SUPPLEMENTAL APPENDIX S2 to: Peterson et al. (2008), Can. J. Fish. Aquat. Sci. **65**(4): 557-573.

SUPPLEMENTAL APPENDIX S2.

Comparison of alternative Bayesian belief networks to analyze assumptions about the variance in population growth rate for westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) and the consistency of predictions under the isolation and invasion analysis and decision Bayesian belief network (*InvAD* BBN)

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Introduction

The goal of the research reported in Peterson et al. (2008) was a tool to help biologists concerned with conservation of westslope cutthroat trout (WCT, *Oncorhynchus clarkii lewisi*) and to quantify trade-offs between the threats of isolation and invasion by nonnative brook trout. The result was the isolation and invasion analysis and decision (*InvAD*) Bayesian belief network (BBN, collectively InvAD BBN).

The *InvAD* BBN was based on two underlying population models used to characterize the growth and persistence of WCT – a stage-based matrix population model and the diffusion-approximation persistence model of Dennis et al. (1991) (see Peterson et al. 2008; see Supplemental Appendix S1[4]). The range of population growth rates and the range of variances in population growth rates were based on the synthesis of McIntyre and Rieman (1995). Given the underlying models, the *InvAD* BBN assumed that the variance in population growth rate for WCT was inversely related to population size, citing evidence of this relationship in populations of another wide-ranging salmonid species native to the region (e.g., Rieman and McIntyre 1993). The conditional probabilities in the link matrices (CPTs) for nodes representing *population growth rate* and *persistence* of WCT were estimated with the stage-based matrix and Dennis et al. models, respectively. Because little work has been done to quantify population growth rates or variances in WCT or any salmonid populations, our assumptions about the variance in those growth rates are uncertain. Conceivably, the variance in population growth rate for WCT may range widely among populations and may even be independent of population size. Differences in the characteristics of population growth and the underlying CPT had the potential to affect the BBN's predictions and resulting management guidance, so we constructed several alternate BBNs to examine the importance of our assumptions.

Methods

Concurrent with the development of *InvAD*, we developed three competing BBN's conceptually identical to *InvAD* (i.e., with the same box-and-arrow diagram as Figure 1 in Peterson et al. 2008) but different CPTs for one or two nodes. We compared the behavior of these alternative models to *InvAD* as summarized in Peterson et al. (2008). To contrast our basic

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[4] Additional supplementary information for Peterson et al. (2008) can be found in SUPPLEMENTAL APPENDIX S1, available on the Canadian Journal and Fisheries and Aquatic Sciences web site (cjfas.nrc.ca).

assumption that the variance in population growth rate is inversely related to population size, we built alternate BBNs where the CPT for *persistence* assumed that the variance in population growth rate was either independent of population size with a constant value of 0.2 (low constant variance) or independent of population size with a value of 0.8 (high constant variance). To determine if expert judgment strongly deviated from the output of the matrix and Dennis et al. models, we also developed a BBN where the CPT for *population growth rate* and *persistence* were based on opinion as informed by empirical data, professional experience, etc. (opinion only).

We conducted two analyses using *InvAD* and the three alternate models. First, we compared the overall agreement in the sensitivities of *population growth rate* and *persistence* to information at other nodes using Kendall's coefficient of concordance (Sokal and Rohlf 1981). Sensitivities were based on entropy reduction values appropriate for discrete or categorical variables (see Marcot et al. 2006). This concordance test indicates whether the relative influence of particular variables (nodes) differed among the alternative models. Second, we compared qualitative model behavior (i.e., general patterns in predictions) among alternatives using the hypothetical management scenario from Peterson et al (2008). Briefly, we generated a set of predictions for each alternative model using 48 different scenarios based on a range of initial environmental conditions typical of WCT streams in the northern Rocky Mountains (see Table 3 in Peterson et al. 2008). We subsequently examined whether the predictions and general patterns resulting from each model were generally consistent (i.e., would provide similar guidance to biologists).

Results and Discussion

We did not find strong differences in the predicted invasion-isolation trad-eoff among the four BBNs. Under uniform prior probabilities for all input nodes, the rank order in sensitivities of *persistence* (to other nodes) were highly concordant among the four models (Kendall's W = 0.921, $p < 0.001$, $n = 21$ variables, where $W = 1$ is perfect concordance; Table S2-1 and Table 4 of Peterson et al. 2008). Similarly, the sensitivity of *population growth rate* (to other nodes) was concordant between *InvAD* and the opinion only alternative ($W = 0.982$, $p = 0.012$, $n = 17$ variables). The low constant variance and high constant variance alternatives were not included in the comparison for the *population growth rate* node because they had identical CPTs.

