Assessing the Feasibility of Native Fish Reintroductions: A Framework and Example Applied to Bull Trout in the Clackamas River, Oregon

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Conversion Factors

Multiply	By	To obtain
centimeter (cm)	0.3937	inch (in.)
kilometer (km)	0.6214	mile (mi)
meter (m)	3.281	foot (ft)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Assessing the Feasibility of Native Fish Reintroductions: A Framework and Example Applied to Bull Trout in the Clackamas River, Oregon

Jason Dunham[1], Kirsten Gallo[2]

Abstract

In a species conservation context, translocations can be an important tool, but they frequently fail to successfully establish new populations. We consider the case of reintroductions for bull trout *(Salvelinus confluentus)*, a federally-listed threatened species with a widespread but declining distribution in western North America. Our specific objectives in this work were to: 1) develop a general framework for assessing the feasibility of reintroduction for bull trout, 2) provide a detailed example of implementing this framework to assess the feasibility of reintroducing bull trout in the Clackamas River, Oregon, and 3) discuss the implications of this effort in the more general context of fish reintroductions as a conservation tool. Review of several case histories and our assessment of the Clackamas River suggest that an attempt to reintroduce bull trout could be successful, assuming adequate resources are committed to the subsequent stages of implementation, monitoring, and evaluation.

Keywords

Reintroductions, translocations, decision support, decision framework, bull trout, *Salvelinus confluentus*

Introduction

Translocations are a common activity in species conservation (Griffith *et al.* 1989, Seddon *et al.* 2007). Among vertebrates, published studies of translocations for conservation are best represented by cases involving mammals and birds, whereas fishes are strongly underrepresented (Fischer and Lindenmayer 2000, Seddon *et al.* 2005, 2007). This relative dearth of documentation for translocations of fishes stands in contrast to the large number of actual translocations that have been attempted (*e.g.*, Welcomme 1988, Lever 1996), including >400 translocations in efforts to conserve a single species (Gila topminnow *Poeciliopsis occidentalis*, Hendricksen and Brooks 2001, Sheller *et al.* 2006). In a species conservation context, translocations can be an important tool, but the efficacy of translocations is often in question because they frequently fail to successfully establish new populations (Minckley 1995). Here we focus on the problem of translocation of fish from a wild source to re-establish populations in formerly occupied habitat, namely "reintroduction."

There are readily available guidelines for translocations of fishes (*e.g.*, Williams *et al.* 1988, Minckley 1995, IUCN 1998), which identify several steps in species reintroductions including: 1) an initial assessment of the feasibility of such an effort, 2) actual implementation if an effort is deemed feasible, and 3) monitoring and evaluation to determine if the reintroduction was successful or to determine the reasons for failure. Most of the existing peer-reviewed literature on fishes has retrospectively evaluated the success of reintroductions from genetic (*e.g.*, Stockwell *et al.* 1996, Stockwell and Leberg) or ecological perspectives (Harig and Fausch 2002, Shute *et al.* 2005, Sheller *et al.* 2006). In contrast, examples of feasibility assessments for specific reintroductions are still lacking in the literature on fish or for any species (Seddon *et al.* 2007). Feasibility assessments can be a critical step, and the general lack of success of reintroductions cited for many fishes could be attributed to inadequate feasibility assessments or a general lack of understanding of factors likely to contribute to the success of reintroductions (Minckley 1995).

Here we consider the case of reintroductions for bull trout *(Salvelinus confluentus)*, a federally-listed threatened species with a widespread, but declining distribution in western North America (USFWS 2002). A major reason for declines in this species is habitat loss and fragmentation, but many potentially suitable unoccupied habitats may exist (*e.g.*, Dunham and Rieman 1999). Given this possibility, the question of reintroductions has arisen in several situations (*e.g.*, Epifanio *et al.* 2003), and reintroductions of bull trout have been attempted in at least two cases, including the McCloud River in California (Buchanan *et al.* 1997) and Middle Fork Willamette River in Oregon (M. Wade, Oregon Department of Fish and Wildlife,

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pers. comm.). The former case did not result in successful establishment of bull trout, and the latter effort is still in progress. Our specific objectives in this work were to: 1) develop a general framework for assessing the feasibility of reintroduction for bull trout, 2) provide a detailed example of implementing this framework to assess the feasibility of reintroducing bull trout in the Clackamas River, Oregon, and 3) discuss the implications of this effort in the more general context of fish reintroductions as a conservation tool.

Methods

Framework for assessing the feasibility of a reintroduction

We began the assessment by consulting existing guidelines (Williams *et al.* 1988, Minckely 1995, IUCN 1998, Epifanio *et al.* 2003) to develop a general framework we could apply to assess the feasibility of a bull trout reintroduction. Assuming that a particular recipient habitat has been identified (*e.g.*, priorities among alternative recipient habitats have been considered), we identified two major components of the feasibility assessment:

1. The potential for a given recipient habitat to support a reintroduction, and
2. The potential of available donor populations to support a reintroduction.

Within each component of the assessment, we developed a list of key questions to address. For recipient habitats, questions included the following:

1. Was the recipient habitat likely historically occupied by a self-sustaining population of bull trout?
2. Is it unlikely that bull trout are present now in the recipient habitat?
3. Is the recipient habitat currently suitable for supporting spawning and early rearing of at least one or more self-sustaining local populations of bull trout?
4. Have past, present, and potential future threats in the recipient habitat been mitigated sufficiently to justify a reintroduction?
5. Is natural recolonization of the recipient habitat unlikely in the short term?

To address the second major component of the assessment involving potential donor populations of bull trout to be used in a reintroduction, we identified two key questions:

1. Is there at least one available donor population that is a sufficient evolutionary match to the recipient?
2. Within this pool of potential donor populations is there at least one donor that could provide a sufficient number of propagules without damaging the donor population itself?

The overall assessment was structured as a hierarchical series of evaluations (Figure 1). For each question listed above, we identified major types of evidence needed to answer them. Each major type of evidence was evaluated with available information.

Assessment of the recipient habitat for a possible reintroduction

Was the recipient habitat likely historically occupied by a self-sustaining population of bull trout?

To address this question in the Clackamas effort, we considered three types of evidence: 1) historical and current evidence for presence of any life stage, 2) the current presence of specific life stages, and 3) the likelihood of presence inferred from currently suitable habitat. In this study, the presence of any life stage of bull trout was evaluated by considering several sources of information: the presence of an archived specimen in a scientific collection, written documentation by a professional biologist, verbal accounts by a professional biologist, and anecdotal accounts. The number of accounts was also taken into consideration in the case of verbal and anecdotal accounts. Presence of specific life stages was considered in terms of documented spawning by adults or presence of small individual bull trout (<150 mm, FL), providing evidence of local reproduction, or presence of larger fish only (>150 mm) which do not as reliably indicate local reproduction. This is because bull trout can move extensive distances through river networks (>100 km, Swanberg 1997, Baxter 2000) and can be found in a broad diversity of habitats (Muhlfield and Marotz 2005, Monnot *et al.*, in press). To account for cases in which direct historical observations of bull trout are lacking, we also considered indirect evidence for habitats supporting bull trout, such as a habitat model to predict occurrence (Peterson and Dunham 2003) or simple comparisons of habitat conditions in a potential recipient habitat to those already supporting extant bull trout populations.

Is it unlikely that bull trout are present now in the recipient habitat?

A reintroduction effort cannot proceed unless it is reasonably certain that the species in question is not present. We considered several sources of information for evaluating this possibility. The currently available protocol for estimating the probability of presence for small (<150 mm) bull trout (Peterson *et al.* 2002) was considered to provide the best information. The probability (p) of presence determined by using this protocol or a statistical equivalent (Peterson and Dunham 2003, Mackenzie *et al.* 2006) was deemed unlikely if $p \leq 0.10$.

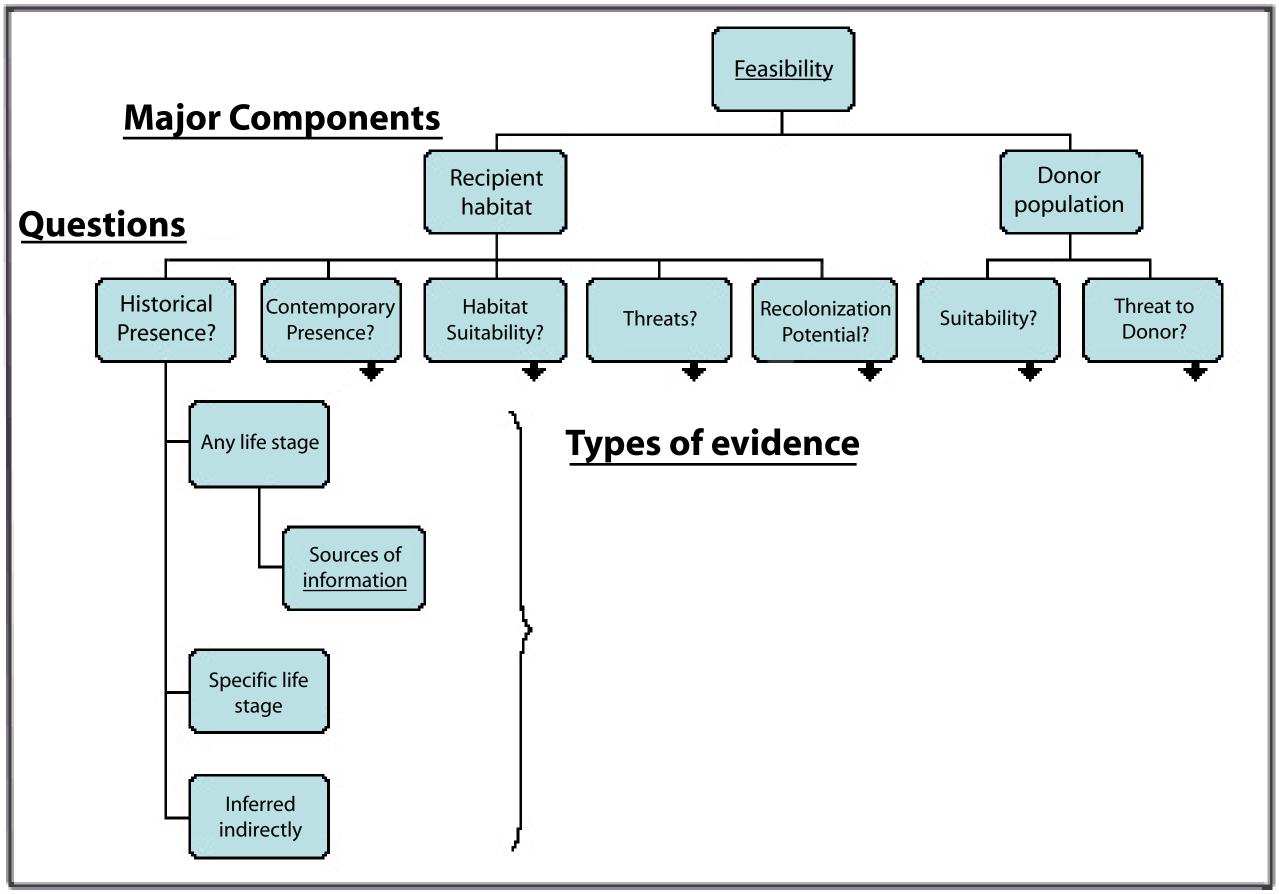

Figure 1. Diagram depicting the hierarchical series of evaluations used to assess the feasibility of a bull trout reintroduction, including the overall assessment of feasibility, its two major components, key questions within each component, types of evidence used to evaluate each question (shown only for "Historical Presence?"), and information used to evaluate each type of evidence (not shown). Downward arrows from other questions point to types of evidence (not shown). Each of these components of the assessment is described completely in the text narrative.

Other sources of information included efforts to detect bull trout in targeted surveys using other protocols, efforts to detect bull trout during sampling or collection efforts targeting other salmonids, and other professional fisheries activities that could document occurrence of bull trout.

Is the recipient habitat currently suitable for supporting spawning and early rearing of at least one or more self-sustaining local populations of bull trout?

In addressing this question we considered criteria indicating both the quality and quantity of potentially suitable habitat. Habitat quality for bull trout, at least in terms of the distribution of habitats used for spawning and early rearing in the field, is primarily a function of water temperature (McPhail and Murray 1979, Dunham *et al.* 2003a). Therefore, we binned habitats into broad categories representing different levels of thermal suitability for spawning and early rearing. Habitats with water temperatures <9 °C during the spawning period and <16 °C summer maximum were classified as highly suitable, whereas those with water temperatures >9 °C during the spawning period and <16 °C summer maximum were deemed moderately suitable, and those where both temperatures were exceeded were considered unsuitable.

The quantity of thermally suitable habitat is also widely recognized as important for persistence of local populations of bull trout (Dunham and Rieman 1999) and other closely related charrs (Morita and Yamamoto 2002, Koizumi and Maekawa 2004). We considered habitat size in terms of the area of watersheds or total length of streams supporting potentially suitable thermal habitat for bull trout. These areas of suitable habitat were designated as "patches" similar to the logic of past work (Dunham *et al.* 2002, Rieman *et al.* 2007), but using measured local water temperatures in place of elevation as a surrogate, since water temperature data were available. If at least one patch supported conditions similar to those sustaining bull trout in nearby watersheds (*i.e.*, similar area or length of suitable streams), habitat quantity was scored as suitable, otherwise it was considered unsuitable.

Have past, present, and potential future threats in the recipient habitat been mitigated sufficiently to justify a reintroduction?

As with any species, assessing threats is an uncertain and difficult task. To consider threats, we adopted an existing protocol (Master *et al.* 2003) that was used by the U.S. Fish and Wildlife Service in a formal review of the status of bull trout (W. Fredenberg and J. Chan, U.S. Fish and Wildlife Service, pers. comm.). For the purposes of evaluating threats over a limited area (*e.g.*, within a single river basin) we limited our assessment to the severity and immediacy of threats and did not consider scope as described by Master *et al.* (2003).

The severity of potential threats was classified into four categories: insignificant, low, moderate, and high. The severity of threats was classified as "insignificant" if the following conditions were satisfied: essentially no reduction of population or degradation of habitat or ecological community due to threats, or populations, habitats, or ecological communities able to recover quickly (within 10 years) from minor temporary loss. The severity of threats was considered to be "low" if the following were deemed likely: reductions of species populations or reversible degradation or reductions of habitat or ecological community in area affected were likely, with habitat or population recovery expected in 10-50 years. The severity of threats was considered "moderate" if the following were deemed likely: a major reduction of species population or long-term degradation or reduction of habitat or ecological community in area affected, requiring 50-100 years for recovery. The severity of threats was considered to be "high" if the following was deemed likely: loss of species population (all individuals) or destruction of species habitat or ecological community in area affected, with effects essentially irreversible or requiring long-term recovery (>100 years).

The immediacy of threats was considered "insignificant" if threats were not likely to be operational within 20 years, "low" if threats were likely to be operational within 5-20 years, "unknown" if little available information exists to evaluate the immediacy of threat effect, "moderate" if threats were likely to be operational within 2-5 years, and "high" if threat effects were operational (happening now) or imminent (within a year). Our characterization of threats was admittedly simple and subjective, but no other method was readily available to meet our needs.

Is natural recolonization of the recipient habitat unlikely in the short term?

The ability of bull trout to move extensively through stream networks raises the possibility of natural recolonization as an important mechanism in maintaining habitat occupancy (Rieman and McIntyre 1993, Dunham and Rieman 1999, Whiteley *et al.* 2007). If natural recolonization is likely within a given habitat, then a reintroduction effort may not be warranted, or may even be detrimental if interbreeding between naturally isolated populations is promoted. To determine whether recolonization was likely in the short term, we addressed four types of evidence: 1) influence of fish movement barriers, 2) distance to habitats currently occupied by bull trout, 3) abundance of bull trout in adjacent habitats, and 4) migratory life history of bull trout in adjacent habitats.

In the first of these, fish movement barriers were classified into four broad categories: 1) complete barriers resulting from blockage of both up- and downstream movement, 2) limited connectivity resulting from up- or downstream restrictions on movement (*e.g.*, limited downstream passage via entrainment through dams) or from severely degraded migratory corridors (*e.g.*, limited flows, degraded water quality), 3) partial connectivity as related to two-way fish passage structures or human-assisted transport of fish over barriers or moderately degraded migratory corridors, and 4) complete up- and downstream connectivity (no substantial barriers present).

Distance is an important and distinct component of connectivity. We considered distance at three arbitrary levels (<20 km, >20-100km, >100 km), based on distances that bull trout are found to move through stream networks (*e.g.*, Swanberg 1997, Baxter 2000). We did not have information to consider how natal homing may condition the influence of distance, nor did we attempt to account for this. The degree of fidelity of bull trout in terms of migrating back to their habitats of natal origin is unknown (Whiteley *et al.* 2007). In addition to distance, the number of individuals should also influence the probability of recolonization. For lack of reliable information, we used three subjectively determined levels of abundance (>500 adults, 100-500 adults, <100 adults) representing the abundance of bull trout in adjacent occupied habitats that could potentially recolonize the recipient habitat. A fourth possible influence is development of migratory life history, with an assumption that adjacent populations having stronger representation of migratory life histories should be more likely to supply individuals that could recolonize a recipient habitat. These were classified into three subjective levels ("strong," "depressed," and "absent," Rieman *et al.* 1997). Overall our consideration of recolonization potential was subjective for lack of quantitative information on local populations of bull trout, but we attempted to consider all of the major factors that could influence the potential for recolonization over relatively short (20 yr) time frames.

Assessment of donor populations to be used for a possible reintroduction

Assessment of donor populations represented a series of considerations separate from assessing the suitability of a receiving habitat for a reintroduction. We focused on two basic questions about donor populations, including: 1) Is there at least one available donor population that is a sufficient evolutionary match to the recipient? and 2) "Within this pool of potential donor populations is there at least one donor that could provide a sufficient number of propagules without damaging the donor population itself?" To address the first question, we considered information on how historical populations of bull trout within the Willamette River basin may have shared a common evolutionary history with other extant populations of bull trout (*e.g.*, Haas and McPhail 1991, Taylor *et al.* 1999, Spruell *et al.* 2003). We assumed that any population within a well-defined lineage could serve as a donor, unless there was compelling evidence to suggest that local environmental conditions may have selected for local population characteristics that were not compatible with the receiving environment. To address the second question, we evaluated information on numbers of spawning adult bull trout in potential donor populations. Our primary concern was to avoid adverse impacts to the viability of donor populations from removals of individuals for a potential reintroduction. To maintain sufficiently large effective sizes of donor populations, we considered only donors supporting greater than 1000 spawning adults per year (Rieman and Allendorf 2001). Potential donors with fewer than 1000 spawning adults per year were considered too small for removal of adults or the demographic equivalent of adults (*e.g.*, eggs, juveniles) without risking adverse genetic or demographic influences.

System for evaluating the evidence

Questions within each component of the assessment (recipient habitat and donor populations) were evaluated based on the types of evidence specified above. Scores ranged between -1 and 1 to represent our degree of belief in the affirmative (maximum score =1 or "yes") or negative (minimum score = -1 or "no"). A score of zero was used when available information provided no basis for an evaluation. In most cases, a score of zero should be interpreted as a sign that more information is needed before proceeding further with a feasibility assessment.

Scores for each type of evidence were summed across all types (if there was more than one type considered) to produce an overall value for each question ranging between -1 (= "no") and 1 (= "yes") to allow an evaluation of each question. In some cases particular scores served as a "trump" value (see below). A score equal or close to zero represented cases where uncertainty is high, and in some cases, where additional information may be needed for an assessment to proceed (Appendix). The system of scoring provided a simple and transparent summary of the logic for addressing each question about the feasibility of a reintroduction. To illustrate, consider the question about suitability of the recipient habitat (Table 1). For this question we considered two types of evidence (quality and quantity of habitat), each with different information indicating different aspects of suitability. A simple average was used to combine scores for each question, except in cases where quantity of habitat was not sufficient or habitat quality was unsuitable. In these cases, a trump score of -1 was assigned overall, rather than an average. Similar scoring was used for each question within each of the two components of the assessment (Appendix).

Scores for each question were combined to yield an overall combined score for each component that ranged between 1

Table 1. An example of scoring for a particular question within a component of the reintroduction feasibility assessment (Figure 1). For each of the two types of evidence there are several sources of information to be evaluated. The score for each type of evidence is summed across all types of evidence to produce an overall score for the question resulting in a value ranging from 1 (answer = "yes") to -1 (answer = "no"). In this case a score of zero should indicate the need to suspend a feasibility assessment and to gather the necessary information. Specific descriptions of sources of information indicated here are given in the text.

Question	Type of evidence	Sources of information	Score
Is the recipient habitat potentially suitable?	Sufficient quality of habitat?	Highly suitable for both incubation and early rearing	1
		Moderately suitable for egg incubation, suitable for rearing	0.75
		No information	0
		Not suitable for egg incubation or rearing	-1
	Sufficient quantity of habitat?	Yes	1
		No information	0
		Not enough habitat	-1

and -1. To develop a final overall score for assessing the feasibility of reintroduction, scores for each component were combined in a similar fashion. Thus, a score near 1 would indicate a strong belief in the feasibility of a potential reintroduction, and scores near -1 would indicate that such an effort is not considered feasible (Table 2). A spreadsheet that combines the scores for all components of the feasibility assessment is available from the authors.

It is important to recognize that this system was not created to justify our interpretation of the evidence. Rather, we adopted it as a formal and transparent approach for articulating our logic in arriving at an overall assessment. In the case of the Clackamas River basin, the technical team chose to adopt a consensus approach in terms of arriving at an overall score for the feasibility assessment. The system is very flexible, however, and could be adapted to incorporate uncertainty in the form of differences in the interpretation of individuals or degrees of belief in the evidence supporting the assessment, rather than using discrete scores as applied here.

Applying the Framework to the Clackamas River Basin

Study system

The Clackamas River is a major tributary of the lower Willamette River in western Oregon (Figure 2). Bull trout are extirpated from most formerly occupied habitat in Willamette River basin. Extant populations are confined to several isolated enclaves persisting in the McKenzie River (Buchanan *et al.* 1997). Up until the 1990s, bull trout were also present in the upper Middle Fork of the Willamette River (Buchanan *et al.* 1997), which is currently the focus of reintroduction efforts involving donor populations from the adjacent McKenzie River (M. Wade, Oregon Department of Fish and Wildlife, pers. comm.).

The draft recovery plan for bull trout (USFWS 2002) identified the Willamette River basin as one of 27 "recovery" or "management" units for the species within the conterminous United States. Draft recovery criteria for this unit address goals for population distribution, population abundance, population trends, and habitat connectivity (USFWS 2002). In this draft, reintroduction of bull trout in the Clackamas River was stated specifically as an action that could meet the draft recovery goal of establishing bull trout in a third local population in the Willamette River basin. It is important to note here that we do not consider how to prioritize among potential recipient habitats for a reintroduction. Some potential guidelines for classifying bull trout habitat suitability, which may apply to reintroduction efforts, are provided elsewhere (Peterson and Dunham 2003)

We considered the feasibility of reintroducing bull trout into the headwaters of the Clackamas River and its tributaries upstream of North Fork Dam (Shively *et al.* 2007). Historical observations of bull trout in the Clackamas River include this portion of the basin, as well as the Oak Grove Fork and Collawash Rivers (Buchanan *et al.* 1997). At present, habitats in the Oak Grove Fork are extensively altered for hydropower generation, and restoration of habitat conditions that may be suitable for bull trout is unlikely within a short (20 year) time frame. Within the Collawash River, summer maximum temperatures are generally too warm to support spawning and early rearing of bull trout (Shively *et al.* 2007). For these

Table 2. Overview of the system of scores used to assess the feasibility of a bull trout reintroduction. Shown are levels of the assessment (*e.g.*, Figure 1) and specific actions taken at each to ultimately produce a score corresponding to the feasibility of a reintroduction.

Level	Action	Example
Type of evidence	Determine score based on available information. Consider terminating assessment when key information is lacking (score = 0).	Evidence for historical presence of any life stage
Key questions	Combine scores for each type of evidence. Includes "trump" values (occurs when a score for a given type of evidence is allowed to "trump" other scores).	Historical presence of bull trout?
Components	Use average of scores for each question to produce an overall score for each component.	Recipient habitat
Feasibility	Use average between components to produce an overall assessment of feasibility.	

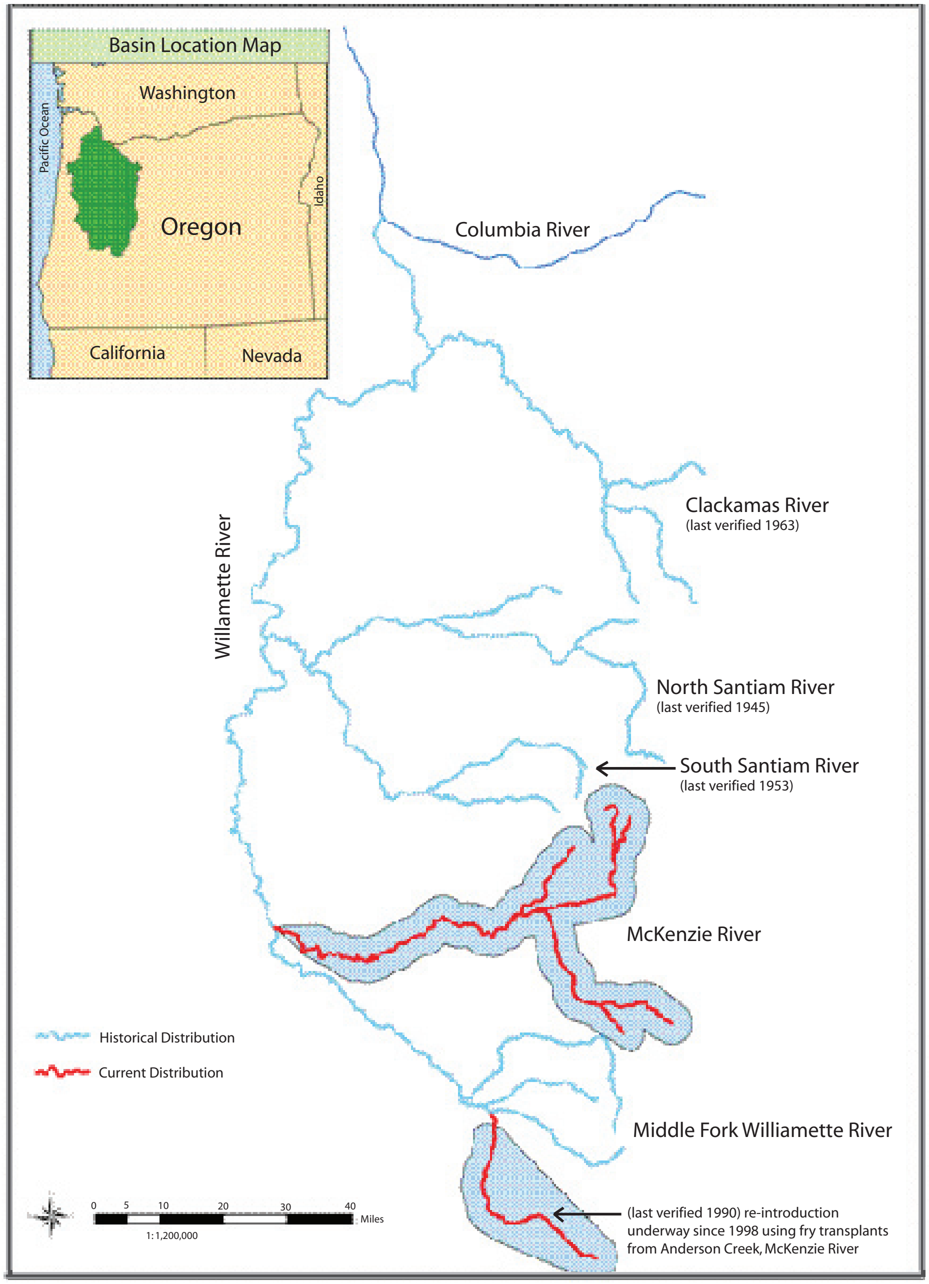

Figure 2. Current distribution of bull trout within the Willamette River recovery unit (inset, USFWS 2002) showing historical distribution of all life stages of bull trout (spawning, rearing, migration) and last dates that bull trout was verified in major river basins (from Shively *et al.* 2007)

reasons, we excluded these major tributary basins from our feasibility assessment.

The upper Clackamas River is characterized by a mixed flow regime that is strongly influenced by discontinuities in geology, landform, and climate in the western Oregon Cascade Mountains (O'Connor and Grant 2003, Tague and Grant 2004). In higher elevations the combination of snow-dominated precipitation, lower elevation relief, and catchment geology that is dominated by volcanic bedrock leads to a flow regime that is characterized by strong influences from subsurface flow. In lower elevations, rain-dominated precipitation, steeper topography, and relatively impermeable substrates lead to flow regimes that are more strongly responsive to seasonal patterns of precipitation (*e.g.*, "flashy perennial" flow regimes, Poff 1996). In general, streams dominated by volcanic bedrock geology yield discharges that are more constant or moderated through time, with less flooding in winter and greater stream flow during seasonal droughts that typically occur in summer and autumn (*e.g.*, "stable and superstable groundwater" flow regime, Poff 1996). Stream temperatures also follow this discharge regime, with the influence of groundwater in volcanic geologies leading to relatively cool (<10 °C) summer water temperatures and moderate winter temperatures (O'Connor and Grant 2003, Jefferson 2006). Although bull trout occupy habitats with a wide range of geologies and flow regimes throughout its broad geographic range, the contemporary distribution of the species within southern Cascade Mountains is tied strongly to the influence of volcanic geology (Goetz 1989).

Assessment of the recipient habitat

Evidence supporting the potential feasibility of the Clackamas River for a bull trout reintroduction

A technical team was assembled in 2003 to address the feasibility of reintroducing bull trout into the Clackamas River. This team represented major regulatory agencies and private stakeholders charged with fisheries, water, and land management responsibilities and interests within the Clackamas River (Shively *et al.* 2007). To illustrate an application of the above framework for assessing the feasibility of a bull trout reintroduction, we draw upon the most relevant findings in this assessment, which should be consulted for additional supporting details beyond the scope of this paper. We begin by summarizing evidence relevant to addressing each major question concerning suitability of the receiving habitat and donor populations of bull trout and then provide a brief overview of results from applying the framework (see Appendix for complete results).

Was the recipient habitat likely historically occupied by a self-sustaining population of bull trout?

Bull trout were first collected from the Clackamas River by Livingston Stone in 1878, and a specimen is archived in the Smithsonian Institution (museum catalog number 22355, www.mnh.si.edu/). It was 100 years later that the bull trout was described as a unique species separate from Dolly Varden (Cavendar 1978), so records of bull trout before this time were referred to as Dolly Varden or a related synonym. During the early 20th century, bull trout were commonly reported in creel surveys in the upper Clackamas River conducted by the Oregon Department of Fisheries and Wildlife and in accounts by local fisherman (Shively *et al.* 2007). After the early 1960s, bull trout were no longer regularly observed, and there are no reports of any kind after the early 1970s in spite of numerous surveys for other salmon and trout, continued angler surveys, and informal targeted surveys for bull trout (Buchanan *et al.* 1997, Zimmerman 1999). In reference to the levels of evidence needed to address this question (Appendix), we can confidently say that bull trout were present in the Clackamas River, but from direct observations alone, we cannot determine if there were smaller (<150 mm) bull trout present historically. From an assessment of the suitability of habitat (see below), however, we determined it was very possible that the Clackamas River could have supported all life stages of bull trout.

Is it unlikely that bull trout are present now in the recipient habitat?

Whereas historical surveys of many types failed to detect bull trout in the Clackamas River, we were concerned that sampling designs and low sampling efficiencies of many methods may have been biased against detection of small (<150 mm) bull trout. To provide a final confirmation of the low probability of occurrence of bull trout in the upper Clackamas River, we employed formal surveys in 2004 (Shively *et al.* 2007). These surveys followed guidelines in Peterson *et al.* (2002) with the following specifications:

- The sampling frame was restricted to habitats with access to other migratory salmonids (salmon and steelhead trout and presumably bull trout) and with measured summer maximum temperatures < 16 °C, which are more likely to support spawning and early rearing of bull trout (Dunham *et al.* 2003a).

- Streams less than 2 m in base flow (summer) wetted width were considered unlikely to support bull trout relative to larger streams (Dunham and Rieman 1999) and were excluded from the sampling frame. Although bull trout can occur in streams smaller than 2 m in width, we assumed our likelihood of actually encountering bull trout was greater in streams with larger widths.

- Some sites that were unsafe to sample were excluded from consideration. We assumed this did not bias our detection probability.

- In place of block nets recommended by the protocol (Peterson *et al.* 2002), sampling units were enlarged to 200 m in length to compensate for the effects of fish disturbed from snorkeling and potentially leaving the sample site (Peterson *et al.* 2005). It was assumed that detection probabilities were at least as high as those with 100 m sites with block nets in place to prevent fish escape during sampling.

Surveys in 2004 to detect bull trout were conducted by snorkeling at night with a single pass in an upstream direction, and completed for 21 sampling units equaling 4.2 km of stream or 9.3 percent of the sampling frame in the upper Clackamas River. In addition to sampling to detect bull trout in the field, we also used a Bayesian method proposed by Peterson and Dunham (2003) that allows combined information from sampling effort and prior information (*e.g.*, habitat model predictions, professional opinion, or other forms of prior knowledge) to estimate the probability of presence for bull trout. From the 2004 sampling effort, a probability of presence of 0.12 was estimated based on Peterson *et al.* (2002). Using a prior probability of presence based on expert opinion of 0.10 and the method of Peterson and Dunham (2003) yielded a combined posterior probability of 0.01 for presence of bull trout in the upper Clackamas River. Prior probabilities estimated from local experts ranged from 0.01 to 0.05, but we used a higher prior (0.10) in our application as a precautionary measure to account for potential biases in underestimating the prior probability. From these results, we determined that it was very unlikely that bull trout were still present in the upper Clackamas River (Appendix).

Is the recipient habitat currently suitable for supporting spawning and early rearing of at least one or more self-sustaining local populations of bull trout?

To measure the quality of habitats in the upper Clackamas River, we focused on water temperature, which is a major factor influencing spawning and early rearing by bull trout within river networks (McPhail and Murray 1979, Dunham *et al.* 2003a). A combination of existing data from past monitoring efforts (1996-2003; n=12) and deployments of water temperature data loggers in 2004 (n=14) was used to identify coldwater habitats during summer (July through September) throughout the upper Clackamas River. Sampling was focused near the mouths of major tributaries and at several points along the main upper Clackamas River. Overall a total of 139.5 km of habitat was identified with suitably cold (< 16 °C) water for occurrence, and temperatures exceeded a summer maximum of 16 °C in only one location on the main Clackamas River at river kilometer 92 (16.6 °C). Sampled stream reaches to exceed a mean of 9 °C in September (the expected time of spawning) included two reaches of the main Clackamas River (9.1-9.4 °C), Lowe Creek (9.8 °C), Hunter Creek (9.3 °C), and the lower portion of Cub Creek (9.2 °C). The degrees to which temperatures exceeding a summer maximum of 16 °C or a mean September temperature of 9 °C were within the range of measurement error for temperature data loggers (Dunham *et al.* 2005).

In terms of hydrological processes (Tague and Grant 2004, Tague *et al.* 2007) and species composition in the Willamette River basin, the most comparable system to the Clackamas River is the McKenzie River. The McKenzie River supports the only known self-sustaining populations of bull trout left in the Willamette River basin. The total amount of habitat that is potentially suitable for spawning and early rearing of bull trout in the upper Clackamas River compares favorably to the McKenzie River, where an estimated 170 km of habitat is used by all life stages of bull trout, including habitats used only for migration (USFWS 2002). Furthermore, the McKenzie River bull trout population is fragmented into three isolated enclaves, with two of them occupying only a small fraction of this total habitat. Within the largest enclave in the McKenzie River, spawning occurs over about 4 km of the tributary stream supporting the greatest numbers of spawning bull trout, and juveniles have been found to occur within the tributary and extending to about 13 km downstream within the main stem McKenzie River (USFWS 2002). If the McKenzie River is accepted as a valid baseline in terms of a minimal amount of habitat required to support a self-sustaining population of bull trout, it compares very well to the Clackamas River in terms of the amount of habitat available for spawning and early rearing. We did not consider habitat availability for migratory bull trout in the Clackamas River, but the river network is presently accessible and used by other migratory salmon and trout, and we assume the same would be true of bull trout, as is the case in other systems where they coexist with other salmonids.

Have past, present, and potential future threats in the recipient habitat been mitigated sufficiently to justify a reintroduction?

A detailed review of the history of fishery, river, and land management in the Clackamas River (Shively *et al.* 2007) provided ample evidence to demonstrate that many significant threats to bull trout from past human influences have been mitigated. A full review of this history is beyond the scope of this paper (Shively *et al.* 2007), but the following major changes have been implemented to mitigate threats:

- Stocking of nonnative trout (*e.g.*, brook trout and hatchery origin rainbow trout) and angling regulations have been modified to benefit native fishes.
- Historical barriers to fish movement have been removed or modified to permit fish passage.
- Land management has been modified to minimize adverse impacts to native salmon and trout, including other federally listed salmonid species in the upper Clackamas River. Lands within the assessment area are primarily under federal ownership and management (U.S. Forest Service and Bureau of Land Management), with regulatory oversight by National Marine Fisheries Service.

All of these factors were likely contributors to the historical extirpation of bull trout from the Clackamas River. With such limited information it is difficult to construct a likely scenario for exactly why the bull trout was extirpated. Here we offer a tentative hypothesis.

Due to strong geological influences on the hydrology of the upper Clackamas River (Tague and Grant 2004), many streams have likely remained consistently suitable for spawning and early rearing of bull trout. If bull trout used these habitats, which seems likely (Goetz 1989), then loss and degradation of habitats in downstream areas may have been more important. Historically, downstream portions of the Clackamas River were strongly impacted by barriers to fish movement. Given that bull trout in similar habitats are strongly migratory (*e.g.*, the McKenzie River), it follows that bull trout in the Clackamas River should have exhibited similar behaviors. Therefore, downstream movement barriers could have substantially impacted populations in the Clackamas River. This loss of migratory connectivity may have been compounded by impacts of intense recreational angling (Post *et al.* 2003) from the nearby Portland metropolitan area, including active efforts to remove bull trout, which were historically reviled by many anglers and fishery managers. Historical introductions of nonnative brook trout are another potential threat (USFWS 2002) that is difficult to quantify. Documented impacts of this species on bull trout vary widely from strong to non-detectable (*e.g.*, Rieman *et al.* 2006). Nonnative brook trout are present in comparable habitats with extant populations of bull trout in the Willamette River basin (*e.g.*, the McKenzie River) and is not widespread within the Clackamas River. This could be due to the fact that many habitats within the Clackamas River support water temperatures that may be too cold to sustain brook trout (Adams 2000, Rieman *et al.* 2006, Benjamin *et al.* 2007), thus permitting coexistence with bull trout, which can use much colder water temperatures (Dunham *et al.* 2003a).

Loss of cold water and changes to flow regimes in the future could substantially impact many fishes in rivers of the Pacific Northwest if anticipated climate change scenarios are realized over longer (>20 yr) time frames (Battin *et al.* 2007). Assessments of changes in the distribution of bull trout under climate change scenarios are suggestive of major losses of habitat across the species' range (Rieman *et al.* 2007), but these models are based on generalized assumptions about relationships between water temperatures and elevation gradients. At a local scale it is known that these generalized relationships do not apply (Dunham and Chandler 2001). This is due to the fact that elevation is not a process directly influencing heat budgets and resulting water temperatures of streams (Johnson 2003, Moore *et al.* 2005). Thus, the likely impacts of climate change on local water temperatures and flow regimes in the upper Clackamas River are highly uncertain. What is known is that many habitats in the upper Clackamas River support water temperatures that would have to increase by several degrees to become unsuitable for bull trout, at least according to our current understanding of thermal habitat requirements for this species (Dunham *et al.* 2003a). Further work is clearly needed to better understand local hydrological processes and how these may influence water temperatures in the future (Jefferson 2006).

Is natural recolonization of the recipient habitat unlikely in the short term?

Perhaps the strongest evidence to address this question is lack of recolonization of the Clackamas River by bull trout in nearby populations in the >40 yr since bull trout were last known to occur. Fish movement barriers between the Clackamas River and other localities supporting extant bull trout do not prevent the possibility of recolonization, but seasonal conditions in movement corridors (*e.g.*, the lower mainstem Willamette and Columbia Rivers) can become very unsuitable for bull trout (*e.g.*, water temperatures >20 ^{o}C), which may limit potential movement. The nearest population of bull trout that could serve as a possible source of immigrants (North Fork of the Lewis River, Washington) is over 100 km distant. Nearby populations are dominated by individuals with migratory life histories and have relatively large numbers of individuals (>500 adults), which may increase the probability of recolonization. However, we viewed the large distance from the nearest potential source of immigrants as an overriding factor in the present isolation of the Clackamas River.

Assessment of donor populations

Is there at least one available donor population that is a sufficient evolutionary match to the recipient?

The Clackamas River falls within the bounds of a distinct lineage of bull trout (Spruell *et al.* 2003) that was proposed by the U.S. Fish and Wildlife Service to serve as a distinct population segment for recovery planning (Whitesel *et al.* 2004). Within this lineage, we considered donor populations with a direct hydrographic connection to the Clackamas River, including tributaries of the Columbia River and within the Willamette River basin. Within a distinct population segment, the draft bull trout recovery plan (USFWS 2002) recognizes core areas, which consist of one or more interacting local populations. We identified six core areas with extant local populations that could potentially provide donors for a reintroduction, including the upper Willamette River, Lewis River, Klickitat River, lower Deschutes River, Odell Lake, and Hood River.

Within this pool of potential donor populations is there at least one donor that could provide a sufficient number of propagules?

Numbers of adults in core areas and local populations have been determined by survey designs and sampling methods with variable degrees of accuracy or precision (*e.g.*, Dunham *et al.* 2001, Peterson *et al.* 2004, Muhlfeld *et al.* 2006, Thurow *et al.* 2006). Accordingly, as a precautionary measure, we wished to identify potential donor populations with abundances well above a minimum of 1000 spawning adults per year (Rieman and Allendorf 2001). Within the six core areas considered as potential donors, only one (lower Deschutes River) exceeded an abundance of 1000 spawning adults per year from 2001-2005, and abundance for a single local population within the core area, the Metolius River, is estimated at nearly double this minimum level within this time frame (Shively *et al.* 2007). Bull trout within the Metolius River are distributed across several tributaries used for spawning, but recent data from DNA microsatellites indicate there is considerable gene flow among them (W. Ardren and Patrick DeHaan, U.S. Fish and Wildlife Service, pers. comm.). Thus, following our conservative interpretation of minimum numbers of spawning adults per year, we find good evidence for the existence of at least one potential donor population with abundance levels that could support removal of a relatively large number of adults (*e.g.*, >200 individuals) or other life stages (*e.g.*, juveniles) to support a reintroduction effort.

Results of the Clackamas River application

With the evidence summarized above, we applied our framework for a feasibility assessment of a bull trout reintroduction to the Clackamas River (Appendix). An overall score of 0.95 was given to the Clackamas River, indicating a strong belief in the potential of this recipient habitat to support a reintroduction effort. Other biological factors that could influence a final decision on whether to continue with a reintroduction include a risk assessment of the potential for disease transmission by the most likely donor population (Metolius River, S. Gutenberger, U.S. Geological Survey, pers. comm.) and a regulatory consultation to be conducted by the National Marine Fisheries Service on the effects of reintroduction of bull trout on other listed salmon and steelhead in the Clackamas River.

Conclusions

Reintroductions are a potentially powerful tool in recovery of imperiled native fishes, but experience has shown they often fail. Whereas the reasons for failure are not always clear, it is obvious that conducting a feasibility assessment before implementing a reintroduction will increase the chances of success. Ironically, translocations of trout and salmon outside of their native range ranges have been successful in freshwaters worldwide, mostly without the benefit of detailed feasibility assessments (Welcomme 1988). In the case of bull trout, targeted reintroduction attempts have either failed (*e.g.*, McCloud River, CA) or shown evidence of limited local reproduction (Middle Fork Willamette River, OR). Translocations have established locally reproducing populations in several cases, however. In at least one example, human-assisted transfer of adults over an impassible waterfall (Sunset Falls, South Fork Skykomish River, WA) has led to establishment of upstream populations, and migratory adults entrained below dams without upstream passage have established local populations in downstream tributaries (*e.g.*, Cougar Creek, North Fork Lewis River, WA, Moore Creek, Boise River, ID, Twin Creek, Clark Fork River, MT, USFWS 2002). These case histories and our assessment of the Clackamas River suggest that an attempt to reintroduce bull trout could be successful, assuming adequate resources are committed to the subsequent stages of implementation, monitoring, and evaluation.

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Appendix – Application of assessment process to the Clackamas River. Shown are the scores assigned to different kinds of information used in the assessment. Equal weights were assigned to each type of evidence. Information representing the Clackamas River is shown in **bold**.

Question	Type of evidence	Information	Score
Was the recipient habitat historically occupied?	a. Presence of any life stage	**Confirmed record** • Archived specimen • Professional biologist documented	1
		Biologist verbal accounts	
		• >10 Accounts	1
		• 5-10 Accounts	0.75
		• < 5 Accounts	0.5
		Anecdotal record; verbal accounts by public	
		• >10 Accounts	0.5
		• 5-10 Accounts	0.25
		• < 5 Accounts	0
		No evidence	0
	b. Presence of different life stages	Presence of confirmed spawning or bull trout fry	1
		Presence of juvenile (<150 mm) fish	1
		Presence of larger (>150 mm) fish only	0.5
	c. Presence inferred from suitable habitat	**Historical habitat believed to support bull trout**	0.75
		Limited connectivity OR no information[1]	0

[1] If information documenting species presence or that infers presence from habitat is not available, we recommend holding off on the reintroduction until information is available to determine whether the habitat was historically occupied.

Question	Type of evidence	Information	Score
Is bull trout un*likely* present now?	Probability of presence	**Low probability of presence estimated by a formal protocol**	1
		Failure to detect during recent (last 10 yr) using other protocols	0.5
		Failure to detect during recent (last 10 yr) sampling for other salmonids	0.25
		No accounts of bull trout from any source within the last 10 yr	0.1
		No information or effort in the last 10 yr[2]	0
		Documented presence (any life stage) within the last 10 yr.	-1
Is the recipient habitat potentially suitable?	a. Sufficient quality of habitat?	**Highly suitable for both incubation and early rearing**	1
		Moderately suitable for egg incubation, suitable for rearing	0.75
		No information[3]	0
		Not suitable for egg incubation or rearing	-1
	b. Sufficient quantity of habitat?	**Yes**	1
		No information	0
		Not enough habitat	-1
Threats	a. Severity	**Insignificant**	1
		Low	0.5
		Unknown	0
		Moderate	-0.5
		High	-1
	b. Immediacy	Insignificant	1

[2] If species presence surveys have not been conducted, we suggest conducting surveys using a statistically valid sampling protocol before proceeding with the reintroduction.
[3] If habitat surveys have not been conducted, we suggest conducting surveys before proceeding with the reintroduction.

Question	Type of evidence	Information	Score
		Low	0.5
		Unknown	0
		Moderate	-0.5
		High	-1
Short-term recolonization potential	a. Intervening passage barriers?	Complete up- and downstream connectivity	-1
		Partial connectivity	-0.5
		Limited connectivity	0
		Complete two-way movement barrier	1
	b. Distance to nearest occupied habitat	< 20 km	-1
		>20-100km	0
		>100km[4]	1
	c. Abundance in adjacent occupied habitat	**>500 adults**	-1
		100-500 adults	0
		<100 adults	1
	d. Migratory life history in adjacent core area	**Strong**	-1
		Depressed	0
		Absent	1

[4] Distance to nearest occupied habitat >100km is an overriding value, meaning it “trumps” other information given for this particular type of evidence. If the distance to nearest occupied habitat >100km, then score short-term recolonization potential as a 1 regardless of other types of evidence.

Question	Type of evidence	Information	Score
Is there at least one available donor stock?		**Yes**	1
		Unknown	0
		No	-1
Is there at least one donor that could provide propagules without damaging the donor stock?		**Donor population > 1,000 spawning adults per year**	1
		Donor population <1000 spawning adults per year	-1

Clackamas River assessment. Clackamas River information are presented in bold font. All questions and types of evidence are equally weighted. All question scores and the feasibility score are calculated using simple average, unless otherwise specified.

Question	Type of evidence	Information	Score	Type of evidence score	Question Score[5]	Component Score[6]	Feasibility Score[7]
Was the recipient habitat historically occupied?	a. Presence of any life stage	**Confirmed record** • Archived specimen • Professional biologist documented	1	0.75	0.75[8]	0.9	0.95
		Biologist verbal accounts					
		• >10 Accounts	1				
		• 5-10 Accounts	0.75				
		• < 5 Accounts	0.5				
		Anecdotal record; verbal accounts by public					
		• >10 Accounts	0.5				
		• 5-10 Accounts	0.25				
		• < 5 Accounts	0				
		No evidence	0				
	b. Presence of different life stages	Presence of confirmed spawning or bull trout fry	1				
		Presence of juvenile (<150 mm) fish	1				

[5] Average of type of evidence scores for the question
[6] Average of question scores for the component
[7] Average of the two component scores
[8] Average scores from types of evidence a and b, then take the maximum of the a-b average or c.

Question	Type of evidence	Information	Score	Type of evidence score	Question Score[5]	Component Score[6]	Feasibility Score[7]
		Presence of larger (>150 mm) fish only	0.5				
	c. Presence inferred from suitable habitat	**Historical habitat believed to support bull trout**	0.75				
		Limited connectivity OR no information	0				
Is bull trout un*likely* present now?	Probability of presence	**Low probability of presence estimated by a formal protocol**	1	1	1		
		Failure to detect during recent (last 10 yr) using other protocols	0.5				
		Failure to detect during recent (last 10 yr) sampling for other salmonids	0.25				
		No accounts of bull trout from any source within the last 10 yr	0.1				
		No information or effort in the last 10 yr	0				
		Documented presence (any life stage) within the last 10 yr.	-1				
Is the recipient habitat potentially suitable?	a. Sufficient quality of habitat?	**Highly suitable for both incubation and early rearing**	1	1	1		
		Moderately suitable for egg incubation, suitable for rearing	0.75				
		No information	0				

Question	Type of evidence	Information	Score	Type of evidence score	Question Score[5]	Component Score[6]	Feasibility Score[7]
		Not suitable for egg incubation or rearing	-1				
	b. Sufficient quantity of habitat?	**Yes**	1	1			
		No information	0				
		Not enough habitat	-1				
Threats	a. Severity	**Insignificant**	1	1	0.75		
		Low	0.5				
		Unknown	0				
		Moderate	-0.5				
		High	-1				
	b. Immediacy	Insignificant	1	0.5			
		Low	0.5				
		Unknown	0				
		Moderate	-0.5				
		High	-1				
Short-term recolonization potential is unlikely	a. Intervening passage barriers?	Complete up- and downstream connectivity	-1	0.5	1[9]		
		Partial connectivity	-0.5				
		Limited connectivity	0				
		Complete two-way movement barrier	1				

[9] Distance to nearest occupied habitat is an overriding or "trump" value, meaning that it can override the other types of evidence in the question. If distance to nearest occupied habitat is >100km, score short-term recolonization potential as a 1 regardless of other types of evidence.

Question	Type of evidence	Information	Score	Type of evidence score	Question Score[5]	Component Score[6]	Feasibility Score[7]
	b. Distance to nearest occupied habitat	< 20 km	-1	0			
		>20-100km	0				
		>100km	1				
	c. Abundance in adjacent occupied habitat	**>500 adults**	-1	-1			
		100-500 adults	0				
		<100 adults	1				
	d. Migratory life history in adjacent core area	**Strong**	-1	-1			
		Depressed	0				
		Absent	1				
Is there at least one available donor stock?		**Yes**	1		1	1	
		Unknown	0				
		No	-1				
Is there at least one donor that could provide propagules without damaging the donor stock?		**Donor population > 1,000 spawning adults per year**	1		1		

Question	Type of evidence	Information	Score	Type of evidence score	Question Score[5]	Component Score[6]	Feasibility Score[7]
		Donor population <1000 spawning adults per year	-1				