and Trout Genetics Laboratory, University of Montana, personal communication), which may support inclusion of the Musselshell drainage in the historical distribution. Unfortunately, numerous releases of "fine spotted, native trout", a description used for westslope cutthroat trout, were made by residents of Lewistown, Montana in "unnamed local waters" during the early 1900's (Montana Game and Fish Commission 1914). These releases make it impossible to know for certain whether westslope cutthroat trout populations in the Musselshell drainage originated from aboriginal populations or releases of hatchery stocks. However, for the purposes of this report, we assumed that westslope cutthroat trout occupied the entire Missouri River drainage down to, and including, the Musselshell River, the upper Milk River basin, but not the upper Sun River basin.

Based on 1:100,000 scale digital hydrography, a total of just over 58,000 miles of lentic habitats were historically occupied by westslope cutthroat trout in the upper Missouri at the time of European man's expansion into the upper basin, assuming that all waters within the Upper Missouri described above were occupied. In contrast, data from the Montana River Information System (MRIS) indicates that genetically pure populations of westslope cutthroat trout (98% pure and purer) presently inhabit 715 miles of stream (1.2%), 90-97.9% genetically pure populations inhabit 290 miles (0.5%), <90% genetically pure (known hybridized) populations inhabit 433 miles (0.7%), and untested, but suspected, populations inhabit 1,653 miles (2.8%) of total habitat miles within the basin (Table 1). Fish species records are present for 20,184 miles of habitat within the MRIS database which indicates that this number of miles has had some level of fish survey information. The total miles occupied by westslope cutthroat trout by genetic status indicate that pure populations ($\geq$ 98% pure) occupy about 3.5% of surveyed habitats, 90-97.9% pure populations occupy about 1.4%, known hybridized populations occupy about 2.1%, while suspected, but untested, populations occupy about 8.2%. The MRIS database contains a total of 3,611 reaches. Of this total, 160 reaches contained genetically pure populations (4.4%), 33 reaches supported 90-97.9% pure populations (0.9%), known hybridized populations were found in 122 reaches (3.4%), while suspected, but untested, populations were found in 678 reaches (18.8%).

The above review indicates that genetically pure westslope cutthroat trout within the Upper Missouri now probably occupy less than 5% of their historic range. Fish survey data collected by Montana Fish, Wildlife and Parks (FWP), USDA Forest Service (Forest Service), and USDI Bureau of Land Management (BLM) revealed that: 1) at least three populations have been extirpated within the past ten years; 2) many existing populations have been invaded by non-native salmonids; and 3) most remaining populations presently occupy isolated habitat fragments which are less than 5 miles in length. Primary reasons for recent extirpations and fragmentation of habitats are presence of non-native salmonids, primarily rainbow Oncorhynchus mykiss and brook trout Salvelinus fontinalis, and habitat alteration caused by land and water management practices. Genetic introgression with introduced rainbow trout represents a serious threat to westslope cutthroat trout throughout their range (Allendorf and Leary 1988). These factors were also cited as causes for declines by others (Hanzel 1959; Liknes and Graham 1988; McIntyre and Rieman 1995). FWP recently (1996) changed angling regulations within the Upper Missouri to "catch and release" for westslope cutthroat trout in streams and rivers in order to lessen population losses caused by angling. Since almost all westslope cutthroat trout populations within the Upper Missouri now inhabit isolated headwater habitats, most of which have been impacted by either land/water management activities or invasion by non-native salmonids, or both, the risk of extirpation from stochastic environmental effects (Rieman and McIntyre 1993; Shaffer 1987, 1991) are probably high. Due to the relatively high amount of genetic divergence among westslope cutthroat trout populations, Allendorf and Leary (1988) recommended that conservation of many populations throughout its range was necessary to conserve the genetic diversity presently contained within this subspecies.

Concern for the status of westslope cutthroat trout led FWP to form an Upper Missouri Westslope Cutthroat Trout Technical Committee (Technical Committee) in early 1995 to make recommendations to FWP for conserving and restoring westslope cutthroat trout in the Upper Missouri. The Forest Service and BLM wanted to initiate conservation measures for populations of westslope cutthroat trout inhabiting waters within federally administered lands. To justify and prioritize conservation and restoration efforts, federal land and state fish managers needed to know the overall status of the subspecies within the Upper Missouri and the relative risks to each individual population. In this paper, we describe our efforts to provide a comprehensive evaluation of the relative risks of extirpation for 144 populations of westslope cutthroat trout found within federally administered lands within the Upper Missouri. Our analysis relied heavily on the Bayesian Viability Assessment Module (BayVAM) developed at the USDA Forest Service Intermountain Research Station (Lee and Rieman, in review), parameterized for westslope cutthroat trout in the Upper Missouri using data collected by Downs et al. (in review).

Methods

Our assessment of extirpation risks focused on all known populations of westslope cutthroat trout within federally administered lands of the Upper Missouri that were at least 90% genetically pure, as identified through horizontal starch gel electrophoretic testing (Leary et al. 1987). Additional populations were included where electrophoretic testing had not been completed, but were believed to be genetically pure based on field examination of the morphometric features of individual trout. For each population, a two-part assessment was completed by a local fisheries biologists and a team of resource specialists familiar with each population and the watersheds which contained them. Watersheds were delineated based on sixth-code hydrologic unit (HUC) boundaries (USDI Geologic Survey) and ranged from about 20,000 to 40,000 acres in size. In total, eight fisheries biologists and six teams of resource specialists participated. Assessments were completed for 144 populations in 117 watersheds. This represented the majority of known westslope cutthroat trout populations which were at least 90% genetically pure, since only about 200 total reaches in the Upper Missouri were known to support ≥ 90% pure westslope cutthroat trout (Table 1) and several populations analyzed in this risk assessment inhabited more than one reach.

<u>Part 1. Population survey</u>

Part one of the assessment involved completing a survey of population parameters that focused on local population demographics and the suitability of each stream's habitat for supporting a viable population. This survey is an integral part of the BayVAM approach (Lee and Rieman, in review). BayVAM was designed to provide a rigorous method of incorporating subjective judgments about habitat quality in a quantitative risk assessment that explicitly acknowledges uncertainty in parametric estimates, and includes demographic, environmental, and catastrophic stochasticity. Biologists were asked to assign Bayesian probabilities to each of twelve population characteristics (nodes), by assigning likelihood values to various ranges for each node (Table 2). The ranges were set to correspond with reasonable values that might be expected for westslope cutthroat trout within the Upper Missouri based on field research (Downs et al., in review). Guidelines were prepared to provide a common set of assumptions or standards to use in assigning likelihood values (Appendix A). Biologists also estimated the length of stream habitat occupied by each population.

Part 2. Land-use Assessment

Part two of the assessment identified management activities within each watershed now containing a population that may have affected, or are presently affecting, the population. Interdisciplinary (ID) teams were created from resource specialists from local Forest Service, BLM, and FWP staffs. ID teams were created for each of four National Forests and two BLM resource areas, and addressed all relevant streams within their assigned areas. For each watershed that contained a targeted population of westslope cutthroat trout, the ID teams were asked to identify the proportion of stream length affected by each management activity within the watershed in nine categories. For land management activities the proportion of stream length affected by each management activity was rated as follows: low = 1 to 10%; moderate = 11 to 20%; or high > 20%. Land management activities rated included roads, livestock grazing, mineral and/or oil and gas development, and timber harvest. The effects of water withdrawals and impoundments, angling pressure, and the distribution and abundance of non-native fishes were also rated. The estimated catastrophic risk associated with wildfire and, for those streams within Forest Service administered lands, the allocation of those lands through Forest planning was rated as: low = 1 to 25%; moderate = 26 to 50%; and high > 50%. A tenth category, cumulative effects, was intended to capture the ID teams' views on the magnitude of the cumulative effect of all watershed activities on aquatic resources.

Part 3. Data Analysis

The first step in our data analysis was to summarize the survey responses from part one across all populations and generate BayVAM probabilities of persistence in order to provide a perspective on the perceived condition of the populations. Data were summarized by tabulating the frequency of likelihood scores that biologists assigned to each of three classifications (low, moderate, and high) for each individual node used in the BayVAM model. BayVAM results were generated for each population. For any set of likelihood values, the BayVAM model calculates probabilities associated with minimum population size, average population size, and time to extinction (if applicable), based on a 100 year simulation period. We choose to use the probability of persisting for 100 years or more (p_{100}) as a standard for comparisons among populations. Populations were classified into three risk groups based on their estimated probability of extirpation: very high risk = [$p_{100} \leq 50\%$], high risk = [$50\% < p_{100} \leq 80\%$], moderate risk = [$80\% < p_{100} \leq 95\%$]. None of the assessed populations had a p_{100} value greater than 95%, a criterion proposed by Shaffer and Sampson (1985) for low risk.

We were concerned that observer bias might influence our results because we relied on expert opinion from local experts on the status of populations in their management areas. Since we were unable to randomly assign streams to observers (because we used local expert opinion), or to replicate sampling of streams, we assessed observer bias by comparing average probabilities of persistence predicted from the BayVAM model across observers and tested for differences between observers using the Kruskal-Wallis nonparametric test (Daniel 1978).

Populations were also classified based on estimates of genetic purity from horizontal starch gel electrophoresis. Three classes were identified (100%, 98-99.9%, and 90-97.9% pure) based on preliminary genetic classifications for management recommended by the Technical Committee. We also included a class for untested, but suspected pure, populations.

We examined the relationship between management activities, as identified by the ID teams, and population status in two ways. First, we looked for differences in likelihood assignments for each BayVAM node, which could be associated with different activity levels. This was accomplished by calculating an information divergence measure (Kullback and Leibler

1951) that compares the conditional probability distributions (i.e., the nodal likelihood function associated with each activity level) to the marginal probability function (i.e., the nodal likelihood function generated by summing over all activity levels) for each node-activity combination. This information divergence can be interpreted as an average measure of the information difference between two sets of probabilities (Whittaker 1990). It provides a convenient means of illustrating which activities may be most influential in determining the likelihood values assigned to a population characteristic.

Second, we compared landuse activity levels with the probability of persistence directly using an analysis of variance (ANOVA) approach (SAS version 6.03, 1988). We conducted two ANOVA tests. The first test included roads, livestock grazing, mining (including oil and gas development), timber harvest, water diversion, angling, and presence of non-native fishes because ratings of these activities were provided for all 144 populations. We excluded cumulative effects since this variable incorporated effects from the individual activity classes above. The second analysis included cumulative effects, forest plan allocation, and risk of a catastrophic event for 134 populations where ratings were provided for these variables. Ratings of all the above effects, except cumulative effects, were classed as none, low, moderate, or high. The "none" rating was not used for cumulative effects.

Results

Biologists did not always enter values for all population characteristics, therefore sample sizes varied by node. All biologists used the default values for "Age at Maturity" and "Fecundity" nodes, which were based on field observations (Downs et al., in review). Biologists had a relatively high confidence that the "Distribution and Quality of Spawning Habitats" was "High" for a majority of populations (Figure 2). This was the only node where high likelihood values were consistently assigned to the "High" rating. Biologists also were fairly certain that many populations deserved "Low" ratings for the "Initial Population Size" node. Nodes where biologists were fairly confident that most of the populations did not fall into the "High" category, but were less certain as to whether it was "Low" or "Moderate" were "Fry Capacity" (Figure 2), "Expected Population Size" (Figure 3), and, to a lesser extent, "Juvenile/Sub-Adult Survival" (Figure 2). Biologists were less confident in their assessments, or believed nodes fell into the "Moderate" range, for a majority of populations for all other nodes.

BayVAM model predictions of the probabilities that each population would persist for 100 years were plotted to show the number of populations that fell within each 10% probability of persistence category (Figure 4). Most (103 or 71%) of the 144 populations had a "Very High" risk of extirpation ($p_{100} \leq 50\%$), twenty seven populations (19%) exhibited a "High" risk of extirpation ($50\% < p_{100} \leq 80\%$), and fourteen (10%) of the populations had a "Moderate" risk of extinction ($80 < p_{100} \leq 95\%$) (Figure 5). Slightly over half of the populations in all extinction risk categories had tested 100% genetically pure (Table 2 and Figure 5).

Average predicted probabilities of persistence differed between observers (Figure 6) and these differences were significant ($p<0.001$; Kruskal-Wallis test). However, these differences could be partially explained by the fact that observer 7 was known to have assessed mostly westslope cutthroat trout populations with lower-than-average risks, and observer 2 assessed only populations which received high impacts from livestock grazing.

The matrix of information divergence measures indicated that grazing, mineral development, angling, and the presence of non-native fish had the greatest association with assigned likelihood values across all nodes. These are the activities that produced the 15 highest observed values in the information matrix (Table 5). We did not attempt to estimate significance of these values; to do so would require a more intensive analysis based on the sampling properties of the information divergence measure. Rather, we identified noteworthy high values as those greater than 0.668, which is the overall mean of the observed values plus one standard deviation. Sixteen (15%) of the elements within the information matrix exceed this threshold. The highest values span all of the population nodes except spawning habitat, fecundity, initial population, and age at maturity (since age at maturity was constant for all populations, its information divergence was zero).

Higher average estimates of the probability of persistence consistently were associated with those populations inhabiting watersheds with lower levels of management activities (Table 6). The significance of each activity was examined both in terms of the sequential sum of squares where each activity was entered into the ANOVA model first, and in terms of the partial sum of squares where each activity is entered in the ANOVA model last. The resulting ANOVA table (Table 6) presents an interesting pattern that suggest some potential interaction effects or confounding among the management activities, evidenced by substantively different significance values for partial and sequential sums of squares. Unfortunately, the sample size is insufficient to comprehensively test for interaction effects. All activities except mineral development and timber harvest showed a significant effect (or nearly so) when entered first in the ANOVA model. Only grazing and non-native fish explained significant variation in p_{100} values when entered last in the model, among the individual activities, while catastrophic risk and cumulative effect were consistently significant in the more reduced analysis of integrated measures.

There are 25 major watersheds, classified as fourth-code hydrologic units (subbasins) by the USDI Geological Service, within the historical range of westslope cutthroat trout in the Upper Missouri. Sixteen of these subbasins still support at least one westslope cutthroat trout population on federal land (Table 7). Of these 16 subbasins, 14 contain populations with a "Moderate" or "High" estimated risk of extirpation and a genetic purity of at least 98%. These subbasins are spread throughout the Upper Missouri, however, almost all of the remaining populations occupy high elevation, mountainous stream fragments (Figure 7).

Discussion

This analysis indicates that westslope cutthroat trout populations inhabiting federal lands within the Upper Missouri face serious threats of extirpation under existing conditions (i.e., without additional stresses placed on them by new land or water management activities, or a concerted management effort to preserve and restore them). The most damming evidence presented here is the alarmingly low predicted probabilities of persistence for nearly all populations examined. These low estimates arise from a combination of two principal factors. First, there are unmistakable impacts of landuse activities, though admittedly the full nature of these impacts are not entirely clear. Among the independent activities, grazing and the presence of non-native fishes have the most obvious and consistent impacts on population characteristics, and subsequently, on probability of persistence. Mineral development and angling have noticeable associations with population characteristics, but these associations do not translate clearly into significantly different probabilities of persistence. Perhaps this can be explained by confounding or interactions with more dominant factors, but we do not know. The impacts of roads, timber harvesting, and water withdrawal within the present context are even more obscure.

Part of the reason why the effects of management are hard to discern is tied to the second reason why extirpation risks seem so high - because we simply don't precisely know the demographic parameters of the populations that we are trying to manage. It may sound trite, but it's hard to measure effects on something that is unknown to begin with. With the BayVAM approach, this uncertainty not only complicates our understanding of causal relationships, it also increases the estimates of risk for populations being modeled. This is due to the conservative nature of the BayVAM approach, which requires confidence that things are good all over before one can be confident that the population will persist indefinitely (Lee and Rieman, in review). Stated alternatively, if there is uncertainty about a variety of demographic parameters, chances are good that one of those parameters might limit the population's potential. Considerable uncertainty was expressed in the survey questionnaires regarding the demographic parameters. This uncertainty connotes higher risks.

The collective evidence suggest that even if we could reduce our estimates of risk by reducing uncertainty about population parameters, it would not significantly change the overall picture of a subspecies in trouble in the Upper Missouri. The risk estimates may be conservative, but the situation is real. The small habitat fragments which these populations now occupy, shown by a frequency histogram of stream length occupied (Figure 8), and lack of connectivity between these populations further contributes to their tenuous status (Rieman and McIntyre 1993).

Management Implications

Results of this extinction risk assessment contributed to the Governor of Montana convening a Westslope Cutthroat Trout Conservation Workshop in September 1996 to initiate a statewide conservation effort. This conservation and restoration effort is being led by FWP and has already begun in the Upper Missouri. A Steering Group, which consists of agency and private representatives, has been formed to recommend conservation and restoration efforts to FWP. The Technical Committee, which was formed in 1995, interacts with both the Steering Committee and FWP to recommend technically sound conservation and restoration strategies. Local citizen watershed groups have been formed in some of the watersheds of the Upper Missouri to implement conservation and restoration efforts. An ambitious restoration program was recently started in the upper Madison River drainage. All of these conservation and restoration efforts were initiated, in part, due to the focus that this extinction risk assessment placed on the present plight of westslope cutthroat trout in the Upper Missouri.

The Forest Service and BLM also asked the Technical Committee to make interim recommendations, based on preliminary results from this analysis, for conserving westslope cutthroat trout inhabiting federal lands within the Upper Missouri until FWP's conservation and restoration plan was adopted. The Technical Committee recommended that:

1. Aquatic habitats in all 144 streams which now support populations which are at least 90% genetically pure (presently 144 populations) should be protected from existing and future land management impacts. The level of protection should be further specified and related to genetic purity of individual populations. It was recognized that the 144 streams which presently support populations will likely be a dynamic number with some existing populations going extinct and additional populations being found. However, the BLM and Forest Service have defined all 144 streams which presently support populations as suitable habitats which will be protected, regardless of future extinctions. The intent of

this recommendation is that any habitats which now support populations of westslope cutthroat trout ($\geq$ 90% pure) should be protected or restored to allow for recovery of this subspecies in known suitable habitats.

2. Until the basin-wide conservation strategy presently being developed by FWP is adopted, management emphasis must be placed on westslope cutthroat trout in tributaries which support genetically pure populations which have a "Moderate" or "High" probability of extinction. The 100% pure populations should be secured first, and then populations which are 98-99.9% pure (which the Technical Committee has designated as "pure" for management purposes) should be secured. There are presently 21 known 100% genetically pure populations and 6 known 98.0-99.9% pure populations which meet the "Moderate" or "High" risk criteria. Again, it was recognized that these numbers are probably dynamic as new populations are discovered. Local opportunities and information for securing these populations should also be considered in setting priorities.

The rationale for recommending that healthier populations be secured first is that, generally, the level of effort needed to secure a relatively healthy population will be less than that needed to secure populations which are more at risk. We believe that this extinction risk assessment provided a valuable tool for illustrating the relative risk of extinction between populations and put the regional basin-wide extinction risks in perspective for land and fishery managers.

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List of tables

Table 1. Miles and number of reaches westslope cutthroat trout (Oncorhynchus clarki lewisi) presently inhabit in streams and rivers within the upper Missouri River basin of Montana. Information obtained from the Montana River Information System last updated - October 1996.

					WCT (Miles)					WCT (Reaches)				
Hydro Unit	Name	Total Miles	Surveyed Miles	Surveyed Reaches	Pure	90-97.9%	<90%	Untested	Total	Pure	90-97.9%	<90%	Untested	Total
10020001	Red Rock	3488.4	1123.7	289	137.5	90.0	61.4	190.6	479.5	20	6	21	49	96
10020002	Beaverhead	1826.2	643.7	138	74.0	27.5	16.4	87.8	205.0	12	2	4	26	44
10020003	Ruby	1284.7	575.8	152	66.0	39.5	50.3	94.1	249.9	11	2	16	40	69
10020004	Big Hole	3953.7	1579.9	474	125.9	20.1	99.5	416.2	661.7	36	4	23	140	203
10020005	Jefferson	2176.2	456.7	88	31.5		5.8	18.6	55.9	5		1	5	11
10020006	Boulder	998.3	316.1	86	21.7			25.1	46.8	4			6	10
10020007	Madison	2517.1	793.9	226	13.8	13.0	32.4	218.8	275.3	3	2	9	67	81
10020008	Gallatin	2401.3	777.8	209	0.0	13.5	31.3	145.9	190.7		6	12	54	72
TOTAL	Upper Missouri	18645.9	6267.6	1662	470.4	203.6	297.1	1197.1	2164.8	91	22	86	387	586
10030101	Upper Missouri	4763.9	1106.3	315	72.0	3.1	45.8	28.0	150.4	19	1	10	28	58
10030102	Upper Missouri - Dearborn	3538.7	1077.8	163			19.7	18.0	88.3			1	18	19
10030103	Smith	2858.3	986.4	232	26.7	5.1	17.7	103.0	378.4	8	1	5	103	117
10030104	Sun - East	1714.4	708.1	134	2.4	14.2		27.0	144.5	1	2	1	27	31
10030105	Belt	800.5	370.7	87	34.4	11.6		41.0	129.0	9	1	1	41	52
10030201	Two Medicine	1422.2	679.6	141	29.6	28.2	44.9	29.0	113.6	12	4	12	29	57
10030202	Cut Bank	1089.2	508.9	61					0.0					
10030203	Marias	2493.7	1033.7	86					0.0					
10030204	Willow	708.1	333.7	39					0.0					
10030205	Teton	1751.4	774.6	104	30.7	9.0		13.0	70.0	10		1	13	25
TOTAL	Three Forks to Teton	21140.4	7579.8	1362	195.8	71.2	128.1	259.0	1074.2	59	9	31	259	359
10040101	Bullwhacker - Dog	1803.4	682.5	53										
10040102	Arrow	1326.3	520.4	70									1	
10040103	Judith	3222.7	1152.3	131	17.5	15.2	8.0	151.2	191.9	7	2	4	27	40
10040201	Upper Musselshell	4676.3	1568.1	150	17.5			46.0	63.5	1		1	4	6
10040202	Middle Musselshell	2477.2	782.6	60										
10040203	Flatwillow	891.0	336.0	29	8.0				8.0	1				1
10040204	Box Elder	1371.8	507.4	35	6.1				6.1	1				1
10040205	Lower Musselshell	1810.0	608.7	41										
TOTAL	Teton to Musselshell	17578.7	6158.0	569	49.1	15.2	8.0	197.2	269.5	10	2	5	32	48
10050001	Milk Headwaters	650.7	178.3	18										
	GRAND TOTALS	58015.7	20183.7	3611	715.3	290.0	433.2	1653.3	3508.5	160	33	122	678	993
Percent of Entire Basin (excluding upper Sun)														
	Percent				1.2329	0.4999	0.7467	2.8497						
	Cumulative Percent				1.2329	1.7328	2.4795	5.3292						
Percent of Surveyed Basin														
	Percent				3.5439	1.4368	2.1463	8.1913		4.4309	0.9139	3.3786	18.7760	
	Cumulative Percent				3.5439	4.9808	7.1270	15.3183		4.4309	5.3448	8.7233	27.4993	
	Number of reaches with no length measurements			451	5	6	4	57	72	5	6	4	57	72

Table 2. Criteria ranges for nine life history and 6 population level nodes used within the BayVAM model to assess the relative risk of extinction for each of 144 westslope cutthroat trout populations in the upper Missouri River basin of Montana. See Appendix A for details.

Node	Ranges	Node	Ranges
Life History Characteristics		Age at First Maturity	age 3 (30%)
		(% of population)	age 4 (40%)
Spawning Success	60-80%		age 5 (20%)
	85-95%		age 6 (10%)
	100%		
		Local Population Characteristics	
Fecundity (eggs/female)	200-500		
	500-800	Initial Population	< 450
	800-1100	(Adults)	450 - 850
	1100-1500		> 850
Incubation Success	5 - 20%	Expected Population	< 450
	20 - 35%	(Adults)	450 - 850
	35 - 50%		> 850
Maximum Fry Survival	10 - 20%	Population Resilience	
	20 - 30%	(See Appendix A)	
	30 - 40%		
		CV of Juvenile Survival	<40%
Fry Capacity	1000 - 4000		40 - 65%
	4000 - 7000		> 65%
	7000 - 20000		
		CV of Adult Survival	< 25%
Sub-adult Survival	14 - 26%		25 - 50%
	26 - 38%		51 - 100%
	38 - 50%		> 100%
Adult Survival	10 - 30%	Risk of Catastrophe	120 - 170
	30 - 50%	(Year interval)	70 - 120
	50 - 70%		20 - 70

Table 3. Number of westslope cutthroat trout populations, by genetic status, which the BayVAM population viability assessment model predicted had a "Very High", "High", or "Moderate" risk of extirpation in the next 100 years (see the "Results" section for extirpation criteria).

Risk of extinction	Genetic Purity				Total
	100%	98-99.9%	90-97.9%	Untested	
Very High	60	8	29	6	103
High	14	3	7	3	27
Moderate	7	3	4	0	14
Total	81	14	40	9	144

Table 4. Kulback-Leibler (1951) information divergence calculated for each combination of population characteristics (node) and landuse activity. This divergence can be interpreted as an average measure of the information difference between the marginal probability distribution for each node, and a nodal probability distribution conditioned on the level of each activity. Highlighted values represent the highest observed values in the matrix.

	Landuse Activity									
Population characteristic	Roads	Grazing	Minerals	Timber harvest	Water withdrawal	Angling	Non-native fishes	Forest Plan Allocation	Major Risk	Cumulative Effect
spawning habitat	0.21	0.26	0.36	0.36	0.43	0.08	0.09	0.42	0.16	0.17
incubation success	0.57	**0.70**	0.46	0.18	0.11	0.60	0.11	0.12	0.17	0.22
max fry survival	0.06	0.34	0.52	0.09	0.17	**0.83**	**1.22**	0.05	0.23	0.40
fry capacity	0.19	0.24	**0.84**	0.43	0.36	0.43	0.57	0.18	0.15	0.06
juvenile survival	0.19	0.32	**0.97**	0.43	0.27	**0.78**	**1.19**	0.07	0.19	0.44
adult survival	0.45	0.19	**1.05**	0.38	0.17	**1.92**	**0.77**	0.22	0.22	0.42
fecundity	0.09	0.16	0.22	0.10	0.23	0.18	0.19	0.06	0.31	0.12
initial population	0.33	0.20	0.34	0.20	0.36	0.38	0.23	0.07	0.17	0.26
1st year variation	0.15	**0.69**	0.48	**0.67**	0.22	0.50	0.17	0.05	0.17	0.17
adult CV	0.45	0.58	**1.26**	0.46	0.35	**0.72**	0.22	0.20	0.28	0.32
catastrophic risk	0.30	**0.75**	**0.76**	0.31	0.32	0.34	0.57	0.06	0.66	0.10

Table 5. Means (sample size) of probabilities of 144 westslope cutthroat trout populations within the upper Missouri River basin persisting from the BayVAM model by "None", "Low", "Moderate", and "High" rating categories assigned by biologists for effects of management related disturbances on those populations along with results from ANOVA tests. "Major Event" = Catastrophic risk from major event; "Cumul Effects" = rated impacts from cumulative effects of individual management classes; and "Forest Plan' = Forest Plan Allocation.

	Individual Management Classes									
Rated impact	Grazing	Non-native Fish	Roads	Minerals	Timber	Water Withdrawal	Angling	Major Event	Cummul Effects	Forest Plan
None	0.701 (7)	0.592 (27)	0.481 (18)	0.402 (84)	0.407 (68)	0.454 (61)	0.378 (21)	0.255 (12)	N/A[1]	0.414 (2)
Low	0.456 (42)	0.357 (14)	0.407 (73)	0.412 (39)	0.393 (55)	0.366 (47)	0.420 (104)	0.339 (86)	0.573 (26)	0.491 (49)
Moderate	0.412 (40)	0.400 (30)	0.374 (32)	0.328 (12)	0.345 (13)	0.314 (15)	0.343 (11)	0.519 (32)	0.405 (58)	0.321 (30)
High	0.297 (55)	0.328 (73)	0.313 (21)	0.341 (9)	0.390 (8)	0.348 (21)	0.192 (8)	0.481 (6)	0.309 (60)	0.308 (53)
ANOVA test results for individual management classes (N=144): Model F value = 4.33; P < 0.001.										
ANOVA test results for Forest Plan, Cumulative Impacts, and Catastrophic (Major) Events (N=134): Model F value = 8.09; P<0.001.										
Sequential (Type I) Sum of Squares for each treatment when entered first in the model										
F value	11.53	11.83	2.55	0.83	0.37	3.40	3.64	8.65	16.89	8.27
P	0.0001	0.0001	0.0591	0.4795	0.7738	0.0199	0.0147	0.0001	0.0001	0.0001
Partial (Type III) Sum of Squares for each treatment when entered last in the model										
F value	9.63	12.30	1.61	0.03	1.17	1.36	0.98	7.15	11.85	1.09
P	0.0001	0.0001	0.1913	0.9927	0.3225	0.2598	0.4047	0.0002	0.0001	0.3545

[1] N/A indicates no data.

Table 6. Number of westslope cutthroat trout populations by extinction risk and genetic classes in each major sub-basin believed to be within their range in the upper Missouri River basin.

	Moderate risk				High risk				Very High risk				
Sub-basin	100%	98-99.9%	90-97.9%	Untested	100%	98-99.9%	90-97.9%	Untested	100%	98-99.9%	90-97.9%	Untested	TOTAL
Red Rock	1	1	0	1	1	2	1	9	9	2	9	0	27
Beaverhead	1	1	1	0	1	0	1	0	6	0	0	0	11
Big Hole	0	1	1	0	2	1	1	2	17	3	2	2	32
Ruby	0	0	1	0	0	0	0	0	6	2	7	0	16
Jefferson	0	0	0	0	1	0	1	0	0	0	0	1	3
Boulder	0	0	0	0	0	0	0	0	1	0	0	2	3
Madison	2	0	0	0	0	1	0	0	0	0	1	1	5
Gallatin	0	0	0	0	0	0	0	0	0	0	0	0	0
Upper Missouri 1	0	0	0	0	3	0	0	0	7	0	0	0	10
Upper Missouri 2	0	0	0	0	0	0	0	0	0	0	0	0	0
Smith	1	0	0	0	0	0	2	0	7	0	0	0	10
Sun	0	0	0	0	0	0	0	0	0	0	2	0	2
Belt	0	0	0	0	1	0	0	0	3	0	1	0	5
Two Medicine	1	0	0	0	2	0	0	0	1	0	4	0	8
Cut Bank	0	0	0	0	0	0	0	0	0	0	0	0	0
Marias	0	0	0	0	0	0	0	0	0	0	0	0	0
Willow	0	0	0	0	0	0	0	0	0	0	0	0	0
Teton	0	0	0	0	1	0	0	0	1	0	2	0	4
Judith	1	0	0	0	1	0	0	0	2	1	1	0	6
Bullwacker-Dog	0	0	0	0	0	0	0	0	0	0	0	0	0
Arrow	0	0	0	0	0	0	0	0	0	0	0	0	0
Upper Musselshell	0	0	0	0	0	0	0	0	0	0	0	0	0
Middle Musselshell	0	0	0	0	0	0	0	0	0	0	0	0	0
Flatwillow	1	0	0	0	0	0	0	0	0	0	0	0	1
Box Elder	0	0	0	0	1	0	0	0	0	0	0	0	1
Lower Musselshell	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	7	3	4	0	14	3	7	3	60	8	29	6	144

List of Figures

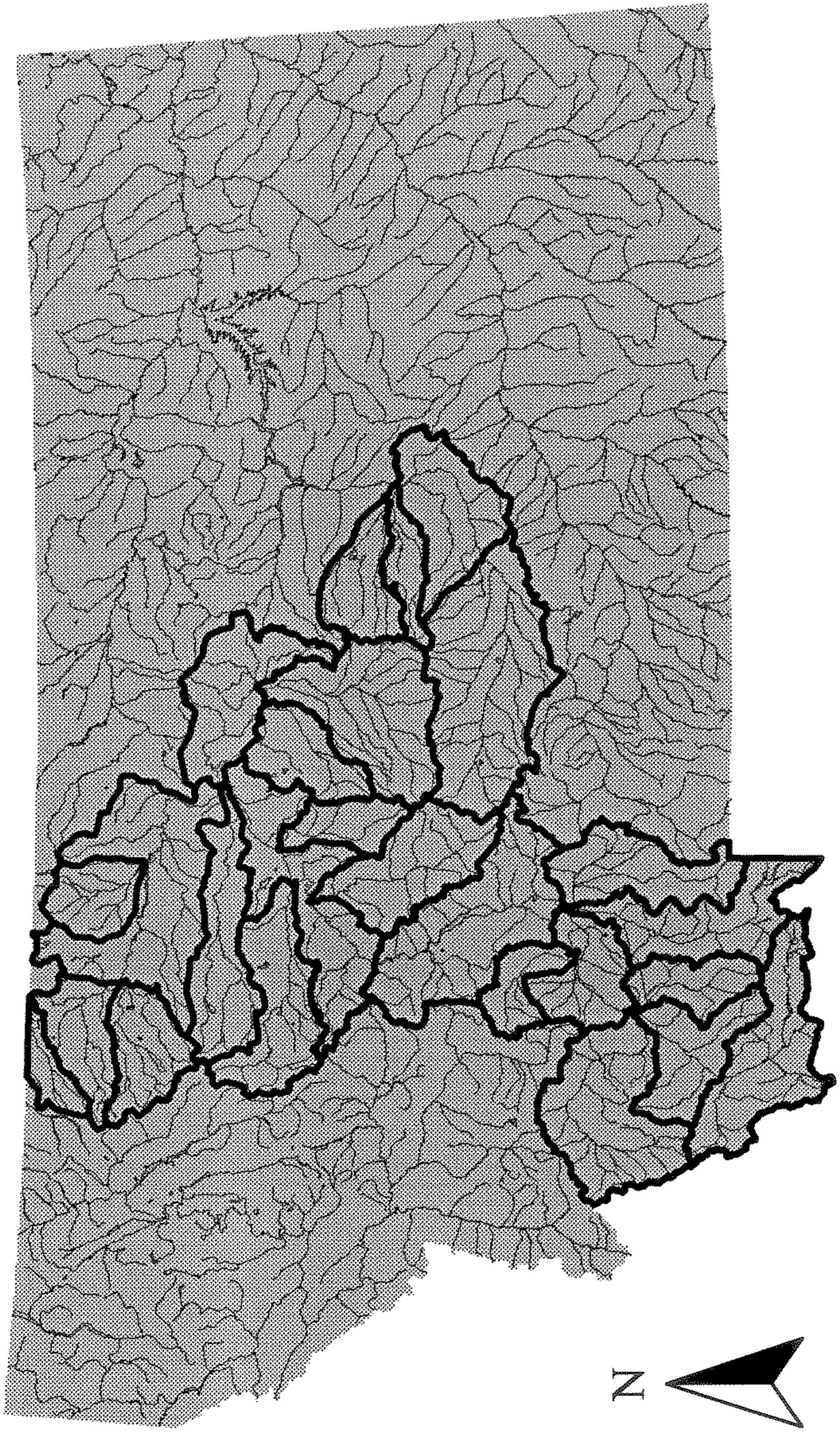


Fig 1

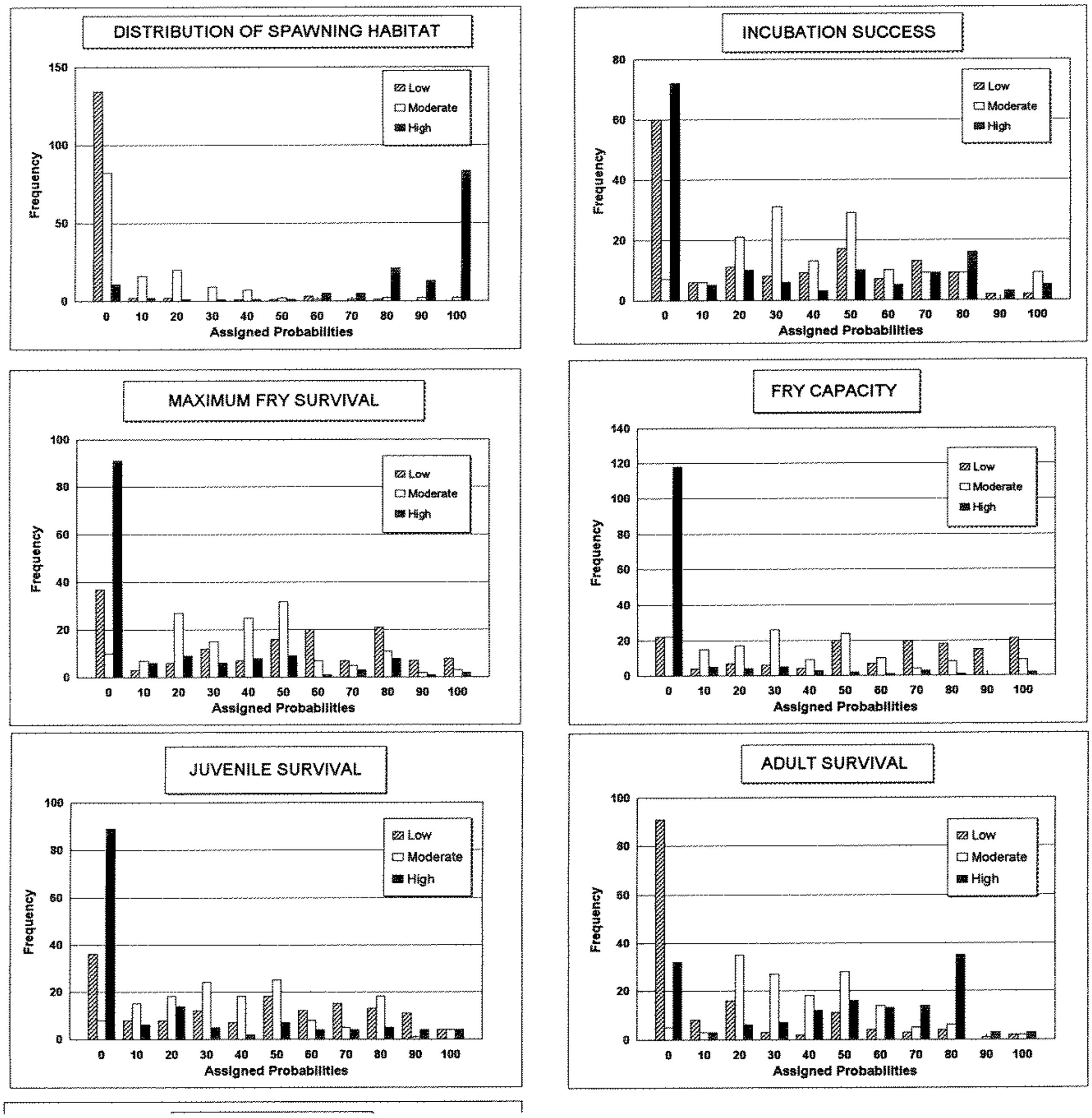

DISTRIBUTION OF SPAWNING HABITAT
INCUBATION SUCCESS
MAXIMUM FRY SURVIVAL
FRY CAPACITY
JUVENILE SURVIVAL
ADULT SURVIVAL
Frequency
Assigned Probabilities
0 10 20 30 40 50 60 70 80 90 100
Low
Moderate
High

Fig 2

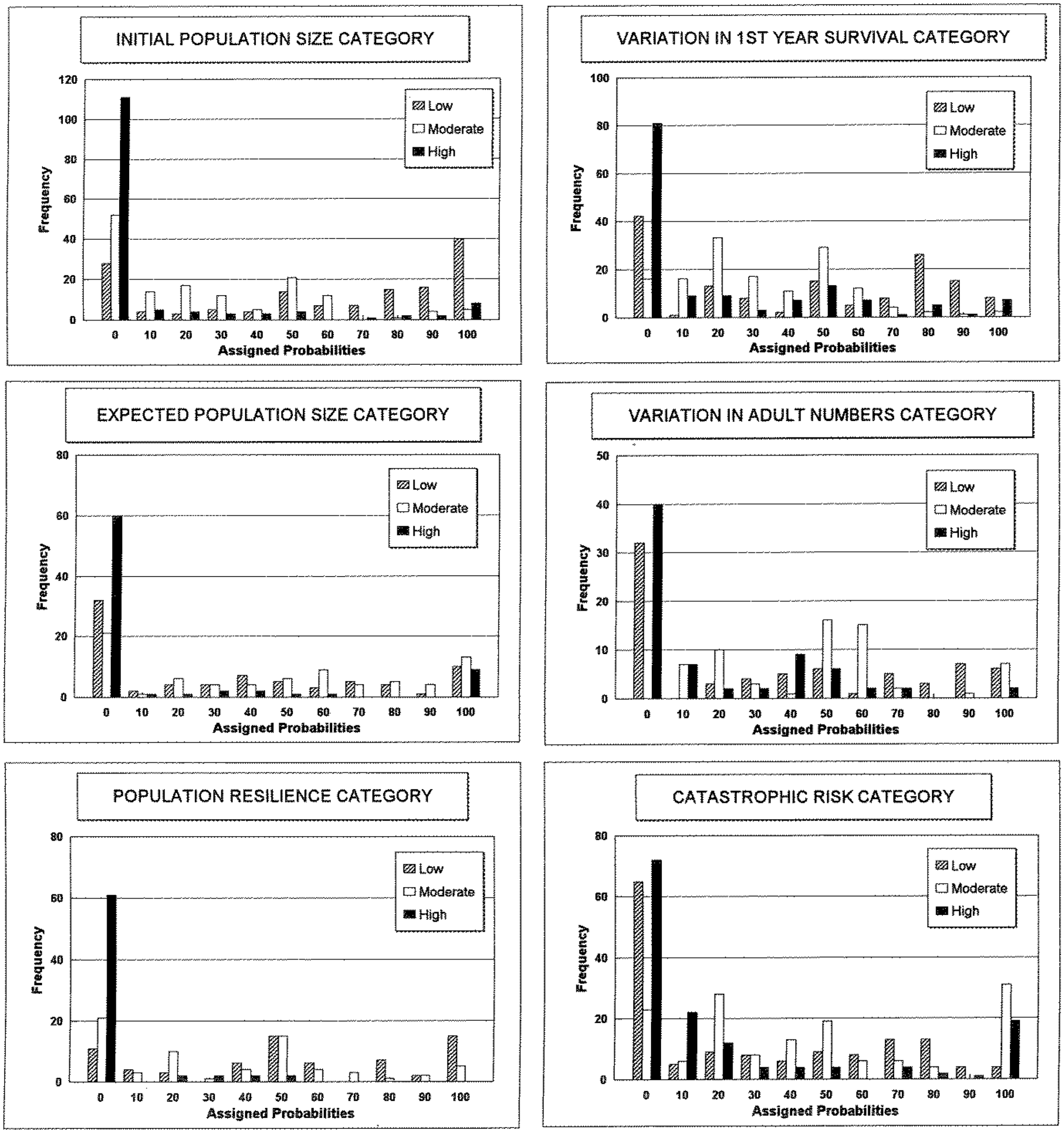
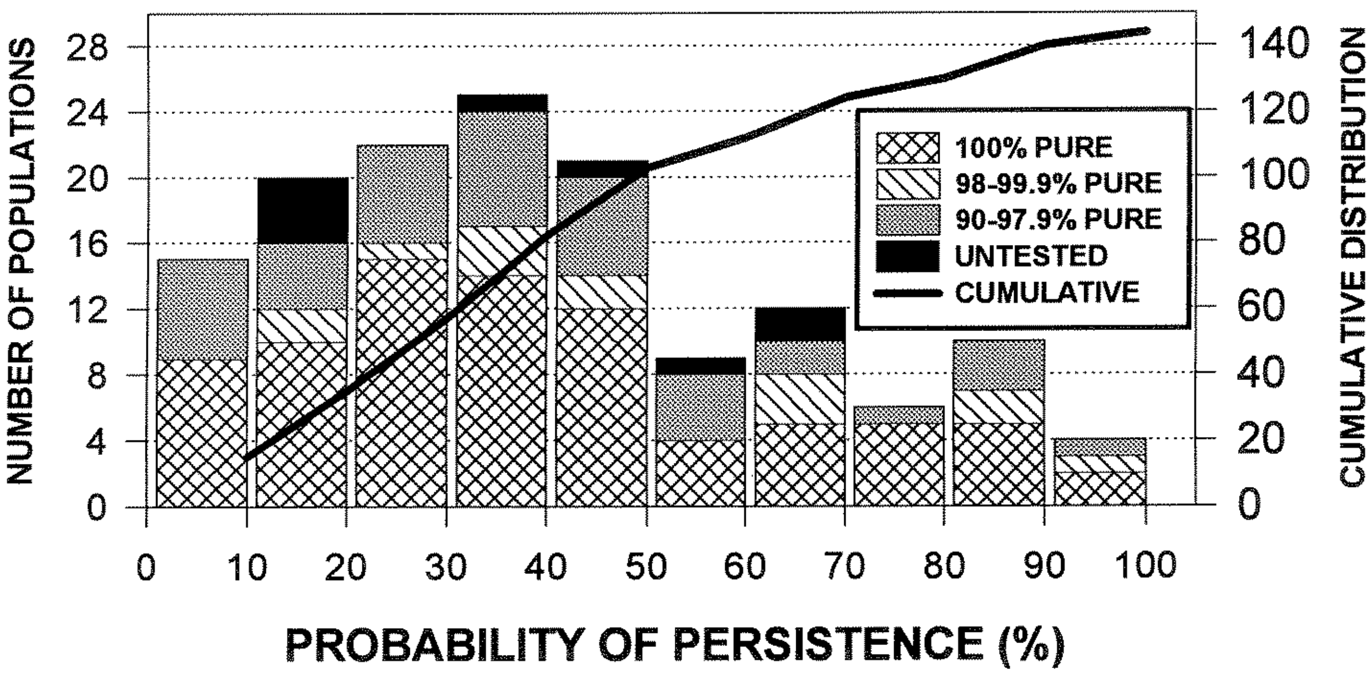
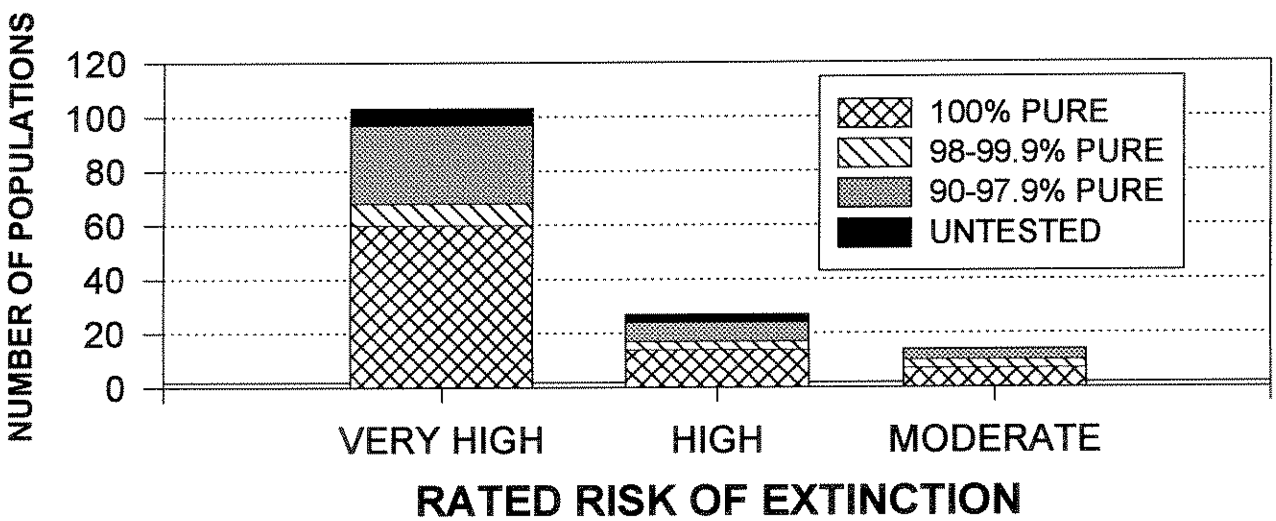

INITIAL POPULATION SIZE CATEGORY
VARIATION IN 1ST YEAR SURVIVAL CATEGORY
EXPECTED POPULATION SIZE CATEGORY
VARIATION IN ADULT NUMBERS CATEGORY
POPULATION RESILIENCE CATEGORY
CATASTROPHIC RISK CATEGORY
Frequency
Assigned Probabilities
0 10 20 30 40 50 60 70 80 90 100
Low
Moderate
High

Fig 3



NUMBER OF POPULATIONS
28
24
20
16
12
8
4
0
0
10
20
30
40
50
60
70
80
90
100
PROBABILITY OF PERSISTENCE (%)
140
120
100
80
60
40
20
0
CUMULATIVE DISTRIBUTION
100% PURE
98-99.9% PURE
90-97.9% PURE
UNTESTED
CUMULATIVE

Fig 4



NUMBER OF POPULATIONS
120
100
80
60
40
20
0
100% PURE
98-99.9% PURE
90-97.9% PURE
UNTESTED
VERY HIGH
HIGH
MODERATE
RATED RISK OF EXTINCTION

Fig 5

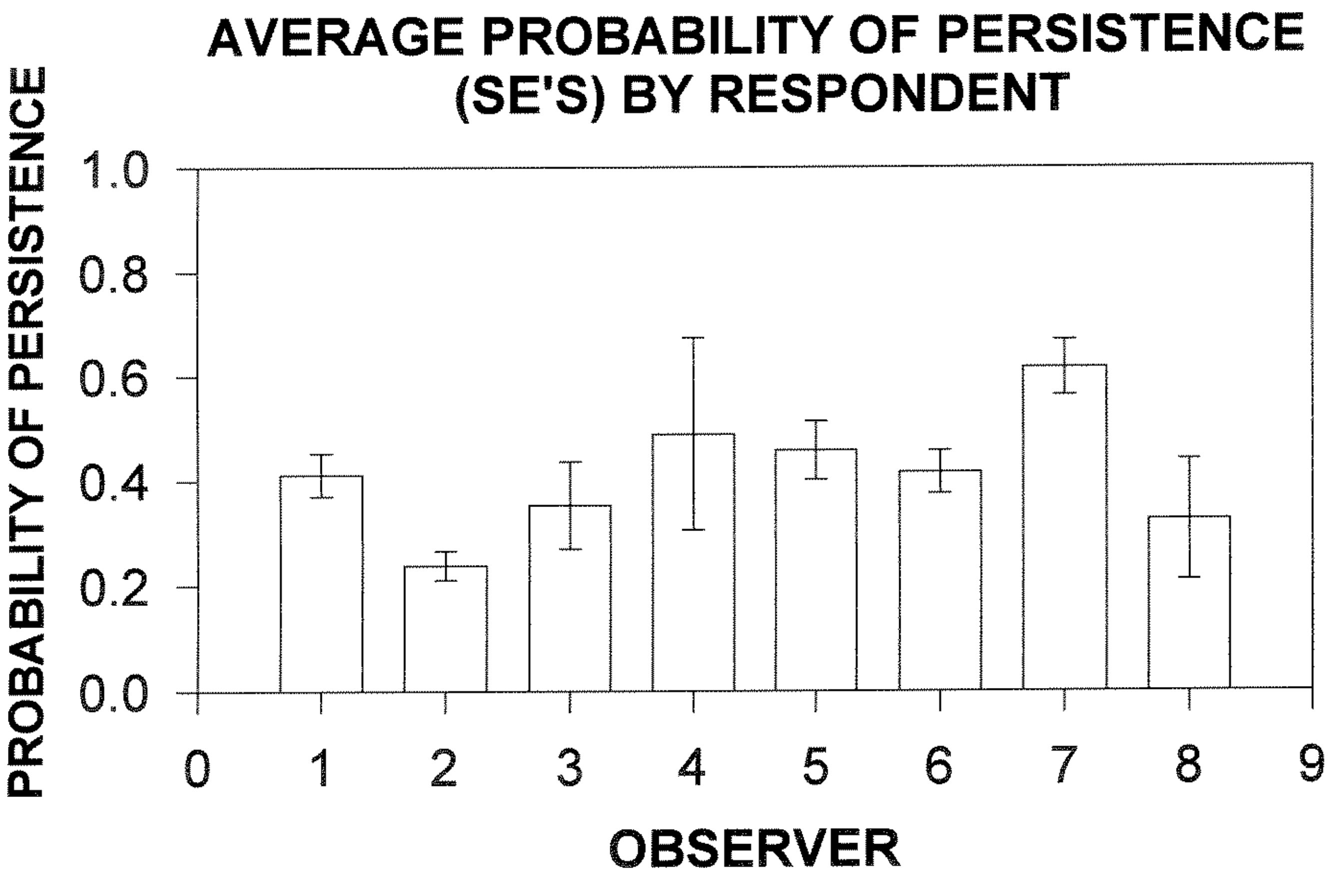

AVERAGE PROBABILITY OF PERSISTENCE
(SE'S) BY RESPONDENT
PROBABILITY OF PERSISTENCE
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
OBSERVER

Fig 6

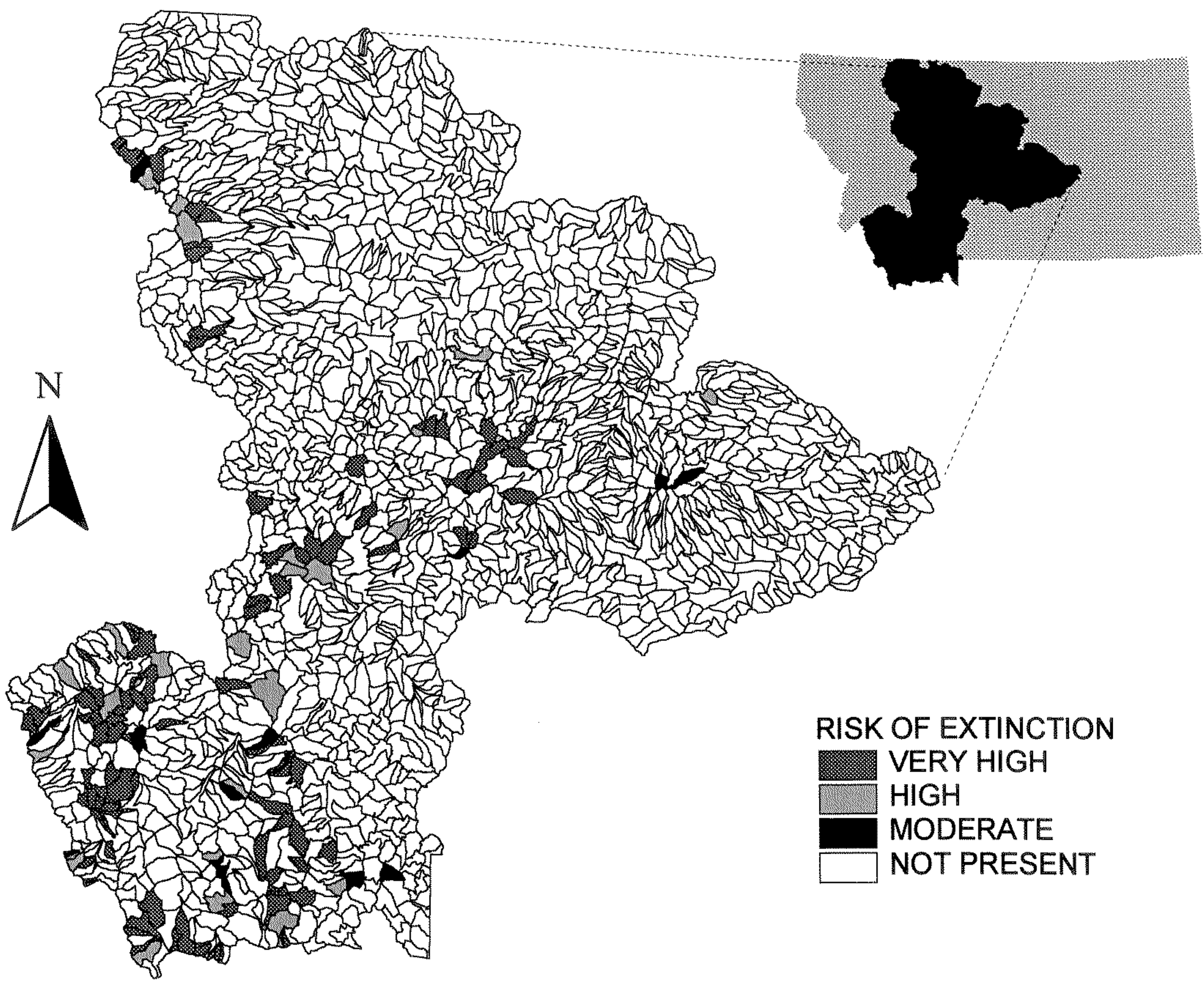


Fig 7a

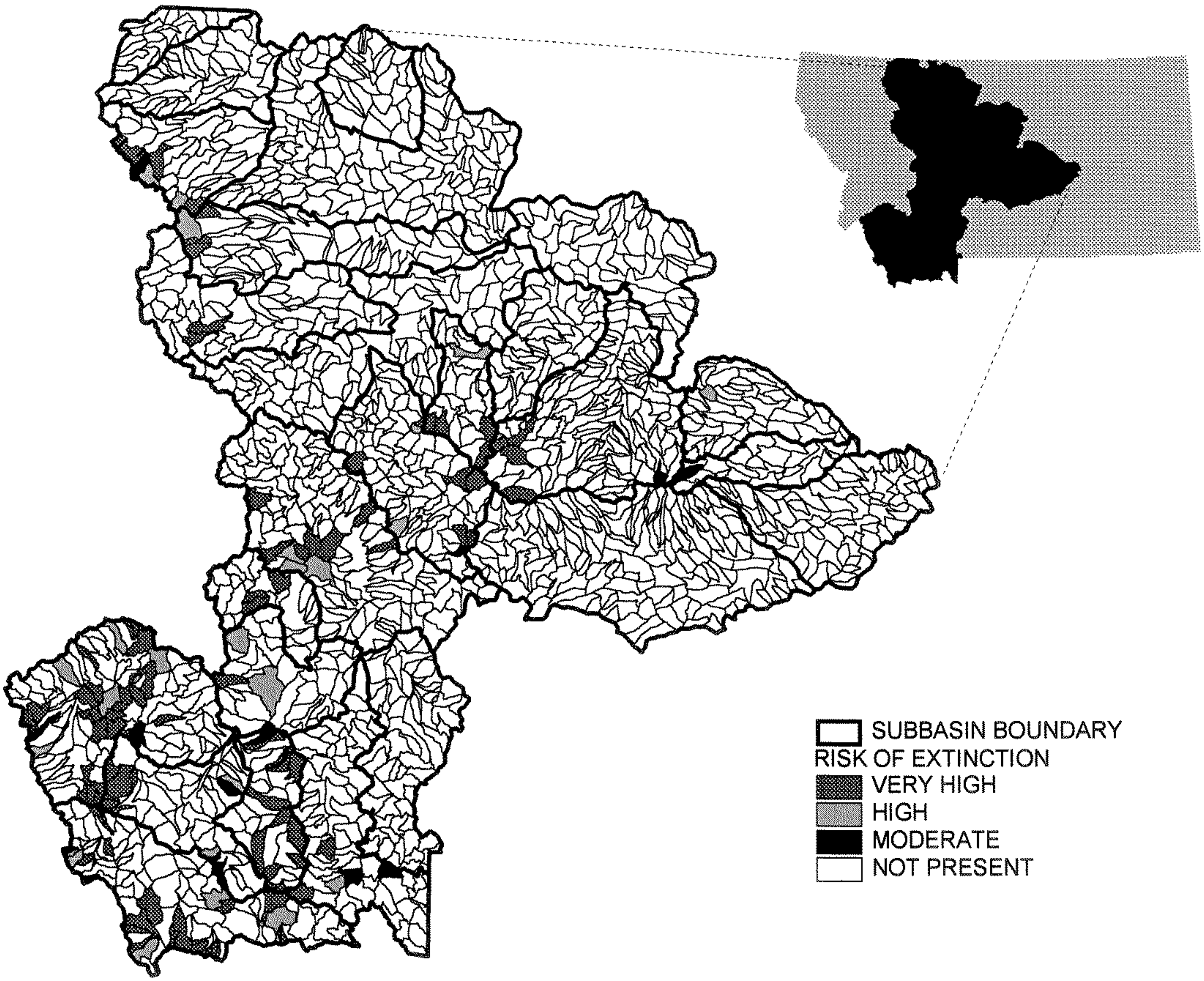

SUBBASIN BOUNDARY
RISK OF EXTINCTION
VERY HIGH
HIGH
MODERATE
NOT PRESENT

Fig 7b

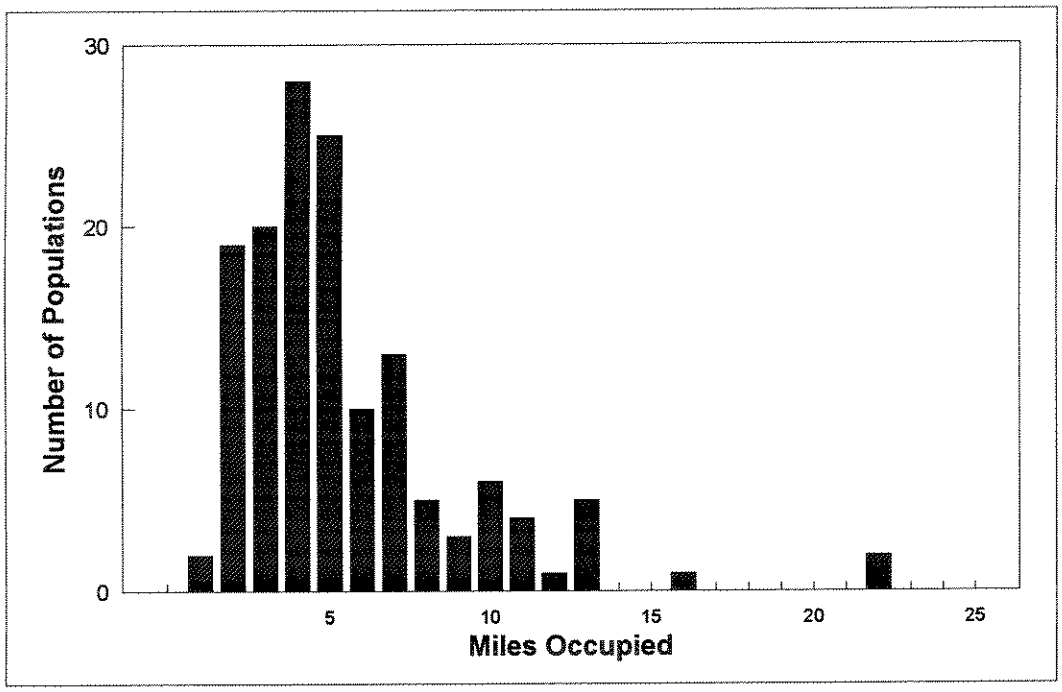


Fig 8

APPENDIX A

In general, local populations are defined by watersheds or stream systems that support self-sustaining, reproductively isolated populations. In most cases, local populations will be recognized on the basis of isolation or fragmentation of suitable habitats. A score or rating was generated by the local fisheries biologist(s) at each model "node" using directions provided in this Appendix. In addition, a narrative was required to be completed at each node identifying citations of available data and other rationale used to support the score or rating given.

The following information was used to also provided at each "node":

LIFE HISTORY CHARACTERISTICS

Quantity and Distribution of Spawning Habitat

Availability of spawning habitat (quantity and distribution) may determine whether available rearing habitat is fully seeded. Three classes of availability of spawning habitat (gravels) were defined: Low (60-80%); Moderate (85-95%); and High (100%). When spawning gravels are readily available throughout the watershed, spawning habitat would not be considered limiting to the local population. In these cases the rating would be High (100%). Unless there is clear evidence that spawning habitat is likely limiting the population, the High rating should be used. Where the quantity or distribution of spawning gravels severely limits the potential for egg deposition, resulting in underseeding of rearing habitat, the user should classify spawning habitat as severely limited. For these populations spawning success would rate between 60-80% (Low). The intermediate class would include situations where spawning habitat is limited in either quantity or distribution, corresponding to spawning success of 85-95%. The user should note that resident westslope cutthroat trout populations where females mature at relatively small sizes (lengths of 150 to 200 mm) suitable spawning habitat may consist of small isolated patches (0.2 m^2) of pea-sized gravel behind water velocity breaks.

Fecundity

Higher fecundity increases reproductive potential, resulting in higher resilience to exploitation or disturbance. Low fecundity is expected for most resident westslope cutthroat trout populations where mean body size of mature females is less than 200 mm (200-500 eggs per adult female). In resident populations where mature female size consistently exceeds 200 mm, fecundity of 500-800 eggs per female would be expected. Since resident westslope cutthroat rarely exceed 300 mm in length, moderate or high fecundity rates would not be expected. Fecundity in the 800-1,100 eggs per female range, although not expected, may occur in migratory populations were mature fish exceed 300 mm in length. It is not expected that any westslope cutthroat trout within the upper Missouri system would have fecundities over 1,100. Fecundities were rated as: Low (200-500); Moderate (500-800); High (800-1,100); and Very High (1100-1500). "Very High" **should not** be used in the upper Missouri River basin analysis.

Incubation Success

Survival at this critical life stage may strongly influence the population growth rate and resilience or the ability of the population to absorb or recover from disturbance. Where incubation and survival to emergence are not reduced due to natural or human caused habitat disruption, incubation survival would be expected to be similar to survivals documented in the field within the best spawning habitats for cutthroat trout (35% to 50%). For this level to be selected: fine sediments or sediment loading should not differ from natural conditions; channel and watershed conditions should be well within sediment/discharge equilibrium; and high water quality and favorable stream flows are maintained throughout the incubation period. The ranges were: Low (5-20%); Moderate (20-35%); and High (35-50%).

"Maximum Fry Survival" (i.e. Density Independent, Early Rearing and Overwinter Survival)

The quality of initial rearing and overwinter habitats for young-of-the-year salmonids is an important determinant of population resiliency, thus influencing temporal variability in population size. High mortality (survivals rates under 20%) during this period may restrict the capability of the population to recover from disturbance. Relative survival ranges were inferred from habitat condition. Superior habitat conditions produce high survival rates (> 30%). Extensive off channel and stream margin habitats and high levels of instream cover are important for cutthroat fry. Instream cover should create low water velocity microhabitats and visually isolate fry occupying these microhabitat sites from other instream terrestrial, and avian habitats (i.e. woody debris and substrate). Unembedded, cobble substrates should be widely available for age 0 cutthroat to use during winter. Non-native fish species, especially brook trout, are believed to have an important influence on cutthroat trout and might be particularly important in disrupted habitats. Non-native fish species should not be present, or have limited potential of introduction through natural dispersal, for an estimated survival rate of >30% to be assigned.

Where early rearing habitats are not widely distributed, where wood debris or other cover is very low, and where off channel habitats are either lacking because of channel geomorphology, or seriously degraded because of channel instability, maximum fry survival should be rated under 20%. Moderately to highly embedded substrates where alternative cover is lacking also suggest a low survival. In addition, low survival would be consistent where one or more species of non-native occur within the watershed and either are, or could be, widely distributed throughout. The influence of non-native fish species could be considered moderate only if it can be shown that the influence of that non-native species has little impact on cutthroat trout. The ranges for the classes are: 10-20% (Low); 20-30% (Moderate); and 30-40% (High).

"Fry Capacity"- Habitat Capacity for Early Rearing

The availability of habitat critical to early rearing and overwinter survival can limit the ultimate size of a population. Habitats capable of supporting more than 7,000 age 1 cutthroat trout would indicate that juvenile rearing habitat is widely distributed throughout the watershed, particularly in relation to spawning sites. For this habitat capacity to be selected, no non-native trout species would occupy, or have easy access to, the portion of habitat where this level of age 1 fish could be supported, and the length of stream occupied by cutthroat trout should be at least 4 km. Low habitat capacity would indicate watersheds where juvenile rearing habitat is in short supply, and is not widely distributed in relation to spawning sites. A low habitat capacity would indicate the habitat is capable of supporting fewer than 4,000 age 1 fish. The presence of non-native fish species, particularly brook trout, should indicate a low fry habitat capacity. Habitats described above may be restricted in availability or in distribution such that habitat for juvenile rearing becomes limiting to the population. Fry capacity classes were: Low (1,000-4,000), Moderate (4,000-7,000); and High (7,000-20,000).

Sub-adult Survival

Sub-adult survival has an important influence on the structure of salmonid populations, influencing year-class strength and resilience. Survival from age 1 to adult may vary substantially between resident and migratory life history forms and be strongly influenced by human caused disturbance and environmental conditions. Interactions with non-native salmonids, especially brook trout, may influence sub-adult survival. Competitive for space and food, or direct mortality from predation may reduce survival of sub-adults. Sub-adult survival rates in the high range (38-50%) would generally be expected for resident populations that do not migrate out of the local watershed, and where high quality pools, complex cover, or other habitats important for rearing and overwinter are widely available. The population would be allopatric (the only fish species present) or exist within native species assemblages. Moderate sub-adult survival rates (26-38%) may occur in allopatric populations occupying degraded habitats; or in populations occupying high quality habitats if they are exposed to competition or predation influences from non-native fishes. Low survival rates (<26%) during this stage would be expected for populations in degraded habitats with limited rearing and over-wintering habitats and where non-native species are present. Low sub-adult survival would also be expected for migratory populations that must use migratory corridors and associated rearing environments (larger rivers, lakes, ocean) where human caused or natural changes (dams and diversions, introduced and or enhanced predator populations, water quality) have significantly reduced survival. The ranges for sub-adult survival are: Low (14-26%); Moderate (26-38%); and High (38-50%).

Adult Survival

A number of factors may influence adult survival (annual survival during and following the year of first maturity), but exploitation is particularly common for westslope cutthroat. For moderate or slow growing populations in unproductive waters, unrestricted fishing effort of 100 to 200 angler hours per km can result in serious over exploitation of mature fish (Rieman and Apperson 1989). The three equal classes are: Low (10-30%); Moderate (30-50%); and High (50-70%).

Age of First Maturity (age 3 to age 6)

Age of maturity, longevity, and fecundity will influence reproductive potential and the potential growth rate of a population. Recent information on westslope cutthroat populations in the Upper Missouri Basin (Downs and Shepard, in prep.) give the following proportions for age at first maturity in females:

age 3: 30%
age 4: 40%
age 5: 20%
age 6: 10%.

Unless specific data exists for the population being evaluated, it is suggested these proportions be used.

POPULATION LEVEL CHARACTERISTICS

The model provides two ways to derive local population characteristics. These characteristics can be derived using information output from the individual life stage portion of the model, or can be input by the user based on their knowledge of an individual population. The local population characteristics which the BayVAM model use are population size and resilience, temporal variability, and catastrophic risk.

Since it is possible for the equilibrium population size and population resiliency to come from two levels, the life stage or population levels, some weighting of the evidence is required. Thus, module users must state whether they wish the population-level information to be given less, equal, more, or much more weight than the life-stage information. In general, life stage information should be weighted more than population information unless time trend population data has been collected.

Initial Population Size

The size of a population influences risk of extinction through environmental variability. Although small watersheds are likely to support smaller populations than large watersheds, population size is best inferred with some basic information on fish density and distribution. Recent estimates of several isolated populations demonstrate that watersheds with only a few kilometers of available habitat can support tens to thousands of individuals. If the data necessary to extrapolate an approximation are available they should be used. Total populations that exceed 850 adults and are not expected to drop below these numbers are considered "high". Adult populations that are consistently below 450 individuals should be considered "low". When estimating adult numbers, consider all mature fish alive in a given year, not just those spawning. It should be noted that initial population size has relatively little effect on model outputs other than setting initial conditions.

Expected Population Size (high, moderate, low, zero)

The information collected at the individual life stage level collectively will predict an expected equilibrium population size. If independent data or information are available that would lead to an independent estimate of the expected number of adults to be found within the basin, this can be included in the analysis. A "high" score would correspond to an estimated adult population size of greater than 850 adults; "moderate" = 450-850 adults; "low" = less than 450. If population monitoring data exists which shows a consistent downward trend, the population is likely headed to extinction, so an equilibrium size of "zero" is appropriate.

Population Resilience (high, moderate, low, none)

Populations with negative growth rates face a "deterministic" extinction unless stabilized by compensation in survival or reproductive rates. A population may have no clear trend in abundance but its inherent resilience will still determine its ability to resist or recover from future disturbance. Both the trend and resilience of a population will be the integration of survival, age at maturity and reproductive potential. The characteristics defined under Individual Life Stages should provide the necessary evidence of resilience but often information will be limited or conflicting. Trends in populations and inferences about resilience may also be possible from information on the population as a whole that will either support or outweigh information available for individual life stages.

A "high" population resilience should show no negative trend in abundance with at least 10 years of good density or population estimates. If the population has been reduced by a short term disturbance, it is clearly recovering. Alternatively densities should be consistent with those reported for strong populations in good habitat. Local habitat quality should be high, and human disturbance or recent natural events should not have altered watershed condition or channel equilibrium. Available estimates of growth and survival should be consistent with other strong populations. If a migratory form is present, the complementary environments (e.g. larger river, lake, ocean, and migratory corridors) do not impose any unusual or increased mortality (e.g. fishing, predation, overwinter survival, smolt survival).

"Low" resilience could be evident from a slow decline in population trend information although inter-annual variability may make the trend statistically insignificant. Low resilience might be expected if habitat has been disrupted to some degree such that a significant reduction in abundance, growth, or survival of any life stage is anticipated in relation to the best habitats and likely will not recover to pre-disturbance conditions within one to two generations. Alternatively a low resilience should be characteristic of a population that appears stable at densities well below those expected for the system; or a population that has been depressed by a short term or recently eliminated disturbance (e.g. exploitation) but shows no evidence of recovery.

A "None" resilience should be concluded from any significant negative trend in number that has extended for several generations. A decline might be inferred from a substantial reduction in population size that can be associated with a continuing, irreversible (in the short term) loss of critical habitat quality or quantity.

Temporal Variability in First Year Survival or Adult Numbers (Juvenile CV and Adult CV in Model)

The most influential determinant of temporal variability in population number is believed to result from environmental variation affecting spawning success and early rearing. Variation in population size may be strongly influenced by the natural disturbance regime but also by the condition of the local habitat and distribution of the population through space. In our underlying model, temporal variability in the population results from fluctuations in juvenile survival. It is mitigated by the degree of population resilience, i.e., more resilient populations exhibit lower levels of variability in population numbers. If information is available on variation in first year survival, it can be incorporated into the analysis in the "Juvenile CV" node. In addition, we can use information on the coefficient of variation in adult numbers to infer both environmental variability and population resilience. Estimates of the coefficient of variation in either juvenile survival/abundance or in total/adult population number are best made from extended time series of population size or density. If this type of information is available, it should provide a more realistic of value the variability experienced by that population, especially if the time series of data is relatively long (ie. ten years or longer). If this data is unavailable, inferences can be made from habitat and population age structure information, however, the confidence in classes assigned from these type of data should be lower.

"Low" variability in juvenile survival could be inferred from low variability in channel events such as extreme flows, or other environmental conditions that likely influence spawning and incubation, and in systems with highly diverse, widely distributed and complex habitats available all life stages. In general, habitat complexity and spatial diversity should strongly influence temporal variability even in noisy environments. The availability of refuges and distribution of the population and critical life stages over a broader area makes the whole population less vulnerable to localized disturbance. Such complexity is characteristic of large watersheds where all resident life stages or necessary habitats (spawning, early rearing) are widely distributed throughout. Ideally multiple tributary streams would exist, each being capable of supporting all life stages should others be lost. There should be no evidence or expectation of year class failures and all age classes would be fully represented in population samples (Coefficient of Variation [CV] in fry survival less than 40%).

"High" temporal variability is expected in systems where survival and recruitment clearly respond to frequent (1 or more per generation) events. Year-class failures would be common and population samples would often show uneven distribution of age classes. High variability might be anticipated in simplified or spatially restricted habitats critical for individual life stages, and in watersheds with only a single tributary stream available for any life stage, especially where extreme flow events (rain on snow, drought) or bedload scour is common. (CV in fry survival is between 65% and 90%).

Evidence temporal variability based on time series of adult numbers can be divided into four categories based on the CV in the adult index: low = CV <25%, moderate = 25% <CV <50%, high = 50% <CV <100%, and very high = CV > 100%.

Catastrophic Risk (high, moderate, low)

Catastrophic events are low frequency events that substantially affect all members of a population. Catastrophic impacts on habitat may take years to recover. Thus, populations are at risk through the event itself, but also are likely to be less resilient and thus at greater risk to some future disturbance following the event.

Massive debris flow and scour, droughts, volcanic eruptions, earthquakes, glaciers, fire storms, toxic spills, and dam failures are all examples of catastrophic events for salmonid populations. Catastrophic events are by nature unpredictable and have been rarely considered in viability assessments. Such events, however, may strongly influence the risks of extinction for many populations. The potential for a catastrophic event will be influenced by physiographic characteristics of the watershed, and by the distribution of fish, critical habitats or refuge . In some cases human disturbance or development may significantly increase the potential for catastrophe from natural extreme events. Some poorly managed watersheds, for example, may suffer catastrophic changes to stream habitats as a result of an extreme hydrologic event within a stream channel impacted by management or by debris or sediment torrents triggered by a combination of natural (climatic) and management (logging and roading) conditions.

A "high" catastrophic potential would be appropriate where a half or more of the population (50% or more) could be lost in a single event expected within 20 to 70 years. Watersheds with high risk also are prone to major channel events such as debris torrents, massive bedload scour or extensive channel dewatering, perhaps because of the combination of intensive watershed disruption and high frequency of extreme hydrologic events (rain on snow, drought). Major fires might result in catastrophic loss in portions of a watershed. Fire likely would not have a high catastrophic potential unless the population were restricted to a relatively small area (single stream), or if the fire occurred in concert with other disturbance of the watershed substantially increasing the risk of a hydrologic event.

"Moderate" catastrophic potential is likely for most watersheds exposed to some human disturbance. This level corresponds to an event expected on a frequency of 70-120 years.

"Low" catastrophic potential could be appropriate for large watersheds that essentially are not exposed to human disturbance or development, are stable geologically and hydrologically, and have populations with all life stages, range of elevations, and multiple tributary streams. Probability of a catastrophic event less than 1 in 120 years.