Predictions generated with *InvAD* were generally consistent with trends and trade-offs observed with the other three alternatives (cf. Table S2-2 with Figure 3 in Peterson et al. 2008). That is, all four BBNs predicted that: probability of WCT persistence increased with increasing *effective network size*, an *invasion barrier* either increased (for resident, isolated population) or decreased (for migratory, connected population) the probability of persistence, and *habitat degradation* and *fishing exploitation* either moderated benefits or increased threats from intentional isolation. Nonetheless, relative differences in predictions among models indicated that alternatives could be either more or less optimistic about expected fate of WCT populations than the *InvAD* BBN in particular situations (cf. Table S2-2 with Figure 3 in Peterson et al. 2008).

The opinion only BBN made no explicit assumption about the variance in population growth rate and produced results qualitatively similar to the other three BBNs. Differences in the influence of certain variables were apparent, but again the general predictions and trade-offs identified by using the opinion only BBN were consistent with the other BBNs. The opinion only alternative was more optimistic about the fate of all smaller populations in the absence of an invasion barrier and about the benefits of an invasion barrier for small, resident populations. This alternative was slightly more pessimistic about the fate of isolating smaller, migratory populations connected to other WCT populations (cf. Table S2-2 with Fig. 3 in Peterson et al. 2008).

Predictions were generally consistent among models, but comparative differences could be attributed to the relative influence of a few key variables. In general, predictions from the opinion only BBN were more sensitive to the presence of and connection with other populations, whereas the other three models were more sensitive to the target population's inherent demographic characteristics. For the three BBNs (*InvAD*, low constant variance, and high constant variance) that had two of their CPTs directly based on output from analytical models, the probability of *persistence* was most sensitive to the state probabilities at the node for *population growth rate* (e.g., Table 4 in Peterson et al. 2008). In contrast, for the opinion only BBN *persistence* was most sensitive to probabilities at *colonization and rescue* (Table S2-1).

We concluded that basic results and potential application of our model (i.e., *InvAD* BBN) are not seriously constrained by our key assumptions regarding population growth rates. Clearly, more research is needed to refine the estimates for this process and our understanding of the details in WCT population dynamics. As with any population viability model based on the approximations of complex population dynamics, our results cannot be viewed as estimates of the true probabilities of persistence; they can, however, provide a measure of relative differences in threats associated with isolation and brook trout invasion (Beissenger and Westphal 1998; Reed et al. 2002).

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Table S2-1. Sensitivity of *persistence* and *population growth rate* for westslope cutthroat trout (WCT) to all contributing nodes in four alternative BBNs (*InvAD*, low constant variance, high constant variance, and opinion only) based on the conceptual model presented in Figure 1 of Peterson et al. (2008). Survival and population growth rate nodes refer to WCT. Sensitivity values were calculated using a uniform prior probability distribution for each of the 11 input nodes. Nodes refer to common environmental conditions or westslope cutthroat trout unless otherwise noted.

	Sensitivity (entropy reduction values) [a]				
	Persistence [b]			Population growth rate	
Node [c]	Low constant variance	High constant variance	Opinion	InvAD	Opinion
Population growth rate	0.27322	0.11268	0.07663	-	-
Effective network size	0.07173	0.0608	0.04662	-	-
Subadult-adult survival	0.07231	0.03148	0.01889	0.21536	0.13675
Effective life history	0.05816	0.03385	0.03089	0.13597	0.11113
Egg to age-1 survival	0.044	0.01686	0.00995	0.14783	0.23167
Invasion barrier	0.02986	0.02302	0.04053	0.04815	0.02675
Colonization and rescue	0.02583	0.02664	0.07866	-	-
Juvenile survival	0.02881	0.01123	0.00856	0.09396	0.18305

	Sensitivity (entropy reduction values) [a]				
	Persistence [b]			Population growth rate	
Node [c]	Low constant variance	High constant variance	Opinion	InvAD	Opinion
Habitat degradation	0.02177	0.00841	0.00601	0.06927	0.07463
Fishing exploitation	0.01891	0.00757	0.00248	0.0585	0.03052
Potential spawning and rearing habitat	0.01668	0.00732	0.00651	0.0489	0.09689
Potential life history	0.01557	0.00757	0.00281	0.05471	0.03737
Invasion strength (of brook trout)	0.00782	0.00671	0.01575	0.0008	0.00786
Temperature	0.00419	0.00186	0.00166	0.01327	0.02953
Connectivity	0.000184	0.00374	0.01963	-	-
BKT population status	0.00208	0.002	0.00651	0.00319	0.00771
Stream width	0.0023	0.00103	0.00088	0.00757	0.01625
BKT connectivity	0.00137	0.00072	0.00029	0.00559	0.00533
Potential BKT spawning and rearing habitat	0.00064	0.00026	0.00032	0.0019	0.00496
Gradient	0.00043	0.00019	0.00017	0.00141	0.0031
Hydrologic regime	0.00003	0.00001	0.00001	0.0001	0.0001

[a] Sensitivity values (entropy reduction) calculated using the software program Netica following the formula presented in Marcot et al. (2001; 2006). Note that the use of trade or firm names (e.g., Netica) is for reader information only and does not imply endorsement by the US Department of Agriculture or the US Department of Interior of any product or service.

[b] Sensitivities for *persistence* under the *InvAD* BBN are presented in Table 4 of Peterson et al. (2008).

[c] The rank order of nodes preserved after Table 4 of Peterson et al. (2008).

Table S2-2. Predicted probability of presence for westslope cutthroat trout (WCT) after 20 years under three alternative BBNs and the scenarios portrayed in the hypothetical management example described in Table 3 of Peterson et al. (2008). "Low constant variance" and "High constant variance" networks have conditional probability tables for *persistence* developed assuming a population growth rate variance of 0.2 and 0.8, respectively, and using the model of Dennis et al. (1991). The "opinion only" network has conditional probability tables for *population growth rate* and *persistence* parameterized using expert opinion.

	Node and state			Probability of WCT being present after 20 yr					
				Effective network size					
				Very small		Medium		Very large	
BBN	Fishing	Life history/ Connectivity	Habitat degradation	No Barrier	Barrier	No Barrier	Barrier	No Barrier	Barrier
Low constant variance	Low	Migratory/Connected	Pristine	0.67	0.58	0.91	0.90	0.96	0.97
			Degraded	0.46	0.14	0.75	0.43	0.87	0.62
		Resident/Isolated	Pristine	0.13	0.58	0.40	0.90	0.59	0.97
			Degraded	0.068	0.14	0.27	0.43	0.47	0.62
	High	Migratory/Connected	Pristine	0.36	0.21	0.67	0.54	0.82	0.72
			Degraded	0.25	0.037	0.56	0.22	0.76	0.43
		Resident/Isolated	Pristine	0.042	0.21	0.22	0.54	0.42	0.72
			Degraded	0.024	0.037	0.18	0.22	0.38	0.43

	Node and state			Probability of WCT being present after 20 yr					
				Effective network size					
				Very small		Medium		Very large	
BBN	Fishing	Life history/ Connectivity	Habitat degradation	No Barrier	Barrier	No Barrier	Barrier	No Barrier	Barrier
High constant var	Low	Migratory/Connected	Pristine	0.42	0.28	0.80	0.65	0.90	0.79
			Degraded	0.31	0.097	0.67	0.32	0.79	0.46
		Resident/Isolated	Pristine	0.094	0.28	0.31	0.65	0.45	0.79
			Degraded	0.067	0.097	0.25	0.32	0.38	0.46
	High	Migratory/Connected	Pristine	0.26	0.13	0.60	0.39	0.74	0.53
			Degraded	0.20	0.054	0.52	0.22	0.68	0.35
		Resident/Isolated	Pristine	0.055	0.13	0.22	0.39	0.34	0.53
			Degraded	0.047	0.054	0.20	0.22	0.32	0.35
Opinion only	Low	Migratory/Connected	Pristine	0.75	0.36	0.82	0.55	0.97	0.70
			Degraded	0.69	0.23	0.77	0.38	0.94	0.58
		Resident/Isolated	Pristine	0.19	0.36	0.33	0.55	0.55	0.70
			Degraded	0.12	0.23	0.24	0.38	0.51	0.58

	Node and state			Probability of WCT being present after 20 yr					
				Effective network size					
				Very small		Medium		Very large	
BBN	Fishing	Life history/ Connectivity	Habitat degradation	No Barrier	Barrier	No Barrier	Barrier	No Barrier	Barrier
	High	Migratory/Connected	Pristine	0.68	0.30	0.76	0.47	0.93	0.64
			Degraded	0.65	0.19	0.73	0.32	0.91	0.55
		Resident/Isolated	Pristine	0.11	0.30	0.22	0.47	0.51	0.64
			Degraded	0.076	0.19	0.17	0.32	0.48	0.55