Large Scale Assessments: Lessons learned for Native Trout Management

Mark Hudy
U.S. Forest Service, Fish and Aquatic Ecology Unit, James Madison University, MSC 7801
Harrisonburg, Virginia 22807

Brett Roper
U.S. Forest Service, Fish and Aquatic Ecology Unit, Forestry Sciences Lab, Logan, Utah 84321

Nathaniel Gillespie
Trout Unlimited, Arlington, Virginia 22209-3801

Abstract.-- Large-scale assessments are useful tools for identifying population status of trout and other species throughout their ranges. We reviewed published and unpublished assessments for 15 native inland trout species in the United States to (1) evaluate common elements; (2) estimate lost habitat for native trout and (3) identify effective approaches or actions taken after completion of assessments to sustain native trout. Land use changes, loss of riparian vegetation, fragmentation of landscapes, poor land management practices, and presence of non-native fishes were the most common perturbations associated with the loss of native trout. We conservatively estimate that over half of the streams in the United States that historically supported native trout no longer do so. Many extirpated habitats may be hard to restore because of the difficulty of reversing land use changes or removing non-native fishes. Many extirpations occurred in the first 150 years after pioneer settlement but additional losses continue today. While many assessments have been effective at educating environmental professionals, most have had little influence in changing land use or realigning budgets for preservation or restoration. As human population growth and demands for natural resources increase, threats to native trout will likely increase resulting in further declines and extirpations.

Introduction

Large-scale assessments have become useful tools for identifying spatial configurations and population status of North American trout species throughout their ranges (Nature Serve Explorer 2007). These assessments often are used to compare the current distribution with historic distribution so that changes through time can be assessed. Because assessments are conducted at large scales, they often have sufficient analysis for making determinations whether or not a species should be listed under the Endangered Species Act (ESA) (Nelson et al. 1991). Additionally, decision makers, managers and the public use large scale assessments as common starting points for setting priorities for watershed-level conservation, restoration, and monitoring programs as well as a justification for funding to protect or expand the range of important species (Williams et al. 1993; Davis and Simon 1995; Frissell and Bayles 1996; Warren et al. 1997; Master et al. 1998).

The economic, social and ecological importance of native trout in North America has provided the impetus for nearly 50 assessments over the last century (Table 1). These assessments have concluded that the physical, chemical and biological characteristics of habitats for native trout have been dramatically altered over the last 250 years with the result that many native trout populations have been locally or regionally extirpated (MacCrimmon and Campbell 1969; Gresswell 1988; Meehan 1991; Marschall and Crowder 1996; Hall et al. 1997; Yarnell 1998; Hudy et al. 2005). Specific reasons for these habitat alterations include; historic and current land use practices (King 1937; King 1939; Lennon 1967; Kelly et al. 1980; Nislow and Lowe 2003), declining water quality and quantity (Meisner 1990; Fiss and Carline 1993; Gagen et al. 1993; Keleher and Rahel 1996; Clayton et al. 1998; Hudy et al. 2000; Driscoll et al. 2001), competition and hybridization with non-native fishes (Li and Moyle 1981; Moore et al. 1983; Larson and Moore 1985; Moore and Ridley 1986; Krueger and May 1991; Dowling and Childs 1992; Hayes et al. 1996; Strange and Habera 1998; Galbreath et al. 2001, Allendorf et al. 2001); catastrophic fire (Brown et al. 2001); fragmentation/connectivity of habitats by dams and roads (Belford and Gould

1989; U. S. Army Corps of Engineers 1998; Gibson et al. 2005), grazing (Belsky et al. 1999), stream channelization, sediment (Curry and MacNeil 2004) and natural stochastic events (Roghair et al. 2002).

More recent assessments have collected data, which allow estimation of current and historically occupied habitat at the stream reach, lake or watershed scale (Rieman et al. 1997; Thurow et al. 1997; May et al. 2003; Shepard et al. 2003; Hudy et al. 2005). Use of these newer assessments has allowed decision makers to establish priorities for conservation (Williams et al. 1993; Warren et al. 1997) as well as to better understand the likelihood of long-term species persistence. The objective of this paper is to: (1) evaluate elements common to most assessments; (2) estimate the number of stream miles of habitat lost for trout native to the United States and (3) identify effective approaches/actions taken post assessment to sustain native trout.

Methods

Assessments reviewed

We reviewed published and unpublished assessments, conservation strategies, recovery plans, status reports, petitions for listing and other documents for the following 15 native inland (and primarily non-anadromous) trout and char species in the United States: Apache trout *Oncorhynchus gilae apache* (USFWS 1983; Behnke 1992; Behnke 2002); Brook Trout *Salvelinus fontinalis* (King 1937; MacCrimmon and Campbell 1969; Kelly et al. 1980; Hudy et al. 2005; EBTJV 2006)*;* Bonneville cutthroat trout *Oncorhynchus clarki utah* (Behnke 1992; Kershner 1995; Hepworth et al. 1997; USFWS 2001); Bull trout *Salvelinus confluentus* (Behnke 1992;Thurow et al. 1997; Rieman et al. 1997; USFWS 1999a; USFWS 2005; Budy et al. 2007); California Golden trout *Oncorhynchus mykiss aguabonita* (Behnke 1992; Behnke 2002; Stephens et al. 2004); Colorado cutthroat trout *Oncorhynchus clarki pleuriticus* (Behnke 1992; Young et al. 1996; Kershner et al. 1997; Behnke 2002; Hirsch et al. 2006). Coastal cutthroat trout *Oncorhynchus clarki clarki* (Nehlsen et al. 1991; Behnke 1992; Hall et al. 1997; Johnson et al. 1999; Behnke 2002; Johnson et al. (in press); Gila trout *Oncorhynchus gilae gilae* (Behnke 1992; Behnke 2002; USFWS 2003); Greenback cutthroat trout *Oncorhynchus clarki stomias* (Behnke 1992; USFWS 1998; Behnke 2002); Lahontan cutthroat trout *Oncorhynchus clarki henshawi* (Behnke 1992; USFWS 1994; Behnke 2002); Paiute cutthroat trout *Oncorhynchus clarki seleniris* (Behnke 1992; Thurow et al. 1997; Behnke 2002; USFWS 2004); Redband trout *Oncorhynchus mykiss gairdneri* (Behnke 1992; Thurow et al. 1997; Behnke 2002); Rio Grande cutthroat trout *Oncorhynchus clarki virginalis* (Behnke 1992; Behnke 2002; Japhet 2007); Westslope cutthroat trout *Oncorhynchus clarki lewisi* (Behnke 1992; Shepard et al. 1997; Thurow et al. 1997; USFWS 1999b; Shepard et al. 2003); and Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* (Jordan 1891; Hanzel 1959; Behnke 1992; Thurow et al. 1997; Kruse et al. 2000; May et al. 2003).

Based on these assessments and literature cited within these documents we summarized: (1) the legal history of each species under the 1974 Endangered Species Act (ESA); (2) differences in the common elements of scale, historic reference points, genetics, handling of unknown data, population status determinations and perturbations; and (3) an estimation of the percentage of historic habitat no longer supporting reproducing populations. Finally, we used these trends to talk about the future of native trout within the United States.

Results and Discussion

Common themes among assessments

These assessments had a myriad of objectives, methods, completeness, quality, and resolution. Many assessments were triggered by actions taken under the Endangered Species Act but others were intended to better understand the threats to these species. Despite many differences there also were

common themes in how these assessments addressed scale, historic reference, genetics, unknown data, and the characterization of populations.

All assessments addressed how to determine the correct scale based on the objectives of the assessment (Table 1). The finest scale used was 1:24,000. The big advantage of this scale is the ability to use 1:100,000 cartographic feature files and hierarchically evaluate distributions within watersheds of various sizes (typically 4th – 6th hydrologic unit (HU) codes (EPA 2002), or within meaningful polygons such as eco-regions, evolutionary significant units (ESU's), geographic management units (GMU's) and political boundaries.

Assessments often summarized the distribution of native trout species at the watershed scale instead of stream segments because data were often difficult to obtain for all stream segments. This increases consistency but can reduce the resolution of the analysis and impair the ability to determine why a species may or may not be present in a specific location (Thurow et al 1997; Rieman et al. 1997; Hudy et al. 2005)(Table 1). Because many earlier assessments tended to not be repeatable, more recent assessments have employed rule sets for compatibility with future assessments (May et al. 2003; Hudy et al. 2005). Even with consistent rule sets, the stream mileage estimates (Table 1) may be biased because of bias in the underlying GIS datasets and the different assumptions used by the different practitioners.

Generally the reference point for assessment is the time of European settlement. European settlement varied from the 1700's within the range of the brook trout (Hudy et al 2005) to the 1800's for many of the western native trout species (May et al. 2003). In addition, many assessments also described events within a geologic time frame to provide an evolutionary context for populations (Smith et al. 1968; Behnke 1992; Behnke 2002). Exactly how the historical range is determined can have a large effect on estimates of the decline of a species. For example the Eastern Brook Trout Joint Venture (EBTJV) (2006) eliminated several thousand subwatersheds (6th HU) within the potential historic range of brook trout (MacCrimmon and Campbell 1969) because of the lack of historic habitat to support self-sustaining brook trout populations. Similar concerns were addressed within many of the recent assessments conducted for cutthroat trout sub-species (May et al. 2003; Shepard et al. 2003; Hirsch et al. 2006). If habitat that was historically uninhabited is included within the historic range of a species, the result will be an overestimate of the decline.

Nearly all assessments after 2000 give consideration to genetic issues such as hybridization, genetic introgression, and unique life histories (fluvial, adfluvial, resident, anadromous). When genetic data exist for the majority of populations (i.e., Gila trout; Apache trout) or a large sub sample of existing populations (Yellowstone cutthroat trout; westslope cutthroat trout (May et al. 2003) it is often necessary to have an operational definition of a genetically "pure" population. The reduced cost involved in processing genetic material as well as the increasing number of unique markers for a population will enable the detection of introgression at lower and lower thresholds in the future, making specific conservation guidelines difficult to determine (Allendorf et al. 2001). The increasing numbers of genetic markers for sub-species (for example see Pritchard et al. 2007) could also cause changes in the current distribution of some of the cutthroat subspecies (Kevin Rodgers, Colorado Division of Wildlife, personal communication). The brook trout assessment was the only assessment where genetic information was not collected (Hudy et al. 2005) because data were not available for over 90% of the sample units.

All assessments included streams or lakes with no or insufficient data. The methods for assigning status in those areas included qualitative assessments based on expert opinions, assessments that combined expert opinions and sample data, and predictions based on modeling techniques (Riemen et al. 1997; Thurow et al. 1997; Hudy et al. 2005; Thieling 2006).

Introduced and naturalized trout outside of their known historic ranges generally were not considered in the assessments. If locations where fish introductions were included for species such as brook trout, then the North American range would have greatly had increased while the health of the species declined in its native range.

Populations were characterized as present /absent (occupied/not occupied) or various levels of quantitative abundance, or qualitative classifications (i.e. strong, depressed). Assessments at the subwatershed scale usually classified native trout status on the percentage of habitat in each subwatershed still maintaining self-sustaining populations of native trout (Rieman et al. 1997; Thurow et al. 1997; Hudy

et al. 2005). Areas above natural barriers that were historically fishless were noted in many assessments (May et al. 2003), but total areas within a watershed that were inhabited may be overestimated because of difficulties associated with identification of barriers to movement in streams.

There were common perturbations identified for the loss, in both abundance and spatial distribution, of native trout. Land use changes such as conversion from forest to agriculture, loss of riparian vegetation, and landscape fragmentation were usually cited as primary reasons for decline. Along with landscape conversions, poor land management practices (i.e. logging practices, road construction, absence of best management practices) were negatively associated trout abundance and distribution. Biological stresses such as the introduction of non-native fishes (legal and illegal introductions) and the loss of genetic integrity through hybridization also were associated with low abundances and limited distributions. Many extirpations and reductions of native trout numbers and distributions occurred in the first 150 years after pioneer settlement because of dramatic land use changes and the stocking of non-native fishes that quickly followed human settlement. For example, local extirpations of brook trout in New Hampshire lakes and ponds were caused by the introduction of chain pickerel *Esox niger* which were introduced in the 1800's (Noon 2003). Although many historic threats have not been entirely eliminated, the devastating disregard for land and wildlife no longer occurs to the extent that it did between 1750 and 1950. However the historic changes in land cover has resulted in most of the healthy native trout populations now been located on public lands managed by the U.S. Forest Service, National Park Service, and Bureau of Land Management. While being located on public land can be a benefit, local extirpations still occur on public lands. Local extirpations are not limited to historical activities and continue today. For example, the top land use perturbations affecting the 539 conservation populations of westslope cutthroat trout were: grazing (23.7%); roads (25.8) and timber harvest (17.8%)(Shepard et al. 2003). In contrast, declines of brook trout, a species where less public land is available, were associated with: agriculture (36%); increased water temperature (35%); roads (sediment)(27%) and presence of exotic fish species (26%)(Hudy et al. 2005).

Occupied habitat

We conservatively estimate that over half of native trout habitats in the United States have been lost. Over 58 % of stream miles (66,385 stream miles out of 114,155), which historically had native trout, are currently not occupied by at least one native species. Where stream mile estimates were not possible, greater than 39 % of subwatersheds **(**5,908 subwatersheds extirpated out of 14,901 for the aggregate of brook trout, bull trout, redband trout) were no longer occupied (Table 1). No stream mileage or watershed estimate was available for coastal cutthroat trout. When we added together very conservative estimates of the stream miles no longer inhabited by brook trout, bull trout and red band trout, approximately half (280,445 out of 561,185 miles) of the streams are no longer inhabited by native trout. This conservative estimate does not include any uninhabited stream miles in subwatersheds where brook trout, bull trout or redband trout are still present and has no uninhabited stream miles for any coastal cutthroat trout. An unknown percentage of the uninhabited habitat for the western species involves possible double counting because of sympatry with other native trout. Individual native trout species range from having the entire historic habitat occupied to a > 90 % loss of historic habitat (Table 1). Many of the "extirpated" subwatersheds, streams and lakes have lost native trout but still maintain naturalized non-native trout or stocked trout populations. Because many native trout populations are restricted to small headwater streams, and the status reports and figures are based on stream length, the true spatial reduction in distribution may be more significant (Behnke 1992). We could not determine a similar figure for lake habitats but believe the losses are > 90%. Most of the data provided by state and federal agencies used for the estimates of stream mileage had neither been published nor subject to peer review and despite criteria provided for the data, there remains some element of subjectivity. It was impossible to generate a comprehensive review without such data (Rieman et al. 1997). However we believe our estimate of an approximate loss of 50 % of native trout habitat is reasonable and with our stated caveats, conservative.

Differences among assessments

Assessments for the same species often yielded different results. For example, delineation of historical habitats of Yellowstone cutthroat trout by May et al. 2003 differed from previous assessments (Hanzel 1959; Behnke 1979; Varley and Gresswell 1988; Behnke 1992; Gresswell 1995) for a number of reasons including improved mapping techniques (Firman and Jacobs 2002), additional inventory and monitoring, and differences in the reference period and methods for estimating historical occupancy. Differences in the reporting scale also can influence results; in the brook trout assessment, 88 % of 4th level HU watersheds but only 72 % 5th level HU's and 72 % of 6th level HU's were occupied by brook trout. It is estimated by the authors that only 46 % of historic stream miles are occupied by brook trout (Hudy et al. 2005). The scale at which the results are reported can bias impressions of the true status. In general the smaller the scale the smaller the bias, but fine-scale assessments require large amounts of fine scale data that rarely are available for large extents of species distributions.

Several assessments found that many native trout populations consist of independent non-networked units (e.g., a single stream or stream segment) disjunct from adjacent populations (May et al. 2003; Shepard et al. 2003; Hudy et al. 2005). Isolated populations tend to be vulnerable to local extirpation due to stochastic events. If effective population size for native trout consists of 500 reproducing adults based on the 50/500 "rule" (Franklin 1980; Soulé 1980), many biologists have found that most small isolated populations of native trout are at an extremely high risk of extinction (Hilderbrand and Kershner 2000; Kruse et al. 2001). Hilderbrand and Kershner (2000) estimated that to maintain and effective population of 500, cutthroat trout need at least 5.7 miles (9.3 km) of habitat. Harig and Fausch (2002) determined that cutthroat trout translocations were most successful when the drainage area was at least 5.6 square miles (usually inhabited stream lengths of at least 2 to 3 miles). In contrast, Rieman and Dunham (2000) provided data that indicated small, isolated populations of cutthroat trout might not be as prone to extinction as other vertebrates, and even other salmonids, based on their evaluation of the persistence of isolated headwater populations of westslope cutthroat trout in the Coeur d'Alene basin of Idaho. Even with no further decline in habitat or the additional spread of exotic fishes, a number of these isolated populations may become locally extirpated because of their isolation and vulnerability to stochastic events such as wild fire (Propst et al. 1992).

There appears to be an inverse relationship between connectivity and genetic integrity. Many isolated populations show no evidence of genetic introgression. The majority of conservation populations (native trout populations with the primary purpose to sustain the existence of the species or subspecies) of Yellowstone cutthroat trout (73 %) and westslope cutthroat trout (81 %) were considered isolated with no evidence of introgression (May et al. 2003; Shepard et al. 2003). For many native trout populations, genetic introgression and non-native competition probably are currently a greater threat than stochastic events. However, these isolated populations, particularly in the west are vulnerable to wildfires. Isolation of some remaining non-introgressed populations may be a prudent, short-term conservation strategy (Shepard et al. 2003).

Restoration

Most assessments addressed restoration of native trout habitats. Restoration and priority setting need to be viewed in the context of restorability, because many of the over 280,000 miles of extirpated habitat may be lost forever owing to the complexity of removing non-native fishes or reversing land use conversions (i.e. forest to agriculture to urbanization). For example, over 6,200 miles of Yellowstone cutthroat trout habitat (47% of potentially restorable streams) may be difficult to restore because of the need to remove non-native fishes (May et al. 2003). Many miles of potentially restorable brook trout waters are occupied by rainbow trout *Oncorhynchus mykiss* and/or brown trout *Salmo trutta*, and are hence unrestorable given current technology and the socio-political climate. Similarly, land that has progressed from forest to agriculture to urbanization or subdivisions is unlikely to be restored as native trout habitat. In the native range of brook trout, human land uses now average 30 % at the subwatershed scale (USGS 2004). Less than 6 % of intact brook trout subwatersheds had less than 68% forest in the

subwatershed while 71 % of extirpated watersheds had less than 68 % forest in the subwatershed (Hudy et al. 2005). As noted for brook trout, wilderness and roadless areas provide important strongholds for many native western salmonids (Lee et al. 1997). Wilderness and roadless areas are not always a panacea for all native trout populations, as shown by the extirpation of brook trout in roadless/wilderness areas because of acid rain. Similarly, climate change impacts may dramatically change the distribution of some native salmonids where current temperature regimes are marginally suitable for some species. Strategic decisions and funding are needed to determine restoration priorities whether the model is to protect the "best of the best" or to restore "the worst first" (Frissell 1993).

Future changes and effective actions

We believe future changes in native trout distribution and status will be driven primarily by changes in land cover, land use practices and habitat fragmentation (Rieman et al. 1997; Hudy et al. 2005). There is a strong negative relationship between human population centers and strong trout populations (Thieling 2006). While metropolitan population growth may be slowing, population growth rates in rural areas are likely to increase (Johnson and Beale 2003), thereby increasing the likelihood of conflict between human and native trout populations. So while some native trout species are not currently at risk, their futures are not that bright.

Many future landscape changes will result not only from human activities but also from indirect human activity that results in global climate change (Flebbe 1997; Rieman et al. 1997). Given the increased certainty of global warming (Intergovernmental Panel on Climate Change 2007), the risk of losing native trout species or subspecies will continue to increase even if our direct impacts are minimized and it is unlikely that the future direct effects will be minimal.

Certainly an important component of any plan protecting native trout populations is to maintain current strongholds, which are often centered on public lands (Lee et al. 1997). These lands typically are least impacted by humans and are in areas that foster production of cold-water habitats. But while protection of the remaining native trout necessarily will be focused on public lands, if restoration efforts are to be successful, it will be necessary to involve private lands where county and other authorities may be unaware or indifferent about native trout populations. Non-experts often view the outcomes in a pass/fail context as it relates to listing under the Endangered Species Act. In general, education of the non-angling or non-environmental publics has been absent or ineffective (Angermeier 2005) and without broad-based support native trout protection and restoration will at best achieve rearguard status.

Many native fishes have detailed recovery plans and strategies that have never been funded or funded only as brief initiatives even though restoration may take decades. It has been said that conservation without funding is just conversation. There have been lots of conversations about native trout but little long term funding and commitment similar to the North American Waterfowl Plan now in its third decade. Without such long-term commitment, native trout conservation will be a series of brief, ineffective initiatives rolled out every five to ten years. The recent National Fish Habitat Initiative and the various joint ventures under its umbrella have the potential to improve native trout if they can become long-term commitments.

Improved inventory and monitoring is critical to tracking successes and failures of conservation and restoration efforts for native trout. Through monitoring it will be possible to better assess the reasons different restoration efforts have succeeded or failed. Increased sampling also will be needed to evaluate and monitor impacts of land use changes, both on private and public lands, as well as to track the spread of exotic species and hybridization rates. Increased monitoring of the status of native trout should be a priority for long-term conservation efforts and the additional data will help increase the accuracy with which large-scale assessments can be conducted.

This assessment review paints a clear picture that native trout across the United States face similar threats and it is likely that these threats will increase in the future, putting most native trout at risk of further extirpations. The only way to maintain these species is to develop and implement well funded, clearly articulated, coordinated restoration plans among all the different management agencies and

interest groups. Focusing restoration efforts in areas that benefit the species, rather than by political boundaries, will increase the likelihood that native trout will persist.

Acknowledgements:

We thank the many authors of the cited assessments for providing the latest drafts and updates of their work. We thank J. Kershner, A. Dolloff and P. Flebbe for reviewing this paper.

References

Allendorf, F. W., R. F. Leary, P. Spruell, and J. K. Wenburg. 2001. The problems with hybrids: setting conservation guidelines. Trends in Ecology and Evolution 16:613-622.

Angermeier, P.L. 2005. Fish biologists as conservation educators regarding economic growth. Fisheries.Volume 30, Number 12, pages 37-39.

Belford, D. A., and W. R. Gould. 1989. An evaluation of trout passage through six highway culverts in Montana. North American Journal of Fisheries Management 9:437-445.

Behnke, R. J. 1992. Native trout of Western North America. American Fisheries Society, Monograph 6, Bethesda, Maryland.

Behnke, R. J. 2002. Trout and salmon of North America. The Free Press. 359 pp.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation. 54(1): 419-431.

Brown, D.K., A.A. Echelle, D.L. Propst, J.E. Brooks, and W.L. Fisher. 2001. Catastrophic wildfire and number of populations as factors influencing risk of extinction for Gila trout (Oncorhynchus gilae). Western North American Naturalist 61: 139-148.

Budy, P., R. Al-Chokhachy, and G.P. Thiede. 2007. Bull trout population assessment in northeastern Oregon: A template for recovery planning. 2006 Annual Progress Report to the U.S. Fish and Wildlife Service. UTCFWRU 2007(1):1-83.

Caughley, G., D. Grice, R. Barker, and B. Brown. 1988. The edge of the range. Journal of Animal Ecology 57:771-785.

Clayton, J. L., E. S. Dannaway, R. Menendez, H. W. Rauch, J. J. Renton, S. M. Sherlock, and P. E. Zurbuch. 1998. Application of limestone to restore fish communities in acidified streams. North American Journal of Fisheries Management 18:347-360.

Curry, R. A., and W. S. MacNeill. 2004. Population-level responses to sediment during early life in brook trout. North American Benthological Society 23(1): 140-150.

Davis, W. S., and T. P. Simon. 1995. Biological Assessment and Criteria: Tools for Watershed Resource Planning and Decision Making. Lewis Publishers, Washington, D.C. Doppelt, B., M. Scurlock, C. A. Frissell, and J. Karr. 1993. Entering the watershed. Island Press, Covello, California.

Discroll, C. T., G. B. Lawrence, A. J. Bulgur, T. J. Butler, C. S. Cronan, C. Eagar, K. F. Lambert, G. E. Likens, J. L. Stoddard, and K. C. Weathers. 2001. Acidic deposition in the Northeastern United States: sources and inputs, ecosystem effects, and management strategies. Bioscience 51(3): 180-198.

Dowling, T.E and M.R. Childs. 1992. Impact of hybridization on a threatened trout of the Southwestern United States. Conservation Biology. 6(3): 355-364.

EBTJV (Eastern Brook Trout Joint Venture). 2006. http://www.easternbrooktrout.org (December 2006)

EPA (U. S. Environmental Protection Agency). 2002. Hydrologic unit boundaries from USGS. http://www.epa.gov/region02/gis/atlas/hucs.htm. (November 2004).

Fiss, F. C., and R. F. Carline. 1993. Survival of brook trout embryos in three episodically acidified streams. Transactions of the American Fisheries Society 122:268-278.

Firman, J. C., and S. E. Jacobs. 2002. Comparison of stream reach lengths measured in the field and from maps. North American Journal of Fisheries Management 22:1325-1328.

Flebbe, P.A. 1997. Global climate change and fragmentation of native brook trout distribution in the southern Appalachian mountains. (pages 117-121; in R. E. Gresswell, P. Dwyer and R.H. Hamre

editors, Wild Trout VI: Putting the native back in wild trout. Proceedings of the 6th Wild Trout Conference, August 17-20, 1997, Bozeman, Montana.
Franklin, I.A. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. Pages 135-150 in M. E. Soulé, and B. A. Wilcox, editors. Conservation biology: an evolutionary-ecological perspective. Sinauer, Sunderland, MA.
Frissell, C. A. 1993. A new strategy for watershed recovery of Pacific salmon in the Pacific Northwest. Report prepared for the Pacific Rivers Council Inc., Eugene, Oregon. March 1993.
Frissell, C. A., and D. Bayles. 1996. Ecosystem management and the conservation of aquatic biodiversity and ecological integrity. Water Resources Bulletin 32:229-240.
Gagen, C. J., W. E. Sharpe, and R. F. Carline. 1993. Mortality of brook trout, mottled sculpins, and slimy sculpins during acidic episodes. Transactions of the American Fisheries Society 122:616-628.
Galbreath, P. F., N. D. Adams, S. Z. Guffey, C. J. Moore, and J. L. West. 2001. Persistence of Native Southern Appalachian Brook Trout Populations in the Pigeon River System, North Carolina. North American Journal of Fisheries Management 21:927-934.
Gibson, R. J., R. L. Haedrich, and C. M. Wernerheim. 2005. Loss of fish habitat as a consequence of inappropriately constructed stream crossings. Fisheries 30(1):10-17.
Gresswell, R. E. 1995. Yellowstone cutthroat trout. In: Conservation Assessment for Inland Cutthroat Trout. M.K. Young Technical Editor. USDA Forest Service RM-GTR-256. p. 36-54.
Gresswell, R.E. (ed.). 1988. Status and management of interior stocks of cutthroat trout. American Fisheries Society Symposium 4.
Hall, J.D., P.A. Bisson, and R.E. Greswell (eds.). 1997. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter of the American Fisheries Society, Corvallis, Oregon, 183 pp.
Hanzel, D. A. 1959. The distribution of the cutthroat trout (Salmo clarki) in Montana. Proceedings of the Montana Academy of Sciences 19:32-71.
Harig, A. L., and K. D. Fausch. 2001. Minimum habitat requirements for establishing translocated cutthroat trout populations. Ecological Applications 12:535-551.
Hayes, J. P., S. Z. Guffey, F. J. Kriegler, G. F. McCracken, and C. R. Parker. 1996. The genetic diversity of native, stocked, and hybrid populations of brook trout in the southern Appalachians. