

**SUPPLEMENTAL APPENDIX S1.**

**Definitions, justifications, and conditional relationships for variables (nodes)  
comprising the isolation and invasion analysis and decision Bayesian belief  
network (InvAD BBN)**

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## Summary

Peterson et al. (2008) presented a tool to help biologists concerned with conservation of westslope cutthroat trout (or WCT, *Oncorhynchus clarkii lewisi*) quantify tradeoffs between the threats of isolation and invasion by nonnative brook trout (or BKT, *Salvelinus fontinalis*). The result was an isolation and invasion analysis and decision Bayesian belief network (*InvAD* BBN). We developed this Bayesian belief network (BBN) following the general procedures outlined elsewhere (Cain 2001; Marcot et al. 2006; Marcot 2007). We began with a series of meetings between several of the authors and biologists working with WCT throughout its range. We identified the primary environmental conditions associated with WCT, brook trout, and their ecological interactions. Subsequently, the authors developed conceptual models (i.e., box-and-arrow diagrams; synonymous with the terms “influence diagram” in Marcot et al. 2006 or “directed acyclic graph” in Pearl 1991) that depicted the hypothesized causal relationships and processes important to these species. The conceptual models were refined through iterative discussion to capture only the essential (and quantifiable) relationships in their simplest possible forms. The final conceptual model (Fig. 1 in Peterson et al. 2008) was converted to a Bayesian belief network (Fig. S1-1) by quantifying the conditional relationships among the attributes and processes represented by the diagram. Each network variable or *node* was described as a set of discrete states that represented possible conditions or values given the node’s definition. Arrows represented dependence or a cause-and-effect relationship between corresponding nodes. Conditional (quantitative) relationships among nodes were represented by conditional probability tables (CPTs) that quantify the combined response of each node to its contributing nodes, along with the uncertainty in that response. The completed BBN (*InvAD*) contained 22 variables (nodes), so for brevity Peterson et al. (2008) presented only concise definitions for each node (see Table 1 in Peterson et al. 2008), generalized each node’s influence, and summarized the quantitative conditional relationships among them. A representative example of these quantitative conditional relationships (i.e., CPTs) was given for a single node (see Table 2 in Peterson et al. 2008), but there are 11 such CPTs that underlie the *InvAD* BBN.

The following sections present more detailed node and state definitions along with the underlying scientific support for the ecological process or environmental condition represented by each of the 22 nodes in the *InvAD* BBN, and the quantitative conditional relationships (CPTs)

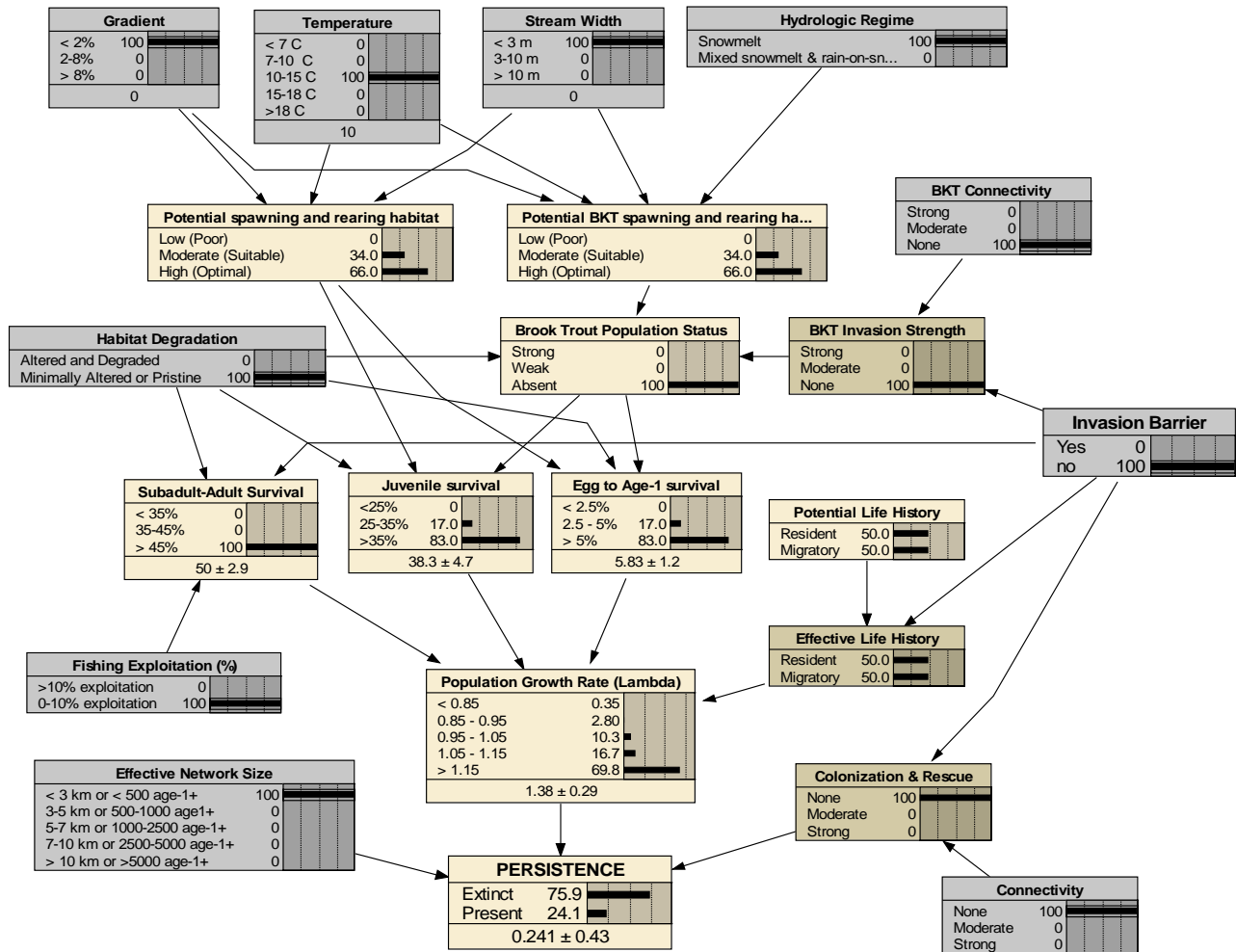
for each of the 11 nodes that have two or more parents (i.e., contributing nodes) (Tables S1-1 to Tables S1-11)<sup>4</sup>.

A hyperlinked list of nodes definitions (left column) and associated CPTs (right column) follows, and nodes refer to common environmental conditions or westslope cutthroat trout (WCT) unless specifically noted:

Node name	Conditional probability table (CPT)
<a href="#">Temperature</a>	-
<a href="#">Gradient</a>	-
<a href="#">Stream width</a>	-
<a href="#">Hydrologic regime</a>	-
<a href="#">Potential spawning and rearing habitat</a>	<a href="#">Table S1-1</a>
<a href="#">Potential BKT spawning and rearing habitat</a>	<a href="#">Table S1-2</a>
<a href="#">BKT connectivity</a>	-
<a href="#">Invasion barrier</a>	-
<a href="#">Invasion strength (for brook trout)</a>	<a href="#">Table S1-3</a>
<a href="#">Habitat degradation</a>	-
<a href="#">Brook trout population status</a>	<a href="#">Table S1-4</a>
<a href="#">Fishing exploitation</a>	-
<a href="#">Egg to age-1 survival</a>	<a href="#">Table S1-5</a>
<a href="#">Juvenile survival</a>	<a href="#">Table S1-6</a>
<a href="#">Subadult-adult survival</a>	<a href="#">Table S1-7</a>
<a href="#">Potential life history</a>	-
<a href="#">Effective life history</a>	<a href="#">Table S1-8</a>
<a href="#">Population growth rate</a>	<a href="#">Table S1-9</a>
<a href="#">Connectivity</a>	-
<a href="#">Colonization and rescue</a>	<a href="#">Table S1-10</a>
<a href="#">Effective network size</a>	-
<a href="#">Persistence</a>	<a href="#">Table S1-11</a>

<sup>4</sup> CPTs for three alternate or competing BBNs that have box-and-arrow identical to *InvAD* are also presented (see Tables S1-9 and S1-10). Analyses of results from the alternative models are presented in SUPPLEMENTAL APPENDIX S2, available on the Canadian Journal and Fisheries and Aquatic Sciences web site (cjfas.nrc.ca).

**BBN to analyze tradeoffs between brook trout invasion versus intentional isolation of westslope cutthroat trout**



InvAD Version 1.1, 13 February 2007  
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**Fig. S1-1.** The isolation and invasion analysis and decision Bayesian belief network (*InvAD* BBN) as represented in the Netica modeling software. The black horizontal bars within each node (box) indicate the probability (%) of being in a particular state. (Note: 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.)

**Node and state definitions - *temperature***

*Temperature* is defined as the mean “summer” temperature over the stream network approximately July 15 through September 15. This period is roughly symmetrical about the time of maximum temperatures observed in mountain streams of the northern interior western US (Rieman and Chandler 1998). Temperatures are believed to have an important influence on habitat potential for both brook trout and cutthroat trout primarily through growth and the demographic processes related to growth. The five states for the *temperature* variable (node) are:

<i>Temperature</i>	
State name	Values
Very low	<7°C
Low	7-10°C
Optimum	10-15°C
High	15-18°C
Very high	>18°C

The definition and states for *temperature* were authored by KDF and BER.

*Background and justification - Temperature*

Temperature can impose important constraints on growth (Bear 2005; Bear et al. 2007; McMahan et al. 2007) and demographic processes related to growth of both cutthroat and brook trout (Adams 1999; Coleman and Fausch 2007a, 2007b). Ultimately temperature is believed to constrain distributions, abundances and resilience of populations of these and related species in the stream habitats that are accessible to them (e.g., Paul and Post 2001; Rieman et al. 2006). Temperature can also mediate the interaction between species. In laboratory experiments De Staso and Rahel (1994) found that brook trout were able to dominate cutthroat trout at higher temperatures (20°C), but that neither species had an advantage at lower temperatures (10°C). For these reasons we believe that temperature will influence both the distribution and the interactions of cutthroat and brook trout even though they appear to have similar temperature optima. Both species can persist over a range of mean temperatures from approximately 7 to 18°C and perhaps even beyond (e.g., Adams 1999; Selong et al. 2001; Harig and Fausch 2002; Sloat et al. 2005;

Benjamin 2006; Coleman and Fausch 2007a, 2007b). In the laboratory the optimal range for growth appears to be between about 12 to 16°C for fish fed to satiation (Bear 2005; Bear et al. 2007; McMahon et al. 2007), but brook trout might have better performance at higher temperatures (our interpretation of these data). Given that temperatures for optimal growth are generally lower for fish with limited rations (Wootton 1998) we anticipate that optimal temperatures in the wild will be at least 1 or 2°C lower.

**Node and state definitions - *gradient***

*Gradient* is defined as the mean percent gradient over the stream network. The three states for the *gradient* variable (node) are:

<i>Gradient</i>	
State name	Values
Low	<2%
Moderate	2%–8%
High	>8%

The definition and states for *gradient* were authored by KDF, DPP and BER.

*Background and justification - gradient*

Distribution and abundance of nonnative brook trout and native cutthroat trout are apparently related to stream gradient and habitat factors correlated with gradient. High gradient stream reaches may directly limit fish distribution where such reaches are impassible. High gradient stream reaches can also impose demographic constraints on fishes where spawning, rearing and survival are limited by habitat conditions (e.g., Fausch 1989). Studies of invasion and general habitat requirements for both species indicate that cutthroat trout populations may be less limited by increasing stream gradient than brook trout.

Several studies from the Rocky Mountains (USA) have observed an inverse relationship between stream gradient and biomass of brook trout (Chisholm and Hubert 1986; Fausch 1989; Rieman et al. 1999), and brook trout appear to have difficulty establishing populations in streams with gradients steeper than 4-7% (Fausch et al. 2006). Adult brook trout can move through and

occupy high gradient (e.g., >12%) stream reaches (Adams et al. 2000, 2001), leading to hypotheses that lack of upwelling ground water needed for egg incubation, scour of eggs or fry, and lack of off-channel or lateral nursery habitats in steep channel slopes may limit reproduction and recruitment (Fausch 1989; Adams 1999).

Small cutthroat trout have been observed over a wide range of stream gradients, and do not appear to be as constrained by moderate or even high gradient stream channels compared to brook trout. Moore and Gregory (1988) and Abbott (2000) associated the most productive natal areas for cutthroat trout with low gradient and unconfined channels, but Fausch (1989) and Rieman et al. (1999) found densities of small cutthroat trout were generally highest at intermediate gradients (e.g., 2%–8%). Interspecific competition whereby brook trout appear have an advantage in low gradient reaches may confound simple interpretation of a gradient-density relationships for cutthroat trout when the two species are sympatric (e.g., Fausch 1989).

We conclude that stream gradients >8% will represent marginal or even unsuitable natal habitat for brook trout while optimal spawning and rearing habitat will be more common in stream segments with gradient <2%. We assume that spawning and rearing habitat for cutthroat trout will be less strongly constrained by channel gradient.

**Node and state definitions - *stream width***

*Stream width* is defined as the mean wetted width over the stream network during base flow. The three states for *stream width* are:

<i>Stream width</i>	
State name	Values
Small	<3 m
Medium	3-10 m
Large	>10 m

The definition and states for *stream width* were authored DPP and BER.

*Background and justification – stream width*

Geomorphic features such as stream size constrain the basic limits of fish habitat (Sheldon 1968), and stream size is believed to influence the distribution and abundance of stream salmonids in the western USA (Bozek and Hubert 1992; Mullan et al. 1992; Rieman and McIntyre 1995; Harig and Fausch 2002; Rich et al. 2003; but see Stritchert et al. 2001). Stream size is hypothesized to be an important correlate for the frequency and diversity of habitats need for reproduction and recruitment by brook trout and cutthroat trout.

Longitudinal patterns in the distribution of cutthroat trout and brook trout suggest that brook trout may better utilize larger natal habitats. Numerous studies have reported that cutthroat trout tend to occupy smaller streams in the upper watershed, while brook trout predominate in larger segments downstream (MacPhee 1966; Griffith 1972; Fausch 1989; Bozek and Hubert 1992; Paul and Post 2001; Peterson 2002), though exceptions are possible (Adams 1999). Data suggesting that brook trout are better able to utilize larger habitats, led Schroeter (1998) to hypothesize that habitat utilization and behavior differ between the two species. Brook trout exhibit a preference for pool habitats (Griffith 1972), and pools tend to be more frequent in larger, lower gradient streams (Hubert and Kozel 1993; Schroeter 1998).

Rieman et al. (1999) summarized the distribution and abundance of brook trout and westslope cutthroat trout from sites in Idaho and Montana, USA, in relation to geomorphic features. They found that small brook trout occur throughout streams 1-10 m wide, but that their density decreased in streams >10 m wide. A re-analysis of these data indicated they are most abundant when stream width was greater than 2-3 m (B.E. Rieman, unpublished data). Presence of competitors (brown trout, *Salmo trutta*) or habitat degradation in downstream segments may limit brook trout to smaller habitats in some cases (Kozel and Hubert 1989; Rahel and Nibbelink 1999). Westslope cutthroat trout are generally believed to spawn and rear in small tributary streams (Johnson 1963; Lukens 1978; Lewinsky 1986; McIntyre and Rieman 1995). Occurrence of age-0 (young of the year) westslope cutthroat trout was associated with streams less than 7.7 m wide (Abbot 2000) or less than 4th order (Dunnigan 1997). An inverse relationship between density of juveniles and stream width across a range of stream sizes (1.1-8.3 m width) has been reported for other cutthroat trout subspecies (Horan et al. 2000), but a positive relationship between cutthroat trout abundance and width has been observed where the range of mean widths was less (1.0-5.4 m, Harig and Fausch 2002). Densities of small westslope cutthroat trout in



Montana and Idaho were greatest in streams less than 3-5 m in width (Rieman et al. 1999; B.E. Rieman, unpublished data).

Based on our interpretation of the preceding data, we defined states for *stream width* whereby optimal natal habitats for cutthroat trout are most frequently found in small streams (<3 m), whereas optimal natal habitat for brook trout was slightly larger (3-10 m).

**Node and state definitions – *hydrologic regime***

*Hydrologic regime* is defined as the seasonal patterns of runoff and flooding that might influence bed scour and subsequent incubation or emergence success of fall spawning salmonids like brook trout. The three states for *hydrologic regime* are:

<i>Hydrologic regime</i>	
State name	Description
Snowmelt	Peak flows generally ( $\geq 80\%$ of years) occur during spring snow melt and after March 1.
Mixed rain-on-snow and snowmelt	Peak flows occur at least occasionally ( $> 20\%$ of years) between early November and mid March.

The definition and states for *hydrologic regime* were authored BER and KDF.

*Background and justification – hydrologic regime*

Hydrologic regime and the patterns and timing of flooding vary across western North America, as influenced by climate and landform (Sanborn and Bledsoe 2006; Beechie et al. 2006). Distinct regimes including winter rain, snow melt, and rain-on-snow (or transitional) have been considered constraints on the distribution and diversity of stream fishes (e.g., Montgomery et al. 1999; Beechie et al. 2006). Regionally, we expect differences between snowmelt compared with mixed rain-on-snow and snowmelt hydrologic regimes to strongly

influence brook trout reproductive success. Several investigators have reported strong negative effects of winter flooding on brook trout embryo or fry survival (Elwood and Waters 1969; Seegrist and Gard 1972, Erman et al. 1988). Similar effects have been observed with other fall spawning salmonids (Strange et al. 1992; Strange and Foin 1999) where incubating embryos and pre-emergent alevins are vulnerable to bed mobilization and scour (Montgomery et al. 1999, Lapointe et al. 2000). Flooding that occurs shortly after emergence may also flush small fish from the stream, and elevated runoff has been shown to reduced recruitment of introduced stream salmonids in the Rocky Mountains, USA (Nehring and Anderson 1993; Laterell et al. 1998).

Presumably salmonids have adapted to minimize vulnerability to such events in their native range, but introduction to a novel environment may constrain reproductive success. For example, Fausch et al. (2001) showed that invasion of rainbow trout (*Oncorhynchus mykiss*) was more successful in regions where flow regimes more closely matched those in the native range (winter rain – summer low flow) than where they did not. Because brook trout did not evolve with a mixed hydrologic regime we assume that they will be less well adapted to those flow patterns. We anticipate that frequent or even occasional winter flooding will constrain the success of brook trout invasion, establishment, or the strength of a resulting population (if the first two occur), although that effect may also depend on geomorphic characteristics of available habitats (Montgomery et al. 1999). Anecdotal evidence suggests this mechanism could be important to explain the varied success of brook trout invasions in interior western North America and the Rocky Mountains (Fausch et al. 2006).

### **Node and state definitions - *potential spawning and rearing habitat***

*Potential spawning and rearing habitat* for westslope cutthroat trout is defined as the potential for successful reproduction and early rearing by cutthroat trout based on the physical template for natal habitat as influenced by stream gradient, summer water temperature and stream size (width). This definition assumes that cutthroat trout are or should be present and are not constrained by habitat degradation, barriers, competition, or other factors. The three states for *potential spawning and rearing habitat* are:

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*Potential spawning and rearing habitat*

State name

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Low (Poor)

Moderate (Suitable)

High (Optimal)

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The definition and states for *potential spawning and rearing habitat* for cutthroat trout were authored DPP and BER.

*Background and justification - potential spawning and rearing habitat*

The potential for natal habitat to produce juvenile cutthroat trout is defined as a function of abiotic and physical factors defined in contributing (parent) nodes (Table S1-1). While westslope cutthroat trout and other salmonids are certainly affected by seasonal and interannual variability in flow conditions (e.g., Strange and Foin 1999), we assumed they were adapted to the prevailing flow conditions across the native range of the species so *hydrologic regime* was not designated as a variable influencing WCT in the *InvAD* BBN. We assumed that very low (<7°C) and very high (>18°C) mean summer temperatures impose major limitations on cutthroat trout reproduction and recruitment and will be a prevailing influence. We further assumed that cutthroat trout natal habitat will generally be poor in larger channels, and that their optimal natal habitat would be found in small, low to moderate-gradient stream channels where temperatures were 10-15°C.

Based on the distribution of observations of small cutthroat trout (<100 mm) in Idaho and Montana (Rieman et al. 1999), we estimate that low, moderate and high states are roughly equivalent with the potential for natal habitats to produce densities of <5, 5-15, and >15 small westslope cutthroat trout/100m<sup>2</sup>, respectively.

**Node and state definitions - *potential brook trout (BKT) spawning and rearing habitat***

*Potential brook trout (BKT) spawning and rearing habitat* is defined as the potential for successful reproduction and early rearing by brook trout based on the physical template for natal habitat as influenced by stream gradient, summer water temperature, stream size (width), and the

dominant hydrologic regime. This definition assumes that brook trout are or should be present and are not constrained by habitat degradation, barriers, competition, or other factors. The three states for *potential brook trout (BKT) spawning and rearing habitat* are:

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*Potential BKT spawning and rearing habitat*

State name

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Low (Poor)

Moderate (Suitable)

High (Optimal)

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The definition and states for *potential brook trout (BKT) spawning and rearing habitat* were authored DPP and BER.

*Background and justification - potential brook trout (BKT) spawning and rearing habitat*

The potential for natal habitat to produce juvenile brook trout is defined as a function of abiotic and physical factors defined in contributing (parent) nodes (Table S1-2). We assumed that a mixed hydrologic regime imposes a major limitation on brook trout reproduction and recruitment and will be a prevailing influence even when other abiotic or physical factors are suitable. We further assumed that brook trout never do well in high-gradient channels of any size, and that their optimal natal habitat would be found in medium width low-gradient stream channels where temperatures were 10-15°C.

Based on the distribution of observations of small brook trout (<100 mm) in Idaho and Montana (Rieman et al. 1999), we estimate that low, moderate and high states are roughly equivalent with the potential for natal habitats to produce densities of <5, 5-15, and >15 small brook trout/100m<sup>2</sup>, respectively. These values are within the range of densities observed by other investigators (Adams 1999).

**Node and state definitions - *invasion barrier***

*Invasion barrier* is defined as a natural or human-constructed barrier that precludes upstream movement by stream fishes. The two states for *invasion barrier* are:

<i>Invasion barrier</i>	
State name	Description
Yes	Barrier is already present or will be constructed.
No	No barrier exists and none is planned.

The definition and states for *invasion barrier* were authored DPP.

*Background and justification – invasion barrier*

Whether or not to install an invasion barrier is the primary management decision considered by the *InvAD* BBN.

**Node and state definitions - brook trout (*BKT*) connectivity and invasion strength**

*Brook trout (BKT) connectivity* characterizes the potential for invasion by brook trout into the local stream network based on the magnitude and frequency of brook trout immigration. *Invasion strength* describes the realized connectivity as influenced by the number, distribution, and attributes of potential source brook trout populations outside the local stream network; and the characteristics of the movement corridor including whether or not an invasion barrier is present or will be installed.

The three states for *brook trout (BKT) connectivity*, and its dependent node, *invasion strength*, are:

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*(BKT) connectivity and invasion strength*

State name	Description
Strong	Potential for immigration of multiple adults into the local stream network on an annual basis. Robust neighboring populations are within 5 km (stream distance) or more distant populations (5-10 km) are known to exhibit jump dispersal, and the migration corridor is suitable.
Moderate	Immigration is episodic and/or includes few individuals because adjacent populations are weak or dispersal distances are far (>10 km), or partial migration barriers limit effective dispersal.
None	No immigration is expected because source populations either do not exist or are too far away, or because an upstream migration barrier is present in the movement corridor.

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The definition and states for *brook trout (BKT) connectivity* and *invasion strength* were authored by DPP.

*Background and Justification - brook trout (BKT) connectivity and invasion strength*

Arrival of immigrants through natural dispersal or human intervention is the first phase of an invasion process that can lead to successful establishment and ecological effects in the

receiving ecosystem (Kolar and Lodge 2001; Dunham et al. 2002). The probability that invaders will successfully colonize a new habitat can depend strongly on the frequency and magnitude of immigration (i.e., propagule pressure) (Lockwood et al. 2005). The related concept of connectivity, or in the context of nonnative species its synonym invasion strength, describes the linkage between occupied or unoccupied habitat patches in terms of movement and the spatial structuring of populations.

A variety of metrics can be used to quantify connectivity, ranging from simple nearest-neighbor relationships to more explicit incidence functions that consider multiple source populations and patch characteristics (Moilanen and Nieminen 2002; Calabrese and Fagan 2004). The underlying considerations for connectivity or invasion strength will be distance to source populations, dispersal ability of the invader, propensity of source populations to produce immigrants, and physical (and perhaps biological) characteristics of the movement corridor that may influence the effective distance.

Invasion strength is presumed to be inversely related to distance between source and recipient habitats (Sheldon and Meffee 1995). However, the ability of stream fishes like brook trout to exhibit jump dispersal (e.g., Peterson and Fausch 2003a) means that nearest-neighbor relationships may not capture all significant immigration processes. There is little information to provide direct estimates of dispersal or dispersal kernels, but empirical studies of movement by brook trout indicates intra-annual movement distances can be at least 2 km even in small streams (Gowan and Fausch 1996a; Peterson and Fausch 2003a), and tens of kilometers for migratory forms (Curry et al. 2002). Similarly, demographic studies of stream salmonids indicate dispersal is more common among neighboring (within ~5-10 km) populations (Dunham and Rieman 1999; Koizumi and Maekawa 2004). Invasion strength (connectivity) can be weighted by patch or population size (Calabrese and Fagan 2004) on the assumption that larger populations produce more immigrants (e.g., Jager et al. 2001). Limited evidence indicates that immigration by brook trout can be proportional to source population density (Peterson and Fausch 2003a; Peterson et al. 2004). Physical (and in some cases biological) characteristics of the dispersal corridor, for example high-gradient reaches, may impede immigration by stream fishes and increase the effective distance between source and recipient habitat. Consequently, we assume a general relationship where *invasion strength* is inversely related to the distance and strength of source

populations, where active dispersal of 2-5 km is probable but distances of 10 km or more are less likely, and where migration barriers effectively stop upstream dispersal (Table S1-3).

**Node and state definitions - *habitat degradation***

*Habitat degradation* is defined as whether salmonid habitat and the processes that create and maintain it have been altered by human activity. A central assumption is that watersheds without human disruption will tend to support more complex habitats resilient to disturbance.

The two state definitions for *habitat degradation* were based on differences between managed and unmanaged watersheds used by McIntosh et al. (2000) and Kershner et al. (2004):

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*Habitat degradation*

State name	Description
Altered and degraded	Activities that disrupt watersheds, such as logging, road construction, grazing, mining, water development, or other activities that influence erosion, wood loading, channel-floodplain connectivity, flood flows, or other hydrologic and geomorphic processes have been extensive and their effects persistent. The role of natural processes has been reduced.
Minimally altered or pristine	Activities disrupting watersheds have been infrequent, occurred historically, and were of limited extent and effect, or were entirely absent. Natural processes predominate in habitat formation and maintenance. The unmanaged state would be consistent with wilderness, roadless areas, or areas where previous or ongoing land management is relatively minor.

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The definition and states for *habitat degradation* were authored by MKY, BER, and DPP.



*Background and justification – habitat degradation*

Abundance of adult cutthroat trout has frequently been associated with habitat quality and complexity, particularly the size and number of pools (Jakober et al. 1998; Harig and Fausch 2002). Low watershed or habitat integrity presumably results in habitat degradation and simplification that reduces carrying capacity and increases emigration. Poor habitat quality may increase predation rates on fish forced to occupy areas with less cover or may reduce survival during critical periods, for example during summer thermal maxima, floods, drought, and anchor ice formation, because refugia are few or lacking. Although watersheds that have been altered by natural disturbance may temporarily have poor habitat, recovery may be relatively rapid if natural processes that create and maintain habitat continue unabated and linkages between streams, riparian zones, and uplands remain intact (Beechie and Bolton 1999; Reeves et al. 2006). In contrast, human disturbance tends to be chronic and cumulative i.e., rarely restricted to a single effect at one point in time, and habitat quality may remain depressed indefinitely.

Because the quality and quantity of pools, large wood, and bank-related cover can be strongly influenced by land management (Young et al. 1994; McIntosh et al. 2000; Kershner et al. 2004), the degree of disruption in the watershed is expected to have at least some influence on the survival of juvenile, sub-adult, and adult cutthroat trout. Several studies have shown a negative relationship between indices of habitat disruption (e.g., clearcut logging or road density) and abundance or status of cutthroat trout (Lee et al. 1997; Abbott 2000), and there is some evidence that habitats in wilderness areas relatively free from human disturbance support more robust populations of cutthroat trout than do more heavily managed lands (Rieman and Apperson 1989; Kershner et al. 1997; Shepard et al. 2005). In addition, because habitat conditions might mediate individual growth or the availability of cover, they could also influence the outcome of the interactions between cutthroat trout and brook trout (DeStaso and Rahel 1994; Shepard et al. 2002; Shepard 2004), although we anticipate that this effect will be less important for cutthroat trout older than age 0 (Peterson et al. 2004). Overall, although we posit that habitat degradation resulting from watershed management leads to reduced juvenile, sub-adult, and adult cutthroat trout survival, empirical models quantifying the relationship between habitat condition and survival during these stages are lacking.

In contrast, there is a rich literature demonstrating that many land management activities lead to increases in fine sediment (Megahan et al. 1992; Hartman et al. 1996), which in turn can

reduce the survival to emergence of salmonids (Chapman 1988), including cutthroat trout (Young et al. 1991) and brook trout (Curry and MacNeill 2004).

Brook trout populations appear susceptible to effects of watershed degradation and habitat disruption within their native range (e.g., Hudy et al. 2004), and have been shown to respond positively to site-specific habitat improvements in the western USA (e.g., Gowan and Fausch 1996b). We infer that altered and degraded habitat will influence the population strength of nonnative brook trout populations through mechanisms similar to those affecting cutthroat trout, but assume that brook trout may be somewhat less sensitive based on their widespread distribution across a gradient of habitat quality in the western US (Schade and Bonar 2005).

**Node and state definitions - *brook trout (BKT) population status***

*Brook trout (BKT) population status* is defined as the potential strength of a brook trout population in a stream segment as influenced by the realized condition of natal habitat and the likelihood of brook trout immigration. This node ultimately characterizes the potential for brook trout to become established in a stream segment, expand their population, and to exert biotic pressure, via competition and predation, on cutthroat trout. The three state definitions for *brook trout (BKT) population status* are:

<i>Brook trout (BKT) population status</i>	
State name	Description
Strong	Brook trout are established and maintain at least moderate densities [e.g., >5 small (<100 mm) brook trout per 100 m <sup>2</sup> ].
Weak	Brook trout are successfully established but maintain a population at low density (e.g., ≤ 5 small brook trout per 100 m <sup>2</sup> ).
Absent	Brook trout are not established

The definition and states for *brook trout (BKT) population status* were authored by DPP and BER.

*Background and justification - brook trout (BKT) population status*

The potential for brook trout to establish and maintain a robust population will depend on the ability of brook trout to arrive in the tributary network (a function of *BKT connectivity* and *invasion strength*) and the actual condition of the natal habitat (a function of *potential BKT spawning and rearing habitat* as influenced by *habitat degradation*) (Table S1-4). We made two general assumptions about how the contributing nodes influenced the potential population strength of brook trout. First, even moderate connectivity or invasion strength is expected to result in establishment of a strong population where natal habitat conditions are suitable or better. Second, strong connectivity and invasion strength can potentially overcome the effect of unfavorable natal habitat conditions and result in establishment, but the resulting population is expected to persist at low abundance.

Brook trout will be absent if they cannot immigrate into a tributary network. However, brook trout may also fail to successfully invade accessible habitats (e.g., Adams et al. 2002). We assume that brook trout may also be absent where *invasion strength* is moderate and habitat in the target segment is both inherently unsuitable and degraded. Similar to the rationale described under *potential brook trout spawning and rearing habitat*, general guidelines characterizing weak and strong populations would be average densities of small (juvenile or <100 mm) brook trout of  $\leq 5$  and  $> 5$  fish/100 m<sup>2</sup>, respectively. The evidence for these rough quantitative guidelines and their general applicability are not robust, however we expect the qualitative effect of brook trout population strength on cutthroat trout survival to be dose dependent whereby cutthroat trout survival and brook trout population strength are inversely related (e.g., Peterson et al. 2004).

**Node and state definitions - *fishing exploitation***

*Fishing exploitation* is defined as the exploitation rate of subadult and adult (aged 2 and older) westslope cutthroat trout in a stream network. The two states for *fishing exploitation* are:

<i>Fishing exploitation</i>		
State name	Values	Description
Low	<10% annual exploitation	This often results from limited fishing pressure caused by poor or no roads or trails, long travel times from large towns and cities, or the fishery lacking notoriety. Exploitation may also be limited by special angling regulations.
High	>10% annual exploitation	Even modest levels of fishing pressure can lead to overexploitation, particularly for populations exhibiting low productivity, those lacking special regulations, or for which regulations are ignored or ineffective.

The definition and states for *fishing exploitation* were authored by MYK and BER.

*Background and justification – fishing exploitation*

Rieman and Apperson (1989) summarized much of the literature on the effects of fishing on westslope cutthroat trout which are believed to be particularly vulnerable to exploitation. Even modest angling effort can lead to overexploitation, but angling restrictions have been successful at mitigating this effect (Schill et al. 1986; McIntyre and Rieman 1995). Access to streams and public recognition of a fishery may also play an important role. For example, populations with easy road access and containing large-bodied migratory individuals are more likely to be fished at higher levels than those that are remote or support only small-bodied resident adults. Complex habitats, such as large accumulations of wood, or inaccessible reaches,

such as steep-sided canyons, may provide refuges from angling that reduce overall exploitation rates.

Fishing exploitation rates for depressed cutthroat populations that supported migratory life histories were between 27% and 30% (summary from Rieman and Apperson 1989). Simulations indicate that any exploitation will result in a change in the structure of the sub-adult and adult portion of the population, but persistence will depend on compensation in survival by other life stages and the intensity of exploitation (Rieman and Apperson 1989). For some populations where recruitment is limited by environmental conditions such as low summer water temperatures, there may be little or no compensatory increase in survival among other life stages and populations may rapidly decline. Under such circumstances, even incidental mortality from capture and release angling may not be sustainable (Paul et al. 2003). In other cases, populations with low adult survival but high juvenile survival may be highly resilient, particularly if fishing exploitation can be regulated. Fishing alone should not lead to reduced resilience unless the exploitation is of sufficient intensity and duration to result in the loss of diversity and adaptive potential in the population (e.g., Safina et al. 2005).

**Node and state definitions - egg to age-1 survival**

*Egg to age-1 survival* is defined as westslope cutthroat trout survival from egg to age 1 as influenced by realized habitat conditions and interactions with nonnative brook trout. The three states for *egg to age-1 survival* are:

<i>Egg to age-1 survival</i>		
State name	Values	Description
Low	<2.5%	The physical habitat template is poor for cutthroat trout spawning and rearing and/or the stream habitat is highly impacted by land use; or, if habitat conditions are suitable, then brook trout are present and relatively abundant.
Moderate	2.5%–5%	Realized habitat conditions may be suitable, with only minor degradation; or, if habitat conditions are optimal then brook trout are only present at low abundance.
High	>5%	No brook trout are present and habitat conditions are suitable to optimal (not degraded).

The definition and states for *egg to age-1 survival* were authored by DPP and BER.

*Background and justification – egg to age-1 survival*

The period from egg deposition and fertilization through first summer and winter is believed to be a key life stage influencing the resilience of salmonid populations. This life stage experiences relatively high mortality, so even modest changes in these rates can have profound

effects on the growth rate of a population (Rieman and Apperson 1989; Kareiva et al. 2000; Dambacher et al. 2001). There are at least three periods shown to be highly sensitive to environmental conditions and variability: incubation, emergence and early rearing, and overwintering. Salmonid fishes, including cutthroat trout, deposit and fertilize their eggs in nests (redds) constructed in stream gravels, and survival during incubation may be strongly affected by substrate composition and intragravel water flow that influences the oxygen supply to developing embryos (Irving and Bjornn 1984; Chapman 1988). Severe sedimentation can also limit survival by trapping or entombing emerging fry in the nest. Flooding during incubation or emergence can strongly influence survival through effects of scour or physical displacement (Strange et al. 1992; Nehring and Anderson 1993; Laterell et al. 1998; Strange and Foin 1999; Fausch et al. 2001). Early rearing and pre-winter growth conditions must be sufficient for salmonids to withstand metabolic deficits encountered during winter (Cunjak and Power 1987), but actual survival may be strongly influenced by winter severity (Meyer and Griffiths 1997; Coleman 2007).

The quality and quantity of complex habitats and refugia that might buffer against these effects (e.g., pools, off-channel or stream-margin nursery areas, interstices in substrate) can be strongly influenced by land management. Consequently, the magnitude of habitat degradation in a watershed is expected to have an important influence on survival during this life stage. Several studies have shown a negative relationship between indices of habitat disruption (e.g., clearcut logging, road building) and density or abundance of cutthroat trout (e.g., Rieman and Apperson 1989; Abbott 2000). Although reduced juvenile survival is a plausible mechanism to explain these observations, empirical models quantifying the relationship between habitat condition and juvenile survival are lacking, primarily because survival during this period is extremely difficult to measure with any precision.

Nonnative species invasions can strongly influence the population biology of native species, and competitive interactions leading to reduced survival rates, and is believed to be a key mechanism by which brook trout displace cutthroat trout in western North America (Dunham et al. 2002; Peterson and Fausch 2003b; Fausch et al. 2006). Competition and predation among salmonids has proven difficult to quantify in natural systems (Griffith 1988; Fausch 1988, 1998), but both direct (mark-recapture survival estimates, Peterson et al. 2004) and indirect evidence (abundance monitoring, Shepard et al. 2002) indicates that effects of brook

trout on cutthroat trout survival are most pronounced at juvenile life stages, especially during the first year of life, and that this relationship can be density-dependent (Peterson et al. 2004).

Habitat conditions can mediate interactions among competing species (condition-specific competition, Dunson and Travis 1991), and may influence the outcome of interactions between brook trout and cutthroat trout (DeStaso and Rahel 1994; Novinger 2000; Shepard 2004). While degraded habitat conditions are hypothesized to facilitate replacement or displacement of native species by nonnative species (Moyle and Light 1996), including cutthroat trout by brook trout; the widespread distribution of brook trout in undisturbed stream habitats (Schade and Bonar 2005) and displacement of cutthroat trout even in comparatively high-quality habitats (e.g., Shepard et al. 2002) suggests that biotic interactions have primacy under certain conditions.

Survival from egg to age 1 is difficult to precisely estimate for salmonid fishes, but demographic models that depend on these rates have typically approximated them by default based on empirical estimates for other stages (Rieman and Apperson 1989; Kareiva et al. 2000; Rieman and Allendorf 2001); or have used a range of possible values (Shepard et al. 1997), or a single plausible value (Hilderbrand 2003). A few empirical survival estimates for anadromous salmonids range from 2-15% (Dambaucher et al. 2001). An empirically-derived estimate of 2.6% was used in a modeling exercise for adfluvial Yellowstone cutthroat trout (*O.c. bouvieri*, (Stapp and Hayward 2002) and two species of charr averaged 4.5% (range 2.3-15.9%, geometric mean 3.5%, Morita and Yokota 2002). A simple approximation for westslope cutthroat based on general observations or assumptions of plausible rates of survival and fecundity in subadult and adult fish shows that survival to age 1 should be on the order of 1 to 7.5% for populations in equilibrium. The average survival rate necessary to maintain equilibrium will vary with survival at other stages, age at maturity, longevity, sex ratio, spawning frequency, and fecundity (e.g., higher survival will be necessary to support resident populations with small adults and low fecundity).

The *InvAD* BBN was developed assuming that survival of westslope cutthroat trout from egg to age 1 will depend on a suitable physical habitat template (*potential spawning and rearing habitat*), the condition of that habitat template (*habitat degradation*), and the potential presence and strength of a brook trout population (*BKT population status*) (Table S1-5). Degradation of suitable spawning and rearing habitat is assumed to reduce survival because of increases in fine sediment deposition, loss of lateral rearing habitats survival, and increased frequency and



intensity of flooding. Habitat degradation is irrelevant for survival if spawning and rearing habitat is inherently unsuitable. Biotic effects of brook trout are generally expected to override any buffering influence of high quality habitat, and strongly affect (reduce) survival of WCT to age 1.

**Node and state definitions - *juvenile survival***

*Juvenile survival* is defined as westslope cutthroat trout survival from age 1 to age 2 as influenced by realized habitat conditions and interactions with nonnative brook trout. The three states for *juvenile survival* are:

<i>Juvenile survival</i>	
State name	Values
Low	<25% (assuming a range with a minimum of 15%)
Moderate	25%–35%
High	>35% (assuming a range with a maximum of 45%)

The definition and states for *juvenile survival* were authored by DPP and BER.

*Background and justification – juvenile survival*

Empirical data suggests that survival rates for cutthroat trout during the juvenile stage can be less than for adults, and estimates range from about 22 to 45% (Stapp and Hayward 2002; Peterson et al. 2004). Similar to egg to age-1 life stage, the juvenile life stage is expected to exhibit substantial variability in survival rates in response to environmental factors and ecological interactions with other fish species, such as brook trout. Demographic models suggest that population growth rates for cutthroat trout can be very sensitive to survival over this interval (Stapp and Hayward 2002; Hilderbrand 2003).

The factors believed to influence juvenile survival rates are similar to those described for the life stage from egg to age 1. Briefly, the quality and quantity of complex habitats, such as pools, off-channel and stream margin nursery areas, and interstices in streambed substrates, are hypothesized to influence growth and survival. Because watershed processes may strongly

influence these habitat characteristics, disruptive land management can reduce juvenile growth and survival (Suttle et al. 2004). Interactions with nonnative brook trout can also reduce survival of juvenile cutthroat trout (Peterson et al. 2004). Ecological interactions with brook trout may not reduce survival of juvenile cutthroat trout to the same extent as for young-of-the-year cutthroat trout (Peterson et al. 2004), perhaps because of improved competitive ability and reduced predation risk conferred by comparatively larger body size (e.g., Novinger 2000).

The conditional relationships for this node are similar to that for *egg to age-1 survival*, in that survival rates will depend on a suitable physical habitat template (*potential spawning and rearing habitat*), the condition of that template (*habitat degradation*), and the potential presence and strength of a brook trout population (*BKT population status*) (Table S1-6). However, the relative magnitude of the effect of ecological interactions with brook trout will be comparatively less for juveniles, and effect of habitat quality and brook trout population strength is expected to be roughly equivalent.

Juvenile cutthroat trout have not yet recruited to the recreational fishery, and are less likely to be affected by presence of an invasion barrier because they presumably exhibit less ranging behavior than adults (because of lower metabolic demands) and do not migrate to spawn.

**Node and state definitions - *subadult-adult survival***

*Subadult-adult survival* is defined as the annual survival of subadult and adult westslope cutthroat trout (ages 2 and older) as influenced by realized habitat conditions, fishing, and presence of an invasion barrier. The three states for *subadult-adult survival* are:

<i>Subadult-adult survival</i>	
State name	Values
Low	<35% (assuming a range with a minimum of 25%)
Moderate	35%–45%
High	>45% (assuming a range with a maximum of 55%)

The definition and states for *subadult-adult survival* were authored by MKY, BER, and DPP.

*Background and justification – subadult-adult survival*

*Subadult-adult survival* estimates the combined effects of realized habitat conditions, fishing mortality, and the presence of an invasion barrier on subadult and adult cutthroat trout survival (Table S1-7). Rieman and Apperson (1989) estimated that typical natural mortality rates for westslope cutthroat trout were 31-54% (i.e., without exploitation), but this increased to 70-73% in populations that were considered overexploited. Human-caused habitat degradation is expected to reduce the size and resilience of cutthroat trout populations, but we are not aware of good estimates relating natural mortality for subadult and adult cutthroat trout to habitat conditions. However we believe that effects of habitat degradation on this life stage of WCT will be less influential overall than fishing (where such fishing occurs). Evidence that brook trout can influence the survival of adult cutthroat trout is weak or absent (Griffith 1972; Cummings 1987; Schroeter 1998; Shepard et al. 2002; Peterson et al. 2004).

Installation of an invasion barrier to inhibit colonization by brook trout may also indirectly affect survival of cutthroat trout by disrupting movement patterns. Spawning migrations of resident cutthroat trout could be influenced by invasion barriers depending on the extent of such migrations relative to the location of the barrier. For example, decreased apparent survival will result where WCT move downstream over an (upstream) migration barrier, cannot return to their natal habitat to spawn, and are effectively lost from the local population in question (Note: the effect of an invasion barrier on cutthroat trout migratory life histories is considered under the nodes representing *potential life history* and *effective life history*). Invasion barriers can also influence cutthroat trout survival where they affect non-spawning movements, such as those movements to: summer feeding areas, refuges from ice and predation in winter, shelter from floods, or thermal refuges from high summer water temperatures. These movements may not be temporally predictable, but they are probably inevitable. For example, a local resource bottleneck may only happen once in a fish's lifetime, or several times in a single year. Also, some resource crises are likely to be ontogenetically driven i.e., larger individuals are more likely to outgrow food availability because their bioenergetic demands are greater, and they will more frequently be confronted with the choice of staying and suffering reduced growth or moving in an attempt to locate a bioenergetically favorable site and displace a smaller individual from it (because the best sites should always be occupied). Consequently, 5 km of

stream isolated by a barrier will contain fewer fish than 5 km of stream that remains connected to some undefined length of stream because, in the isolated stream, complementary habitats are fewer and the fish that seek them can be lost if they pass downstream over a migration barrier.

The physical habitat template for cutthroat trout defined in our model (i.e., the combination of *temperature*, *gradient*, and *stream width*) focuses on natal habitat. While these physical characteristics may, in part, influence the behavior, growth, and ultimately the survival of subadult and adult cutthroat trout, we assumed their effect on this older life stage was not quantifiable relative their influence on earlier life stages (egg through juvenile) which have more specific requirements. Accordingly, we assumed a priori that the physical habitat template at both the segment and stream network scales is suitable for subadult and adult cutthroat trout (i.e., the model has no explicit link between *potential spawning and rearing habitat* and *subadult-adult survival*), and that directed movement or ranging behavior links complementary feeding and refuge habitats distributed across the riverscape (e.g., Schlosser and Angermeier 1995; Northcote 1997; Gowan and Fausch 2002; Fausch et al. 2002). Degraded watershed conditions affect the quality and quantity of these complementary habitats.

The range of survival values used in the state definitions were consistent with those estimated for cutthroat trout estimated using mark-recapture methods (e.g., 23-57%, Peterson et al. 2004) or derived from long-term monitoring data (e.g., 37-48%, Stapp and Hayward 2002). Survival rates in moderate to high states encompassed values predicted to result in stationary or increasing populations using demographic models (e.g., Stapp and Hayward 2002; Hilderbrand 2002, 2003; D.P. Peterson, unpublished data).

**Node and state definitions - *potential life history* and *effective life history***

*Potential life history* and *effective life history* characterize the potential and realized life history expression, respectively, for a local population of westslope cutthroat trout. The potential influence of life history expression on the resilience of cutthroat is assumed to be primarily through the differential reproductive contribution of distinct migratory forms. The two states for *potential life history*, and its dependent node, *effective life history* are:

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*Potential life history* and *effective life history*

State name	Description
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Resident	There is no or very limited movement of fish into or out of the local tributary network. Adult females are likely to mature between 150 and 250 mm with fecundities ranging from 180 to 600 eggs per female.
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Migratory	Movement of fish out of the local tributary network into larger rivers and lakes where accelerated growth occurs is extensive. Adult females are likely to mature between 250 and 450 mm (or larger) with fecundities ranging from 600 to 2,200 eggs per female.
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The definition and states for *potential life history* and *effective life history* were authored by BER.

*Background and justification - potential life history and effective life history*

Most salmonids exhibit a diversity of movement patterns expressed in the timing and extent of migration among habitats. Cutthroat trout are often characterized as resident or migratory based on movements from natal habitats to sub-adult rearing areas (McIntyre and Rieman 1995; Fausch et al. 2006). The differential expression of migratory or non-migratory life histories may reflect the degree of movement needed to fulfill all life history requirements or the strategies necessary to maximize fitness along the environmental gradients influencing growth and survival (Northcote 1997; Fausch et al. 2002). The expression of life histories may vary

within and among streams and local populations. Faster growth, larger size at maturity and higher female fecundity is commonly associated with migratory life histories (Rieman and Apperson 1989; Downs 1995). These traits can influence on the demographic characteristics of a population and contribute to higher potential population growth rates (Rieman and Apperson 1989), resilience to disturbance (Rieman and Clayton 1997; Rieman and Dunham 2000) and possibly resistance to invasion (Dunham et al. 2002; Fausch et al. 2006).

We assumed that migratory and resident forms of cutthroat trout would exhibit substantially different growth and fecundities. We estimated the ranges of these characteristics from the summaries of Rieman and Apperson (1989), Downs (1995), and Downs et al. (1997). We anticipate that migratory life histories will be common where the interconnection between natal habitats and rearing areas in larger streams, rivers or lakes are complete and those rearing areas remain productive for cutthroat trout. We assumed resident life histories will dominate where barriers to migration exist between tributary streams (Table S1-8) and more productive downstream rearing environments or where those rearing environments are no longer conducive to rapid growth or survival of rearing individuals. A mix of life history forms may also exist in some streams (McIntyre and Rieman 1995) but we anticipate that the contribution from migratory individuals will likely dominate the demography of local populations where downstream conditions are still productive and conducive to expression of a migratory life history.

**Node and state definitions - *population growth rate***

*Population growth rate* is defined as the potential finite rate of population increase ( $\lambda$ ) for the local population of westslope cutthroat trout as influenced by reproductive success and recruitment, stage-specific survival rates, and fecundity based on the predominant life history. The node defines population growth potential in the absence of density-dependence and environmental variation. The five states for *population growth rate* are:

<i>Population growth rate</i>		
State name	Values	Description
Very low	$\lambda < 0.85$	The combination of low reproductive output, low survivorship and low fecundity from migratory individuals results in an annual decline of >15%.
Low	$\lambda = 0.85-0.95$	Conditions intermediate to those in Very low and Moderate states.
Moderate	$\lambda = 0.95-1.05$	Vital rates are intermediate (resident or isolated populations) or low but sufficient demographic support is present to result in a stationary population.
High	$\lambda = 1.05-1.15$	Conditions intermediate to those in Moderate and Very High states.
Very high	$\lambda > 1.15$	Vital rates are high (resident or isolated populations) or vital rates are medium-to-high and migratory individuals provide strong demographic support such that the population can double within a generation (approx. 5 years).

The definition and states for *population growth rate* were authored by DPP and BER.

*Background and Justification – population growth rate*

A population's potential rate of growth is a function of birth rates and death rates which will depend on maturity schedule, fecundity, reproductive success and age specific survivorship. Growth rate can vary through space and time in response to environmental conditions and population density (Gotelli 1998). Population models provide a means to explore the demographic consequences of variation in vital rates (Noon and Sauer 1992). Matrix population models are particularly helpful because they can be used to estimate the finite rate of population increase ( $\lambda$  or  $\lambda$ ), a metric which integrates all vital rates into a single, easily interpreted value representative of a population's trajectory (Caswell 2000). A  $\lambda$  of 1.0 indicates a stationary population, whereas values above and below 1.0 represent increasing and declining populations, respectively. A population with a potential growth rate  $>1.0$  is considered *resilient*, and has the demographic potential to respond and recover when its abundance is reduced through environmental or other factors. We estimated the combined effect of contributing nodes on *population growth rate* (i.e., developed its conditional probability table) using both a demographic model and expert opinion (Table S1-9).

Matrix model-based approach to define the conditional probabilities for *population growth rate*. A deterministic stage-based matrix model was used to approximate the combined influence of reproductive success (*egg to age-1 survival*), stage-specific survival (*juvenile survival* and *subadult-adult survival*), and fecundity (*effective life history*) on the expected population growth of cutthroat trout. We estimated the probability of *population growth rate* being in a particular state by calculating  $\lambda$  (i.e., the dominant eigenvalue of the matrix) based on all possible combinations of the states in four contributing (parent) nodes (Table S1-9).

Maturity schedules were consistent with Rieman and Apperson (1989), McIntyre and Rieman (1995), and Downs et al. (1997), such that female WCT first matured at age 3. Maturity rates varied between age-3 (10% mature) and age-4 (50% mature) classes, and all individuals age 5 and older were mature. The life cycle representing the population model is depicted in Fig. S1-2.

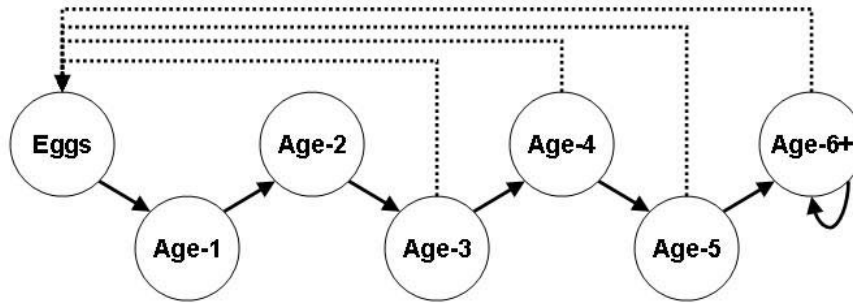
We simulated 1000 matrices for each combination of states for the four parent nodes. For each realization of the matrix, parameter values were randomly selected from a uniform distribution within the range of values for the appropriate state for each parent node. Vital rates



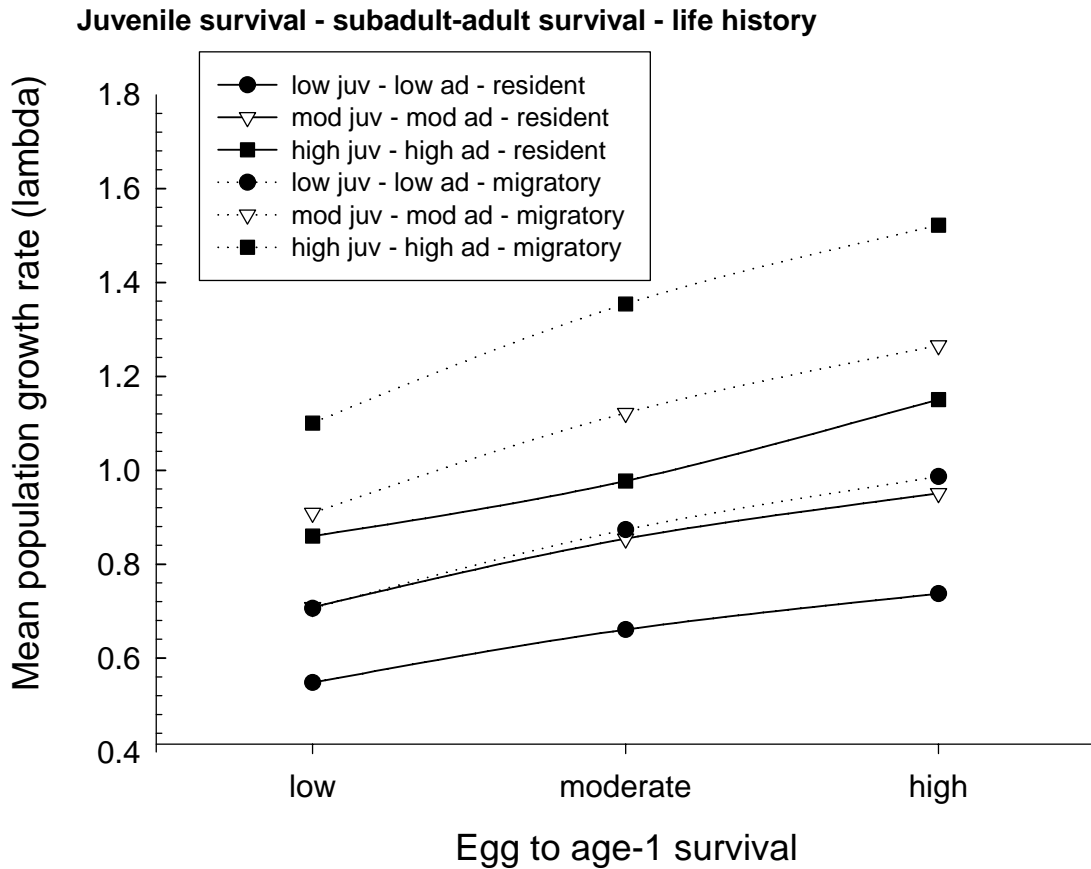
and matrix elements were uncorrelated. The random draw of vital rates reflects uncertainty in the parameter estimates rather than stochastic or demographic processes. We chose to account for environmental variation in population growth rate in another node (see *persistence*) and estimate the probability of persistence using the analytical model of Dennis et al. (1991) rather than a stochastic projection of the matrix population model because of the greater data requirements of the latter (e.g., Besseinger and Westphal 1998). Robust estimates of variance in the vital rates that would account for environmental variation are not available for the parameters in the matrix model. In contrast, empirical estimates of the variance in population growth rate following the analytical model of Dennis et al. (1991) are available for westslope cutthroat trout (McIntyre and Rieman 1995; see definition and justification for *persistence*).

Maturity schedules and rates were constant across all matrix model simulations, and a stable age distribution was assumed so there would be a dominant eigenvalue ( $\lambda$ ) for each realized matrix. Accordingly, each matrix was considered a deterministic representation of a population based on the state of the parent nodes in the absence of density-dependent factors. The conditional probability table for *population growth rate* was parameterized based on the frequency distribution of simulation results. Matrix model simulations were implemented by spreadsheet (Microsoft Excel) using a Monte Carlo procedure and population analysis module developed for Excel (Hood 2004).

Mean simulated population growth rates ranged from 0.55 to 1.5 across a representative range of states for parent nodes (Fig. S1-3). Growth rates for resident populations never averaged greater than one unless at least two or three of the stage-specific survival rates (and including *subadult-adult survival*) were high. Increases in *subadult-adult survival* had a larger relative influence on population growth rate than either *egg to age-1* or *juvenile survival*. The presence of a migratory life history had a stronger relative influence than the combined effect of a one state increase in both *juvenile survival* and *subadult-adult survival* (i.e., from low to moderate or moderate to high survival). Presence of a migratory life history provided sufficient demographic support in some cases to compensate for survival rates that would otherwise result in deterministic extinction for a population.



**Fig. S1-2.** Life cycle diagram of 7-stage matrix population model for westslope cutthroat trout (*Oncorhynchus clarkii lewisi*). Stage-specific reproductive output (eggs) is denoted by dashed arrows and females begin reproducing at age-3. Survival between stages (transitions) are denoted by solid arrows.



**Fig. S1-3.** Simulated mean population growth rate ( $\lambda$ ) for westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) across a representative range of values for *egg to age-1 survival*, *juvenile survival*, *subadult-adult survival*, and *effective life history* (resident or migratory life history, having low or high fecundity, respectively). For brevity, this figure depicts only results where the state values for *juvenile survival* (juv), *subadult-adult survival* (ad) co-varied (i.e., both low, moderate (mod) or high), but conditional probability tables were developed using all possible state combinations of the four contributing nodes (Table S1-9).

Opinion-based approach to define the conditional probabilities for *population growth rate*. In parallel to the matrix-model approach, two authors (BER and DPP) also estimated the probability of *population growth rate* being in a given state based on their interpretation of how the four contributing nodes (*egg to age-1 survival*, *juvenile survival*, *subadult-adult survival*, and *effective life history*) influence WCT populations. The probabilities for *population growth rate* under the assumption of intermediate (i.e., moderate) *egg to age-1 survival* and *juvenile survival* were interpolated based on the low and high estimates for each of those nodes. For the other two contributing nodes, all possible state combinations were directly estimated. Probabilities were averaged across authors to produce an alternate conditional probability table for *population growth rate* based entirely on opinion (Table S1-9).

**Node and state definitions - *effective network size***

*Effective network size* defines the size or spatial extent of the local westslope cutthroat trout population and its vulnerability to environmental variation and catastrophic events. We use population size as our primary metric for the analysis, but assume that population size and stream network size (km) are directly related. Five states are defined because the risk of local extinction appears to increase rapidly as populations drop below moderate numbers. The five states for *effective network size* are:

<i>Effective network size</i>	
State name	Description
Very small	A local population supporting fewer than 500 individuals age 1 and older, or less than 3 km of interconnected stream segments of spawning and early rearing habitat. Populations with a very small <i>effective network size</i> could be highly vulnerable to catastrophic events that can be envisioned for the area in question in the next 20 years.
Small	A local population supporting 500 to 1000 individuals age 1 and older, or alternatively, 3 to 5 km of interconnected stream segments of spawning and early rearing habitat.
Moderate	A local population supporting 1000 to 2500 individuals age 1 and older, or alternatively, 5 to 7 km of interconnected stream segments of spawning and early rearing habitat.
Large	A local population supporting 2500 to 5000 individuals age 1 and older, or alternatively, 7 to 10 km of interconnected stream segments of spawning and early rearing habitat.
Very large	A local population supporting more than 5000 age 1 and older individuals, or alternatively, a network of more than 10 km of

inter- or closely connected stream segments representing suitable spawning and early rearing habitat. Populations with a very large *effective network size* are not likely to be vulnerable to catastrophic events that can be envisioned for the area in question within the next 20 years.

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The definition and states for *effective population size* were authored by BER.

*Background and justification – effective population size*

The size of a network of interconnected stream segments that represents a local population can have an important influence on the persistence of that population. Small populations are more vulnerable to extinction due to loss of genetic variability, small random changes in demographic processes (demographic stochasticity), and normal environmental fluctuations (environmental stochasticity) (see Fausch et al. 2006 for a review), collectively known as small population phenomena (Caughley 1994). Larger-scale perturbations or catastrophes that severely reduce populations and habitats may be important for both small and large populations, particularly if populations are confined to a limited area, a single habitat, or a collection of habitats that could be affected by the same disturbance, such as fire, flood, drought, or temperature extremes. Disturbances that would pose little threat to larger, interconnected populations may become important when populations are small or highly fragmented (e.g., Dunham et al. 2003; Fausch et al. 2006).

We assumed that tributary network size and number of fish in the population will be positively related (e.g., Hilderbrand and Kershner 2000; Young et al. 2005), but the effective size of that tributary network also will be influenced by the complexity and heterogeneity of available habitats and the potential for catastrophic disturbances. Larger and/or more complex and productive habitats should support trout larger populations, and also should be better buffered against environmental variation (Rieman and McIntyre 1993) and catastrophic events if the population is broadly distributed. Recent work (Rieman et al. 1997) suggests that salmonids in tributary networks of more than approximately 10 km are likely large enough to persist following severe fires and subsequent catastrophic stream channel floods or scour events. Smaller populations appear far more vulnerable (e.g., Brown et al. 2001). For these reasons we assumed

that either population size or tributary (habitat) network size could be appropriate measures of *effective network size*. We equated the two based on estimated abundances of inland cutthroat trout from small streams (Hilderbrand and Kershner 2000; Young and Guenther-Gloss 2004; Young et al. 2005). When using the *InvAD* BBN, the probable state of this node can also be assigned by the user based on available local knowledge of the most constraining characteristic for the population in question. Our classification represents a generalization across habitats and environments assuming “moderate” densities ( $\sim 0.2/m$ ) of fish (e.g., Hilderbrand and Kershner 2000; Young et al. 2005). Systems that are known to support unusually good or poor habitat, or are unusually vulnerable to potentially catastrophic events such as fire, flood or drought, could be rescaled as appropriate. For example, 10 km of degraded habitat that is unusually vulnerable to an extended drought and stream drying might be classified as having a moderate or small *effective network size*.

**Node and state definitions - *connectivity and colonization and rescue***

*Connectivity* and *colonization and rescue* define the potential and realized immigration and demographic support, respectively, for a local population of westslope cutthroat trout based on the distribution, interconnection with, and independence of surrounding populations present in other stream tributary networks. It is influenced by the expression of migratory life histories, barriers to movement, and the distribution and characteristics of neighboring populations. The three states for *connectivity*, and its dependent node, *colonization and rescue* are:

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*Connectivity and colonization and rescue*

State name	Description
None	No immigration can (or will) occur because of a barrier to upstream movement, because neighboring populations are non-existent, too far away, or do not support migratory life histories.
Moderate	Immigration can (or will) occur, but is likely to occur only sporadically because surrounding populations are further than 10km, relatively weak or subject to simultaneous catastrophic disturbances, or do not have the full expression of migratory life histories.
Strong	Immigration of multiple adults into the local stream network can (or will) occur on an annual basis. Migratory life histories and the potential for immigration from surrounding populations are maintained through full connection of the stream network with the larger mainstem and other tributary systems. Healthy neighboring populations support migratory life histories, are not likely to experience simultaneous catastrophic events, and are within 5-10km (mouth to mouth) of the local stream network.

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The definition and states for *connectivity* and *colonization and rescue* were authored by BER.



*Background and justification - connectivity and colonization and rescue*

Spatial structure and interconnection among local populations is believed to have a strong influence on the dynamics and persistence of animal populations. There is growing empirical evidence of the importance of such effects in salmonids (Dunham and Rieman 1999; Koizumi and Maekawa 2004; Ayllon et al. 2006; Isaak et al. 2007) including cutthroat trout (Dunham et al. 1997; Neville-Arsenault 2003; Neville et al. 2006). In essence, small isolated populations are far more prone to local extinctions than large or strongly interconnected populations. Theoretical work suggests even low levels of dispersal can dramatically increase the probability of persistence for local populations of cutthroat trout (Hilderbrand 2003) and other fishes (Jager et al. 2001). We assume, then, that dispersal among neighboring cutthroat trout populations can mitigate the effects of small population size and vulnerability to environmental stochasticity or catastrophic events (Dunham et al. 2003; Ayllon et al. 2006). If such dispersal is strong enough, then it could also serve to support populations that might otherwise be prone to deterministic extinction because of consistently negative population growth rates or low resilience (e.g., rescue effects, Brown and Kodric-Brown 1977; Gotelli 1991).

There is limited evidence to estimate dispersal directly, but genetic and demographic studies suggest dispersal is more common among neighboring populations of salmonids than more distant ones (Dunham and Rieman 1999; Koizumi and Maekawa 2004; Ayllon et al. 2006; Whiteley et al. 2006). The occurrence of migratory life histories also appears to influence the propensity for dispersal over longer distances in cutthroat trout (Neville-Arsenault 2003) and other salmonids (Ayllon et al. 2006). Others have suggested that dispersal in fishes is likely to be influenced by the relative size or density of the potential source populations (Jager et al. 2001). Accordingly we assume that effective dispersal into any local habitat of interest will depend directly on the distance to, number and relative strength of surrounding populations, access through a suitable dispersal corridor, and the occurrence of migratory life histories. Effective dispersal that could mitigate potential threats for a population over a period of 20 years will decline quickly as distances among populations exceed 5-10 km or migratory life histories are lost or precluded by migration barriers (Table S1-10).

**Node and state definitions - persistence**

*Persistence* is defined as presence of a functionally viable local westslope cutthroat trout population for at least 20 years. The two states for *persistence* are:

<i>Persistence</i>	
State name	Description
Absent	There are no fish left in the network or the population is so small that it is not expected to recover. Populations that drop below 20 adults are assumed to be functionally extinct because of severe genetic bottlenecks, Allee effects, depensation, or other mechanisms contributing to an extinction vortex such that complete extinction is simply a matter of time (e.g., Gilpin and Soulé 1986; Soulé and Mills 1998).
Present	A functioning population of more than 20 adults is present. A functioning population supports a complement of age classes that will reach maturity and likely reproduce.

The definition and states for *persistence* were authored by BER.

*Background and justification - persistence*

The expectation that a population will persist for a given period of time will be a function of demographic trends and resilience to environmental stochasticity (i.e., *population growth rate*), the size of the population and its vulnerability to environmental variation and catastrophic events (*effective network size*), and the potential for demographic support or recolonization through connectivity with other populations (*colonization and rescue*).

To approximate the combined effects of the three contributing nodes on the expectation of local extinction (i.e., conditional probability table for *persistence*) we used using both the analytic models of Dennis et al. (1991) and expert opinion (Table S1-11).

Model-based approach to define conditional probabilities for *persistence*.

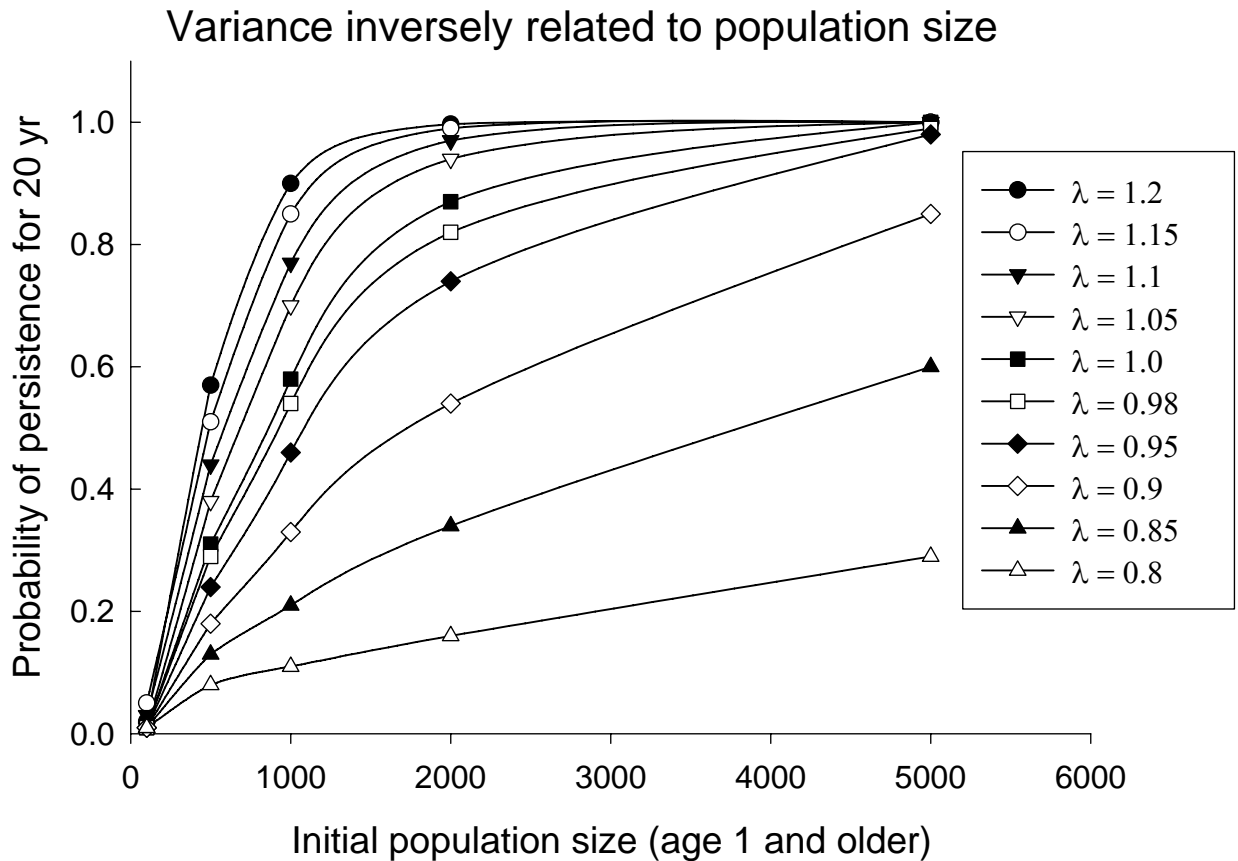
We utilized a range of conditions consistent with our definitions of the states in the respective parental nodes to estimate the probabilities for functional extinction within 20 years. Our analysis followed those outlined by Rieman and McIntyre (1993) for bull trout (*Salvelinus confluentus*) populations, and McIntyre and Rieman (1995) for westslope cutthroat populations and similar applications with other salmonids (Sabo et al. 2004). The models require an estimate of the instantaneous population growth rate, variance in that growth rate, initial total population size, a threshold population size for effective extinction, and the period of time the population must persist. We assumed no density dependence. This could bias the estimates of extinction under optimistic growth rates and larger population sizes, but should be less important under the more constraining (and therefore critical) conditions of low or negative growth and small population size (Sabo et al. 2004) particularly if density dependence is tied primarily to habitat carrying capacities (Beissinger and Westphal 1998) as we suspect for these fishes. Population growth rates (transformed from finite to instantaneous) and initial population sizes (total age 1 and older fish) spanned those defined in the parental nodes. McIntyre and Rieman (1995) used a collection of population monitoring data to estimate the variance in population growth rates for seven different westslope cutthroat populations, with values ranging from 0.11 to 1.02 (mean  $\cong$  0.40). Because sampling error may inflate the apparent variation (e.g., Dunham et al. 2001; Holmes 2001) in population size or interannual growth rate, we assumed that populations would tend toward lower variation with larger population or stream tributary network size. Rieman and McIntyre (1993) found that variance in population growth rate for bull trout increased dramatically with smaller adult population sizes. Others have suggested that both population size and the area and heterogeneity of available habitat will buffer the effects of environmental variation (Pickett and Thompson 1978; Baker 1992). Accordingly we assumed that the variance in population growth rate was directly (and inversely) related to population size increasing from about 0.10 to 0.80 with populations ranging from more than 5000 to fewer than 100 total age-1 and older individuals (Fig. S1-4). Extreme differences in variance for a given population size and population growth rate were also tested (Fig. S1-5). To evaluate the sensitivity of the analytical results to our general assumption about the relationship between the variance in population growth rate and population size, we conducted identical analyses using both low (0.2) and high (0.8) constant variance independent of population size (Fig. S1-6). The sensitivity of

the *InvAD* BBN's predictions to these assumptions is evaluated elsewhere (Supplemental Appendix S2<sup>4</sup>).

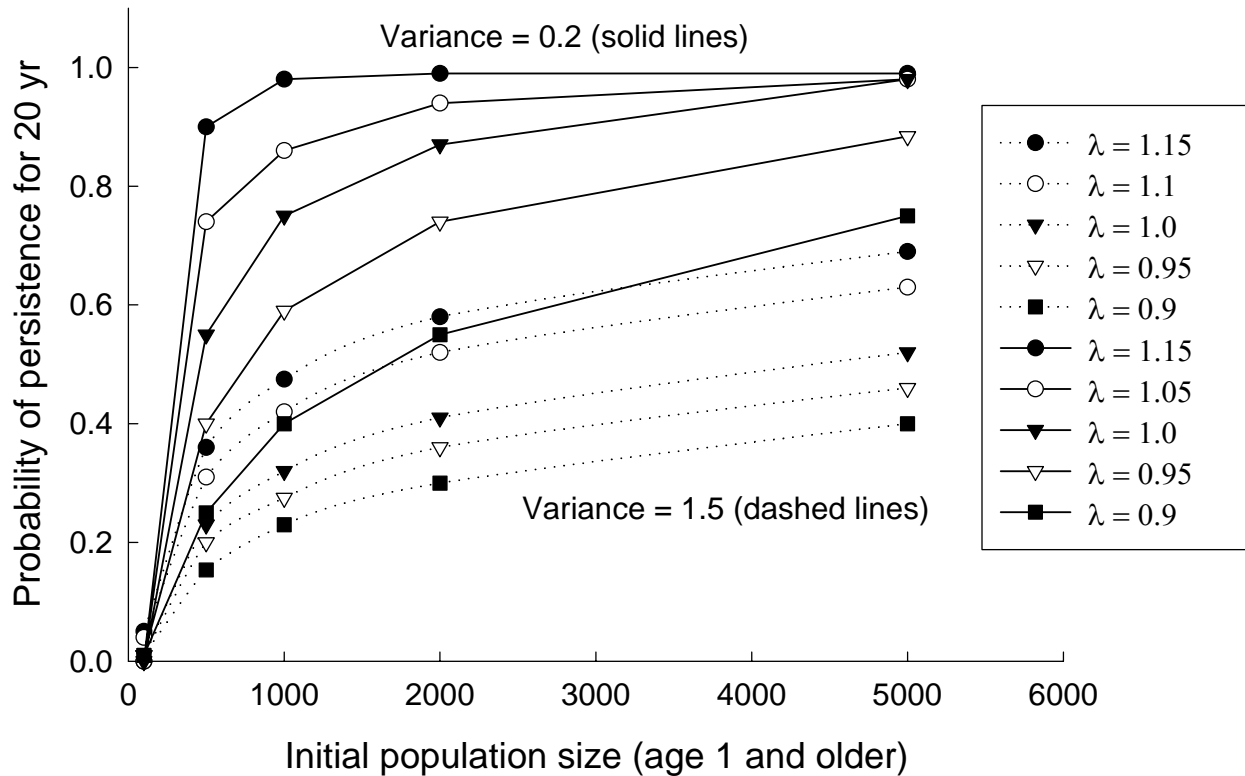
We followed McIntyre and Rieman (1995) in setting a threshold for functional extinction at 100 total age 1 and older individuals which will equate to an adult population less than 20. We assumed that as numbers fall below this level the probability for severe small population effects (e.g., genetic bottlenecks, inbreeding, demographic stochasticity, depensatory mortalities) would virtually guarantee the eventual extinction of the population if it had no demographic or genetic support from outside populations. We used 20 years as our threshold for persistence because it is a more realistic period to anticipate the trends in a population or its habitat than have commonly been used (e.g., 50 to 100 years) in population viability analyses (Beissinger and Westphal 1998; Ralls et al. 2002). Twenty years is roughly the period associated with most land management planning, climatically forced environmental cycles that can influence hydrologic and thermal regimes, and significant changes in habitat associated with both restoration and degradation.

Our analyses with the Dennis et al. model indicated that the probabilities of persistence were strongly influenced by our assumptions of initial population size, population growth rate and variance in that growth rate (Figs. S1-4, S1-5 and S1-6). In general, the expected persistence of WCT declined dramatically as initial populations fell below about 1000 individuals (Figs. S1-4, S1-5 and S1-6). Population growth rate had the most dramatic influence on small- or intermediate-sized populations, and was less important among larger populations unless the growth rate was very low. Because the period over which persistence was evaluated was relatively short (e.g., 3 to 4 generations), larger populations had moderate or even higher probabilities of persistence with even negative growth rates as long as the variance in growth rate was relatively low. Our assumption that smaller populations have higher variance in their population growth rate is conservative when evaluating extinction, but we observed that small populations (500 or fewer individuals) experiencing strong population decline (e.g.,  $\lambda \leq 0.9$ ) were relatively insensitive to this assumption (Figs. S1-5 and S1-6). We used these results (i.e., Figs. S1-4 and S1-6) to directly estimate conditional probabilities for *persistence* associated with isolated populations represented by the midpoints of the classes in the parental nodes for *effective network size* and *population growth rate* (Table S1-11).

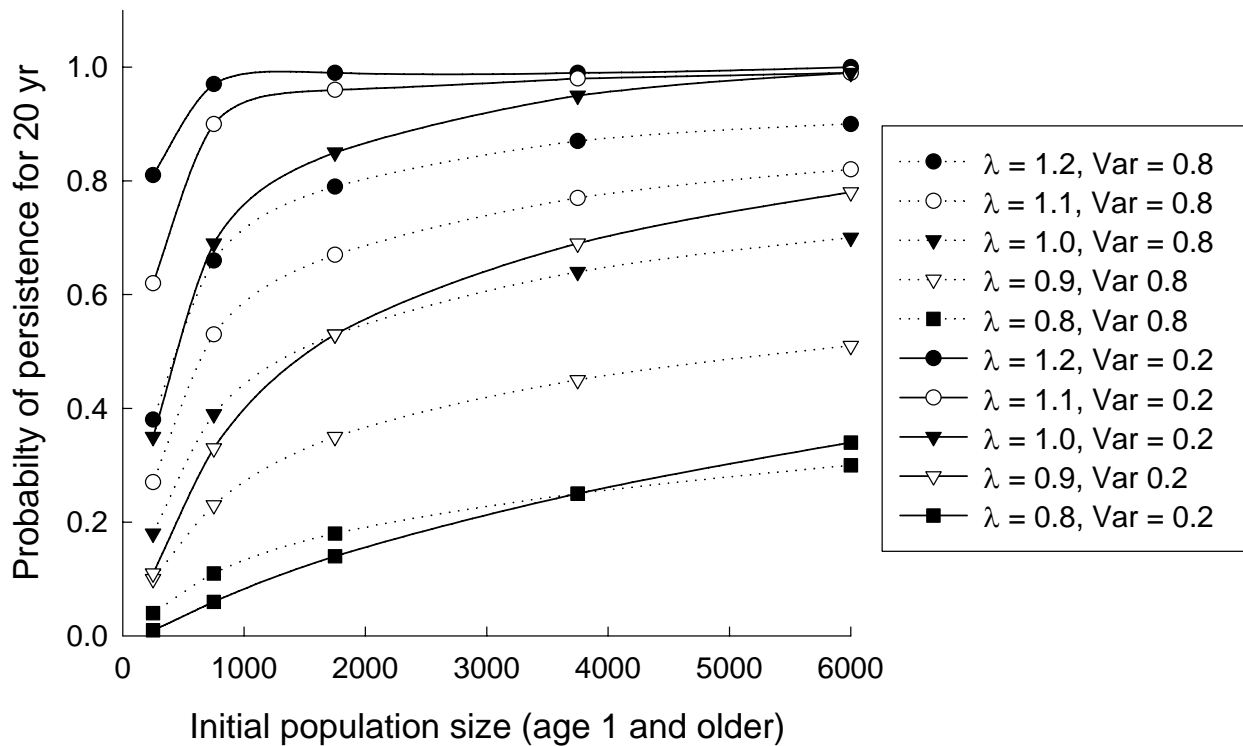
For conditions where *colonization and rescue* was possible we assumed that dispersal could maintain or recolonize populations that might otherwise be doomed to extinction through deterministic or stochastic processes (e.g., Ayllon et al. 2006). If *colonization and rescue* was strong we assumed that demographic support was virtually guaranteed and that populations not in severe population decline would essentially share the combined probability of simultaneous extinction of two independent populations (Table S1-11). We assumed that the benefits of weak connectivity or for populations in severe demographic decline would be less, and interpolated between the values for isolated and strongly connected conditions.



**Fig. S1-4.** Estimated probabilities of persistence for 20 years relative to initial population size and population growth rate ( $\lambda$ ) assuming the variance in growth rate is inversely related to the initial population size, and using the model of Dennis et al. (1991). Population growth ( $\lambda$ ) ranged from 0.8 to 1.15, and was transformed to the equivalent instantaneous rate for analysis. The variance in instantaneous growth rate was varied from 0.10 to 0.80 as initial population size decreased from 5000 (variance = 0.10) to 2000 (variance = 0.2) to 1000 (variance = 0.40) and to 500 or 100 (variance = 0.8). Results were used to develop the conditional probabilities (CPT) for *persistence* with the *InvAD* BBN (see Table S1-11).



**Fig. S1-5.** Estimated probabilities of persistence for 20 years relative to initial population size, population growth rate ( $\lambda$ ), and variance in growth rate, and using the model of Dennis et al. (1991). Finite population growth ( $\lambda$ ) ranged from 0.9 to 1.15, and was transformed to the equivalent instantaneous rate for analysis. The variance in instantaneous growth rates was either 0.20 (solid lines) or 1.5 (dashed lines). Results show that persistence declines sharply below a population size of 1000 and with a higher variance in population growth rate.



**Fig. S1-6.** Estimated probabilities of persistence for 20 years relative to population growth rate ( $\lambda$ ) and initial population size assuming the variance (var) in growth rate is constant at low or high values, and using the model of Dennis et al. (1991). Finite population growth ( $\lambda$ ) ranged from 0.8 to 1.2, and was transformed to the equivalent instantaneous rate for analysis. The variance in instantaneous growth rate was held constant at either low (var = 0.2, solid lines) or high (var = 0.8, dashed lines) values. These estimates of persistence were used to explore the implications of the fundamental uncertainty in the magnitude of the variance in relation to population growth rate. Results were used to develop the conditional probabilities (CPT) for *persistence* in two alternate BBNs (Table S1-11) that were used to evaluate the relative performance of the *InvAD* BBN (see Supplemental Appendix S2<sup>4</sup>).



Opinion-based approach to define conditional probabilities for *persistence*.

In parallel to the approach using the Dennis et al. model, four authors (BER, JBD, MKY, and DPP) also estimated the probability of *persistence* for WCT based on their interpretation of how the three contributing nodes (*effective network size*, *population growth rate*, and *colonization and rescue*) influence a local population in a stream network. The probabilities under the assumption of small (or low) and large (or high) *effective network size* and *population growth rate* were interpolated between values for very small (or very low) and moderate, and moderate and very large (or very high) estimates, respectively, for each of those nodes. Probabilities were averaged across authors to produce an alternate conditional probability table for *persistence* based entirely on expert opinion (Table S1-11).

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**Table S1-1.** Conditional probability table (CPT) for *potential spawning and rearing habitat* for westslope cutthroat trout.

<i>Potential spawning and rearing habitat</i>			Probability (%) of a given state for spawning and rearing habitat		
Contributing (parent) nodes			Low (Poor)	Moderate (Suitable)	High (Optimal)
Temperature (°C)	Gradient (%)	Stream width (m)			
< 7	<2	<3	100	0	0
< 7	<2	3-10	100	0	0
< 7	<2	>10	100	0	0
< 7	2-8	<3	100	0	0
< 7	2-8	3-10	100	0	0
< 7	2-8	>10	100	0	0
< 7	>8	<3	100	0	0
< 7	>8	3-10	100	0	0
< 7	>8	>10	100	0	0
7-10	<2	<3	66	34	0
7-10	<2	3-10	66	34	0
7-10	<2	>10	100	0	0
7-10	2-8	<3	34	66	0
7-10	2-8	3-10	66	34	0
7-10	2-8	>10	100	0	0
7-10	>8	<3	66	34	0
7-10	>8	3-10	100	0	0
7-10	>8	>10	100	0	0
10-15	<2	<3	0	34	66
10-15	<2	3-10	34	66	0
10-15	<2	>10	100	0	0



*Potential spawning and rearing habitat*

Contributing (parent) nodes			Probability (%) of a given state for spawning and rearing habitat		
Temperature (°C)	Gradient (%)	Stream width (m)	Low (Poor)	Moderate (Suitable)	High (Optimal)
10-15	2-8	<3	0	0	100
10-15	2-8	3-10	33	34	33
10-15	2-8	>10	66	34	0
10-15	>8	<3	33	34	33
10-15	>8	3-10	66	34	0
10-15	>8	>10	100	0	0
15-18	<2	<3	66	34	0
15-18	<2	3-10	66	34	0
15-18	<2	>10	100	0	0
15-18	2-8	<3	34	66	0
15-18	2-8	3-10	66	34	0
15-18	2-8	>10	100	0	0
15-18	>8	<3	66	34	0
15-18	>8	3-10	100	0	0
15-18	>8	>10	100	0	0
>18	<2	<3	100	0	0
>18	<2	3-10	100	0	0
>18	<2	>10	100	0	0
>18	2-8	<3	100	0	0
>18	2-8	3-10	100	0	0
>18	2-8	>10	100	0	0
>18	>8	<3	100	0	0
>18	>8	3-10	100	0	0
>18	>8	>10	100	0	0

**Note:** The CPT for *potential spawning and rearing habitat* is based on the consensus opinion of two authors (DPP and BER).

**Table S1-2.** Conditional probability table (CPT) for *potential brook trout (BKT) spawning and rearing habitat*.

<i>Potential brook trout (BKT) spawning and rearing habitat</i>				Probability (%) of a given state for BKT spawning and rearing habitat		
Contributing (parent) node				Low (Poor)	Moderate (Suitable)	High (Optimal)
Hydrologic regime <sup>a</sup>	Temperature (°C)	Gradient (%)	Stream width (m)			
Snowmelt	< 7	<2	<3	100	0	0
Snowmelt	< 7	<2	3-10	100	0	0
Snowmelt	< 7	<2	>10	100	0	0
Snowmelt	< 7	2-8	<3	100	0	0
Snowmelt	< 7	2-8	3-10	100	0	0
Snowmelt	< 7	2-8	>10	100	0	0
Snowmelt	< 7	>8	<3	100	0	0
Snowmelt	< 7	>8	3-10	100	0	0
Snowmelt	< 7	>8	>10	100	0	0
Snowmelt	7-10	<2	<3	34	66	0
Snowmelt	7-10	<2	3-10	0	100	0
Snowmelt	7-10	<2	>10	34	66	0
Snowmelt	7-10	2-8	<3	66	34	0
Snowmelt	7-10	2-8	3-10	34	66	0
Snowmelt	7-10	2-8	>10	66	34	0
Snowmelt	7-10	>8	<3	100	0	0
Snowmelt	7-10	>8	3-10	100	0	0
Snowmelt	7-10	>8	>10	100	0	0
Snowmelt	10-15	<2	<3	0	34	66
Snowmelt	10-15	<2	3-10	0	0	100

*Potential brook trout (BKT) spawning and rearing habitat*

Contributing (parent) node				Probability (%) of a given state for BKT spawning and rearing habitat		
				Low (Poor)	Moderate (Suitable)	High (Optimal)
Hydrologic regime <sup>a</sup>	Temperature (°C)	Gradient (%)	Stream width (m)			
Snowmelt	10-15	<2	>10	0	34	66
Snowmelt	10-15	2-8	<3	34	66	0
Snowmelt	10-15	2-8	3-10	0	34	66
Snowmelt	10-15	2-8	>10	34	66	0
Snowmelt	10-15	>8	<3	100	0	0
Snowmelt	10-15	>8	3-10	100	0	0
Snowmelt	10-15	>8	>10	100	0	0
Snowmelt	15-18	<2	<3	0	100	0
Snowmelt	15-18	<2	3-10	0	66	34
Snowmelt	15-18	<2	>10	0	100	0
Snowmelt	15-18	2-8	<3	66	34	0
Snowmelt	15-18	2-8	3-10	0	100	0
Snowmelt	15-18	2-8	>10	66	34	0
Snowmelt	15-18	>8	<3	100	0	0
Snowmelt	15-18	>8	3-10	100	0	0
Snowmelt	15-18	>8	>10	100	0	0
Snowmelt	>18	<2	<3	66	34	0
Snowmelt	>18	<2	3-10	66	34	0
Snowmelt	>18	<2	>10	100	0	0
Snowmelt	>18	2-8	<3	100	0	0
Snowmelt	>18	2-8	3-10	100	0	0
Snowmelt	>18	2-8	>10	100	0	0
Snowmelt	>18	>8	<3	100	0	0

*Potential brook trout (BKT) spawning and rearing habitat*

Contributing (parent) node				Probability (%) of a given state for BKT spawning and rearing habitat		
				Low (Poor)	Moderate (Suitable)	High (Optimal)
Hydrologic regime <sup>a</sup>	Temperature (°C)	Gradient (%)	Stream width (m)			
Snowmelt	>18	>8	3-10	100	0	0
Snowmelt	>18	>8	>10	100	0	0
Mixed	< 7	<2	<3	100	0	0
Mixed	< 7	<2	3-10	100	0	0
Mixed	< 7	<2	>10	100	0	0
Mixed	< 7	2-8	<3	100	0	0
Mixed	< 7	2-8	3-10	100	0	0
Mixed	< 7	2-8	>10	100	0	0
Mixed	< 7	>8	<3	100	0	0
Mixed	< 7	>8	3-10	100	0	0
Mixed	< 7	>8	>10	100	0	0
Mixed	7-10	<2	<3	100	0	0
Mixed	7-10	<2	3-10	100	0	0
Mixed	7-10	<2	>10	100	0	0
Mixed	7-10	2-8	<3	100	0	0
Mixed	7-10	2-8	3-10	100	0	0
Mixed	7-10	2-8	>10	100	0	0
Mixed	7-10	>8	<3	100	0	0
Mixed	7-10	>8	3-10	100	0	0
Mixed	7-10	>8	>10	100	0	0
Mixed	10-15	<2	<3	34	66	0
Mixed	10-15	<2	3-10	0	100	0
Mixed	10-15	<2	>10	100	0	0

*Potential brook trout (BKT) spawning and rearing habitat*

Contributing (parent) node				Probability (%) of a given state for BKT spawning and rearing habitat		
Hydrologic regime <sup>a</sup>	Temperature (°C)	Gradient (%)	Stream width (m)	Low (Poor)	Moderate (Suitable)	High (Optimal)
Mixed	10-15	2-8	<3	100	0	0
Mixed	10-15	2-8	3-10	66	34	0
Mixed	10-15	2-8	>10	100	0	0
Mixed	10-15	>8	<3	100	0	0
Mixed	10-15	>8	3-10	100	0	0
Mixed	10-15	>8	>10	100	0	0
Mixed	15-18	<2	<3	100	0	0
Mixed	15-18	<2	3-10	100	0	0
Mixed	15-18	<2	>10	100	0	0
Mixed	15-18	2-8	<3	100	0	0
Mixed	15-18	2-8	3-10	100	0	0
Mixed	15-18	2-8	>10	100	0	0
Mixed	15-18	>8	<3	100	0	0
Mixed	15-18	>8	3-10	100	0	0
Mixed	15-18	>8	>10	100	0	0
Mixed	>18	<2	<3	100	0	0
Mixed	>18	<2	3-10	100	0	0
Mixed	>18	<2	>10	100	0	0
Mixed	>18	2-8	<3	100	0	0
Mixed	>18	2-8	3-10	100	0	0
Mixed	>18	2-8	>10	100	0	0
Mixed	>18	>8	<3	100	0	0
Mixed	>18	>8	3-10	100	0	0

*Potential brook trout (BKT) spawning and rearing habitat*

Contributing (parent) node				Probability (%) of a given state for BKT spawning and rearing habitat		
Hydrologic regime <sup>a</sup>	Temperature (°C)	Gradient (%)	Stream width (m)	Low (Poor)	Moderate (Suitable)	High (Optimal)
Mixed	>18	>8	>10	100	0	0

<sup>a</sup> Mixed = *hydrologic regime* is mixed rain-on-snow and snowmelt

**Note:** The CPT for *potential BKT spawning and rearing habitat* is based on the consensus opinion of two authors (DPP and BER).

**Table S1-3.** Conditional probability table (CPT) for brook trout *invasion strength*.

<i>Invasion strength</i>		Probability (%) of a given state for <i>invasion strength</i>		
Contributing (parent) nodes		Strong	Moderate	None
BKT connectivity	Invasion barrier			
Strong	Yes	0	0	100
Strong	No	100	0	0
Moderate	Yes	0	0	100
Moderate	No	0	100	0
None	Yes	0	0	100
None	No	0	0	100

**Note:** The CPT probabilities for *invasion strength* are a deterministic combination based on whether or not brook trout are expected to immigrate (*BKT connectivity*), and whether or not a physical migration barrier (*invasion barrier*) is present or planned. *Invasion barriers* are assumed to be 100% effective.



**Table S1-4.** Conditional probability table (CPT) for *brook trout (BKT) population status*.

<i>Brook trout (BKT) population status</i>			Probability (%) of a given state for BKT population status		
Contributing (parent) nodes					
BKT	Potential BKT		Absent	Weak	Strong
invasion strength	spawning and rearing habitat	Habitat degradation			
Strong	Low	Degraded	35	45	20
Strong	Low	Minimally altered	20	45	35
Strong	Moderate	Degraded	10	60	30
Strong	Moderate	Minimally altered	0	35	65
Strong	High	Degraded	0	30	70
Strong	High	Minimally altered	0	0	100
Moderate	Low	Degraded	75	20	5
Moderate	Low	Minimally altered	40	45	15
Moderate	Moderate	Degraded	35	50	15
Moderate	Moderate	Minimally altered	10	40	50
Moderate	High	Degraded	10	45	45
Moderate	High	Minimally altered	5	20	75
None	Low	Degraded	100	0	0
None	Low	Minimally altered	100	0	0
None	Moderate	Degraded	100	0	0
None	Moderate	Minimally altered	100	0	0
None	High	Degraded	100	0	0
None	High	Minimally altered	100	0	0

**Note:** The CPT for *BKT population status* is based on opinion where the estimates of the five authors were averaged.

**Table S1-5.** Conditional probability table (CPT) for *egg to age-1 survival* of westslope cutthroat trout.

<i>Egg to age-1 survival</i>			Probability (%) of a given state for egg to age-1 survival		
Contributing (parent) nodes					
BKT population status	Potential spawning and rearing habitat	Habitat degradation	Low	Moderate	High
Strong	Low	Degraded	100	0	0
Strong	Low	Minimally altered	100	0	0
Strong	Moderate	Degraded	100	0	0
Strong	Moderate	Minimally altered	90	10	0
Strong	High	Degraded	95	5	0
Strong	High	Minimally altered	75	25	0
Weak	Low	Degraded	85	15	0
Weak	Low	Minimally altered	75	25	0
Weak	Moderate	Degraded	65	35	0
Weak	Moderate	Minimally altered	50	50	0
Weak	High	Degraded	45	45	10
Weak	High	Minimally altered	20	55	25
Absent	Low	Degraded	75	25	0
Absent	Low	Minimally altered	45	50	5
Absent	Moderate	Degraded	15	60	25
Absent	Moderate	Minimally altered	0	50	50
Absent	High	Degraded	5	40	55
Absent	High	Minimally altered	0	0	100

**Note:** The CPT for *egg to age-1 survival* is based on opinion where the estimates of the five authors were averaged.

**Table S1-6.** Conditional probability table (CPT) for *juvenile survival* of westslope cutthroat trout.

<i>Juvenile survival</i>			Probability (%) of a given state for juvenile survival		
Contributing (parent) nodes					
BKT population status	Potential spawning and rearing habitat	Habitat degradation	Low	Moderate	High
Strong	Low	Degraded	100	0	0
Strong	Low	Minimally altered	75	25	0
Strong	Moderate	Degraded	75	25	0
Strong	Moderate	Minimally altered	37.5	62.5	0
Strong	High	Degraded	62.5	37.5	0
Strong	High	Minimally altered	25	50	25
Weak	Low	Degraded	100	0	0
Weak	Low	Minimally altered	50	50	0
Weak	Moderate	Degraded	50	50	0
Weak	Moderate	Minimally altered	0	87.5	12.5
Weak	High	Degraded	25	62.5	12.5
Weak	High	Minimally altered	0	37.5	62.5
Absent	Low	Degraded	75	25	0
Absent	Low	Minimally altered	25	75	0
Absent	Moderate	Degraded	25	62.5	12.5
Absent	Moderate	Minimally altered	0	50	50
Absent	High	Degraded	12.5	50	37.5
Absent	High	Minimally altered	0	0	100

**Note:** The CPT for *juvenile survival* (i.e., survival from age-1 to age-2) is based on opinion where the estimates of two authors (DPP and BER) were averaged.

**Table S1-7.** Conditional probability (CPT) table for *subadult-adult survival* of westslope cutthroat trout.

<i>Subadult-adult survival</i>			Probability (%) of a given state for subadult-adult survival		
Contributing (parent) nodes			Low	Moderate	High
Fishing exploitation	Habitat degradation	Invasion barrier			
High	Degraded	Yes	100	0	0
High	Degraded	No	50	50	0
High	Minimally altered	Yes	50	50	0
High	Minimally altered	No	37.5	50	12.5
Low	Degraded	Yes	25	75	0
Low	Degraded	No	12.5	37.5	50
Low	Minimally altered	Yes	0	10	90
Low	Minimally altered	No	0	0	100

**Note:** The CPT for *subadult-adult survival* (i.e., survival of individuals age-2 and older) is based on opinion where the estimates of two authors (DPP and BER) were averaged.

**Table S1-8.** Conditional probability table (CPT) for *effective life history* of westslope cutthroat trout.

<i>Effective life history</i>		Probability (%) of a given state for <i>effective life history</i>	
Contributing (parent) nodes			
Potential life history	Invasion barrier	Resident	Migratory
Resident	Yes	100	0
Resident	No	100	0
Migratory	Yes	100	0
Migratory	No	0	100

**Note:** The CPT probabilities for *effective life history* are a deterministic combination based on the expectation of a local westslope cutthroat trout population expressing a resident or migratory life history (*potential life history*), and whether a migration barrier (*invasion barrier*) would preclude actual expression of a migratory life history.

**Table S1-9.** Conditional probability tables (CPTs) for *population growth rate* of westslope cutthroat trout based on (a) the frequency distribution of output from a matrix population model (demographic model), and (b) expert opinion (opinion).

<i>Population growth rate</i>													
Contributing (parent) nodes <sup>a</sup>				Probability (%) of a given state for population growth rate									
				(a) Demographic model					(b) Opinion				
Eff.	Egg to	Juv	Subad-	Very				Very	Very				Very
life	age-1 surv	surv	adult surv	low	Low	Mod	High	high	low	Low	Mod	High	high
history													
Res	Low	Low	Low	100	0	0	0	0	100	0	0	0	0
Res	Low	Low	Mod	99.9	0.1	0	0	0	75	25	0	0	0
Res	Low	Low	High	86.5	13.1	0.4	0	0	50	37.5	12.5	0	0
Res	Low	Mod	Low	100	0	0	0	0	68.75	31.25	0	0	0
Res	Low	Mod	Mod	96.3	3.7	0	0	0	50	37.5	12.5	0	0
Res	Low	Mod	High	64.5	30	5.5	0	0	25	43.75	31.25	0	0
Res	Low	High	Low	100	0	0	0	0	50	37.5	12.5	0	0
Res	Low	High	Mod	87.32	12.36	0.32	0	0	25	50	25	0	0
Res	Low	High	High	46.5	36.19	16.16	1.15	0	0	50	50	0	0
Res	Mod	Low	Low	99.9	0.1	0	0	0	50	50	0	0	0
Res	Mod	Low	Mod	80.1	18.8	1.1	0	0	37.5	37.5	25	0	0
Res	Mod	Low	High	25.3	46.3	25.7	2.7	0	25	31.25	43.75	0	0
Res	Mod	Mod	Low	95.9	4.1	0	0	0	31.25	43.75	25	0	0

*Population growth rate*

Contributing (parent) nodes <sup>a</sup>				Probability (%) of a given state for population growth rate									
				(a) Demographic model					(b) Opinion				
Eff.	Egg to	Juv	Subad-	Very	Very	Very	Very	Very	Very	Very	Very	Very	Very
history	age-1 surv	surv	adult surv	low	Low	Mod	High	high	low	Low	Mod	High	high
Res	Mod	Mod	Mod	48	40.5	11.1	0.4	0	9.375	46.875	43.75	0	0
Res	Mod	Mod	High	6.8	31.5	41	19.4	1.3	0	28.125	68.75	3.125	0
Res	Mod	High	Low	85.1	14.4	0.5	0	0	12.5	37.5	50	0	0
Res	Mod	High	Mod	27	42.2	26.4	4.4	0	0	37.5	43.75	18.75	0
Res	Mod	High	High	1.4	17	37.2	34.2	10.2	0	6.25	56.25	37.5	0
Res	High	Low	Low	93.7	6.3	0	0	0	25	50	25	0	0
Res	High	Low	Mod	38.65	44.22	16.47	0.66	0	0	50	50	0	0
Res	High	Low	High	3.8	26.9	41.8	24.5	3	0	25	75	0	0
Res	High	Mod	Low	69.4	27	3.6	0	0	0	50	43.75	6.25	0
Res	High	Mod	Mod	12.48	36.38	38.9	11.96	0.28	0	25	43.75	31.25	0
Res	High	Mod	High	0	7.7	29.1	39.2	24	0	0	62.5	31.25	6.25
Res	High	High	Low	44.2	39.7	15.5	0.6	0	0	12.5	62.5	25	0
Res	High	High	Mod	3.57	23.16	38.34	29.1	5.83	0	12.5	25	50	12.5
Res	High	High	High	0	1.1	14.9	31.9	52.1	0	0	25	37.5	37.5
Migr	Low	Low	Low	93.23	6.52	0.25	0	0	37.5	37.5	25	0	0
Migr	Low	Low	Mod	56.2	29.3	12.8	1.7	0	12.5	62.5	25	0	0

*Population growth rate*

Contributing (parent) nodes <sup>a</sup>				Probability (%) of a given state for population growth rate									
				(a) Demographic model					(b) Opinion				
Eff.	Egg to	Juv	Subad-	Very	Very	Very	Very	Very	Very	Very	Very	Very	Very
history	age-1 surv	surv	adult surv	low	Low	Mod	High	high	low	Low	Mod	High	high
Migr	Low	Low	High	18.4	30.2	30.2	16.8	4.4	0	50	50	0	0
Migr	Low	Mod	Low	75.8	19.6	4.5	0.1	0	18.75	43.75	37.5	0	0
Migr	Low	Mod	Mod	32.02	31.96	24.04	10.84	1.14	0	50	50	0	0
Migr	Low	Mod	High	6.23	19.46	28.99	25.55	19.77	0	25	56.25	18.75	0
Migr	Low	High	Low	59.9	25.7	12.5	1.9	0	0	50	50	0	0
Migr	Low	High	Mod	18.01	26.75	28.25	19.1	7.89	0	25	62.5	12.5	0
Migr	Low	High	High	2.2	11.2	23.8	26.4	36.4	0	0	62.5	37.5	0
Migr	Mod	Low	Low	41.6	35.9	18.6	3.8	0.1	12.5	37.5	50	0	0
Migr	Mod	Low	Mod	4.73	20.47	33.72	28.74	12.34	0	37.5	50	12.5	0
Migr	Mod	Low	High	0	2.4	15	28.4	54.2	0	18.75	56.25	25	0
Migr	Mod	Mod	Low	16.5	30.8	32.1	16.6	4	0	28.125	65.625	6.25	0
Migr	Mod	Mod	Mod	0.34	6.09	21.51	31.13	40.93	0	12.5	53.125	34.375	0
Migr	Mod	Mod	High	0	0.1	3.3	14.4	82.2	0	0	40.625	59.375	0
Migr	Mod	High	Low	6.05	19.9	31.29	27.7	15.06	6.25	31.25	50	12.5	0
Migr	Mod	High	Mod	0	1.2	11.32	23.04	64.44	0	12.5	62.5	25	0
Migr	Mod	High	High	0	0	0.3	6	93.7	0	0	12.5	62.5	25



*Population growth rate*

Contributing (parent) nodes <sup>a</sup>				Probability (%) of a given state for population growth rate									
				(a) Demographic model					(b) Opinion				
Eff.	Egg to	Juv	Subad-	Very	Very	Very	Very	Very	Very	Very	Very	Very	Very
history	age-1 surv	surv	adult surv	low	Low	Mod	High	high	low	Low	Mod	High	high
Migr	High	Low	Low	10.03	27.42	34.27	22.4	5.88	0	25	62.5	12.5	0
Migr	High	Low	Mod	0	3.9	16.8	28.4	50.9	0	0	62.5	37.5	0
Migr	High	Low	High	0	0	1.33	11.14	87.53	0	0	50	37.5	12.5
Migr	High	Mod	Low	1.53	11.32	25.36	31.99	29.8	0	6.25	56.25	31.25	6.25
Migr	High	Mod	Mod	0	0.08	4.05	15.2	80.67	0	0	31.25	50	18.75
Migr	High	Mod	High	0	0	0	1.2	98.8	0	0	12.5	50	37.5
Migr	High	High	Low	0	3.7	15.8	25.1	55.4	0	0	37.5	37.5	25
Migr	High	High	Mod	0	0	0.4	7.2	92.4	0	0	12.5	37.5	50
Migr	High	High	High	0	0	0	0	100	0	0	0	12.5	87.5

<sup>a</sup> Abbreviations: Mod = moderate, Eff life history = *effective life history*, Egg to age-1 surv = *egg to age-1 survival*, Juv surv = *juvenile survival*, and Subad-adult surv = *subadult-adult survival*.

**Note:** The CPT for *population growth rate* based on (a) the demographic model (by DPP), and (b) opinion was based on the mean estimates of two authors (DPP and BER).

**Table S1-10.** Conditional probability table (CPT) for *colonization and rescue* of westslope cutthroat trout.

<i>Colonization and rescue</i>		Probability (%) for a given state of colonization and rescue		
Contributing (parent) nodes		None	Moderate	Strong
Connectivity	Invasion barrier	None	Moderate	Strong
None	Yes	100	0	0
None	No	100	0	0
Moderate	Yes	100	0	0
Moderate	No	0	100	0
Strong	Yes	100	0	0
Strong	No	0	0	100

**Note:** The CPT probabilities for *colonization and rescue* are a deterministic combination based on whether or not cutthroat trout from other populations are expected to provide demographic support to the local population of interest (*connectivity*), and whether or not a physical migration barrier (*invasion barrier*) is present or planned. An *invasion barrier* is assumed to be 100% effective at stopping such demographic support.

**Table S1-11.** Conditional probability tables (CPTs) for 20-year *persistence* of westslope cutthroat trout based on either output from the analytical model of Dennis et al. (1991) where the variance in population growth rate was (a) inversely related to population size (used for the *InvAD* BNN), (b) a constant value of 0.2 (Var=0.2), (c) a constant value of 0.8 (Var=0.8); or (d) where probabilities for a given state were based entirely on expert opinion (Opinion).

<i>Persistence</i>			Probability (%) for a given state of persistence <sup>b</sup>							
Contributing (parent) nodes			(a) InvAD		(b) Var=0.2		(c) Var=0.8		(d) Opinion	
Effective network size (km or age-1 and older) <sup>a</sup>	Population growth rate ( $\lambda$ )	Colonization and rescue	Abs	Pres	Abs	Pres	Abs	Pres	Abs	Pres
< 3 km or <500 age-1+	<0.85	None	95	5	99	1	96	4	100	0
< 3 km or <500 age-1+	<0.85	Moderate	92.5	7.5	98.5	1.5	94.1	5.9	81.3	18.8
< 3 km or <500 age-1+	<0.85	Strong	90	10	98	2	92.2	7.8	56.3	43.8
< 3 km or <500 age-1+	0.85-0.95	None	92	8	89	11	90	10	84.4	15.6
< 3 km or <500 age-1+	0.85-0.95	Moderate	88.5	11.5	84.1	15.9	85.5	14.5	68.8	31.3
< 3 km or <500 age-1+	0.85-0.95	Strong	85	15	79.2	20.8	81	19	40.6	59.4
< 3 km or <500 age-1+	0.95-1.05	None	87	13	65	35	82	18	68.8	31.3
< 3 km or <500 age-1+	0.95-1.05	Moderate	81.5	18.5	53.6	46.4	74.6	25.4	56.3	43.8
< 3 km or <500 age-1+	0.95-1.05	Strong	76	24	42.3	57.8	67.2	32.8	25	75

*Persistence*

Contributing (parent) nodes			Probability (%) for a given state of persistence <sup>b</sup>							
Effective network size (km or age-1 and older) <sup>a</sup>	Population growth rate ( $\lambda$ )	Colonization and rescue	(a) InvAD		(b) Var=0.2		(c) Var=0.8		(d) Opinion	
			Abs	Pres	Abs	Pres	Abs	Pres	Abs	Pres
< 3 km or <500 age-1+	1.05-1.15	None	82	18	38	62	73	27	62.5	37.5
< 3 km or <500 age-1+	1.05-1.15	Moderate	74.5	25.5	26.2	73.8	63.1	36.9	46.9	53.1
< 3 km or <500 age-1+	1.05-1.15	Strong	67	33	14.4	85.6	53.3	46.7	15.6	84.4
< 3 km or <500 age-1+	>1.15	None	72	28	19	81	62	38	56.3	43.8
< 3 km or <500 age-1+	>1.15	Moderate	62	38	11.3	88.7	50.2	49.8	37.5	62.5
< 3 km or <500 age-1+	>1.15	Strong	52	48	3.6	96.4	38.4	61.6	6.3	93.8
3-5 km or 500-1000 age-1+	<0.85	None	90	10	94	6	89	11	96.9	3.1
3-5 km or 500-1000 age-1+	<0.85	Moderate	85.5	14.5	91.2	8.8	84.1	15.9	78.1	21.9
3-5 km or 500-1000 age-1+	<0.85	Strong	81	19	88.4	11.6	79.2	20.8	50	50
3-5 km or 500-1000 age-1+	0.85-0.95	None	70	30	67	33	77	23	78.1	21.9
3-5 km or 500-1000 age-1+	0.85-0.95	Moderate	59.5	40.5	55.9	44.1	68.1	31.9	60.9	39.1
3-5 km or 500-1000 age-1+	0.85-0.95	Strong	49	51	44.9	55.1	59.3	40.7	35.9	64.1
3-5 km or 500-1000 age-1+	0.95-1.05	None	50	50	31	69	61	39	59.4	40.6
3-5 km or 500-1000 age-1+	0.95-1.05	Moderate	37.5	62.5	20.3	79.7	49.1	50.9	43.8	56.3
3-5 km or 500-1000 age-1+	0.95-1.05	Strong	25	75	9.6	90.4	37.2	62.8	21.9	78.1

*Persistence*

Contributing (parent) nodes			Probability (%) for a given state of persistence <sup>b</sup>							
Effective network size (km or age-1 and older) <sup>a</sup>	Population growth rate ( $\lambda$ )	Colonization and rescue	(a) InvAD		(b) Var=0.2		(c) Var=0.8		(d) Opinion	
			Abs	Pres	Abs	Pres	Abs	Pres	Abs	Pres
3-5 km or 500-1000 age-1+	1.05-1.15	None	29	71	10	90	47	53	53.1	46.9
3-5 km or 500-1000 age-1+	1.05-1.15	Moderate	18.5	81.5	5.5	94.5	34.5	65.5	35.9	64.1
3-5 km or 500-1000 age-1+	1.05-1.15	Strong	8	92	1	99	22.1	77.9	12.5	87.5
3-5 km or 500-1000 age-1+	>1.15	None	15	85	3	97	34	66	46.9	53.1
3-5 km or 500-1000 age-1+	>1.15	Moderate	8.5	91.5	1.5	98.5	22.8	77.2	28.1	71.9
3-5 km or 500-1000 age-1+	>1.15	Strong	2	98	0.1	99.9	11.6	88.4	3.1	96.9
5-7 km or 1000-2500 age-1+	<0.85	None	83	17	86	14	82	18	93.8	6.3
5-7 km or 1000-2500 age-1+	<0.85	Moderate	76	24	80	20	74.6	25.4	75	25
5-7 km or 1000-2500 age-1+	<0.85	Strong	69	31	74	26	67.2	32.8	43.8	56.3
5-7 km or 1000-2500 age-1+	0.85-0.95	None	48	52	47	53	65	35	71.9	28.1
5-7 km or 1000-2500 age-1+	0.85-0.95	Moderate	35.5	64.5	34.5	65.5	53.6	46.4	53.1	46.9
5-7 km or 1000-2500 age-1+	0.85-0.95	Strong	23	77	22.1	77.9	42.3	57.8	31.3	68.8
5-7 km or 1000-2500 age-1+	0.95-1.05	None	15	85	15	85	47	53	50	50
5-7 km or 1000-2500 age-1+	0.95-1.05	Moderate	8.5	91.5	8.6	91.4	34.5	65.5	31.3	68.8
5-7 km or 1000-2500 age-1+	0.95-1.05	Strong	2	98	2.3	97.8	22.1	77.9	18.8	81.3

*Persistence*

Contributing (parent) nodes			Probability (%) for a given state of persistence <sup>b</sup>							
Effective network size (km or age-1 and older) <sup>a</sup>	Population growth rate ( $\lambda$ )	Colonization and rescue	(a) InvAD		(b) Var=0.2		(c) Var=0.8		(d) Opinion	
			Abs	Pres	Abs	Pres	Abs	Pres	Abs	Pres
5-7 km or 1000-2500 age-1+	1.05-1.15	None	4	96	4	96	33	67	43.8	56.3
5-7 km or 1000-2500 age-1+	1.05-1.15	Moderate	2	98	2.1	97.9	21.9	78.1	25	75
5-7 km or 1000-2500 age-1+	1.05-1.15	Strong	0	100	0.2	99.8	10.9	89.1	9.4	90.6
5-7 km or 1000-2500 age-1+	>1.15	None	2	98	1	99	21	79	37.5	62.5
5-7 km or 1000-2500 age-1+	>1.15	Moderate	1	99	0.5	99.5	12.7	87.3	18.8	81.3
5-7 km or 1000-2500 age-1+	>1.15	Strong	0	100	0	100	4.4	95.6	0	100
7-10 km or 2500-5000 age-1+	<0.85	None	77	23	75	25	75	25	75	25
7-10 km or 2500-5000 age-1+	<0.85	Moderate	68	32	65.6	34.4	65.6	34.4	65.6	34.4
7-10 km or 2500-5000 age-1+	<0.85	Strong	59	41	56.3	43.8	56.3	43.8	34.4	65.6
7-10 km or 2500-5000 age-1+	0.85-0.95	None	26	74	31	69	55	45	59.4	40.6
7-10 km or 2500-5000 age-1+	0.85-0.95	Moderate	16.5	83.5	20.3	79.7	42.6	57.4	46.9	53.1
7-10 km or 2500-5000 age-1+	0.85-0.95	Strong	7	93	9.6	90.4	30.3	69.8	21.9	78.1
7-10 km or 2500-5000 age-1+	0.95-1.05	None	5	95	5	95	36	64	43.8	56.3
7-10 km or 2500-5000 age-1+	0.95-1.05	Moderate	2.5	97.5	2.6	97.4	24.5	75.5	28.1	71.9
7-10 km or 2500-5000 age-1+	0.95-1.05	Strong	0	100	0.3	99.8	13	87	9.4	90.6

*Persistence*

Contributing (parent) nodes			Probability (%) for a given state of persistence <sup>b</sup>							
Effective network size (km or age-1 and older) <sup>a</sup>	Population growth rate ( $\lambda$ )	Colonization and rescue	(a) InvAD		(b) Var=0.2		(c) Var=0.8		(d) Opinion	
			Abs	Pres	Abs	Pres	Abs	Pres	Abs	Pres
7-10 km or 2500-5000 age-1+	1.05-1.15	None	1	99	2	98	23	77	35.9	64.1
7-10 km or 2500-5000 age-1+	1.05-1.15	Moderate	0.5	99.5	1	99	14.1	85.9	20.3	79.7
7-10 km or 2500-5000 age-1+	1.05-1.15	Strong	0	100	0	100	5.3	94.7	4.7	95.3
7-10 km or 2500-5000 age-1+	>1.15	None	1	99	1	99	13	87	28.1	71.9
7-10 km or 2500-5000 age-1+	>1.15	Moderate	0.5	99.5	0.5	99.5	7.3	92.7	12.5	87.5
7-10 km or 2500-5000 age-1+	>1.15	Strong	0	100	0	100	1.7	98.3	0	100
>10 km or > 5000 age-1+	<0.85	None	70	30	66	34	70	30	56.3	43.8
>10 km or > 5000 age-1+	<0.85	Moderate	59.5	40.5	54.8	45.2	59.5	40.5	56.3	43.8
>10 km or > 5000 age-1+	<0.85	Strong	49	51	43.6	56.4	49	51	25	75
>10 km or > 5000 age-1+	0.85-0.95	None	15	85	22	78	49	51	46.9	53.1
>10 km or > 5000 age-1+	0.85-0.95	Moderate	8.5	91.5	13.4	86.6	36.5	63.5	40.6	59.4
>10 km or > 5000 age-1+	0.85-0.95	Strong	2	98	4.8	95.2	24	76	12.5	87.5
>10 km or > 5000 age-1+	0.95-1.05	None	1	99	1	99	30	70	37.5	62.5
>10 km or > 5000 age-1+	0.95-1.05	Moderate	0.5	99.5	0.5	99.5	19.5	80.5	25	75
>10 km or > 5000 age-1+	0.95-1.05	Strong	0	100	0	100	9	91	0	100

<i>Persistence</i>			Probability (%) for a given state of persistence <sup>b</sup>							
Contributing (parent) nodes			(a) InvAD		(b) Var=0.2		(c) Var=0.8		(d) Opinion	
Effective network size (km or age-1 and older) <sup>a</sup>	Population growth rate ( $\lambda$ )	Colonization and rescue	Abs	Pres	Abs	Pres	Abs	Pres	Abs	Pres
>10 km or > 5000 age-1+	1.05-1.15	None	1	99	1	99	18	82	28.1	71.9
>10 km or > 5000 age-1+	1.05-1.15	Moderate	0.5	99.5	0.5	99.5	10.6	89.4	15.6	84.4
>10 km or > 5000 age-1+	1.05-1.15	Strong	0	100	0	100	3.2	96.8	0	100
>10 km or > 5000 age-1+	>1.15	None	0	100	0	100	10	90	18.8	81.3
>10 km or > 5000 age-1+	>1.15	Moderate	0	100	0	100	5.5	94.5	6.3	93.8
>10 km or > 5000 age-1+	>1.15	Strong	0	100	0	100	1	99	0	100

<sup>a</sup> *Effective network size* can be expressed as either length of connected spawning and rearing habitat in a local stream network (km) or the population size of individuals age 1 and older within the stream network.

<sup>b</sup> Abs = Absent (or extirpated), Pres = Present

**Note:** The CPTs for *persistence* based on the Dennis et al. model (a-c) were completed by BER. The CPT based on opinion represents the mean estimates of four authors (DPP, BER, JBD, and MKY).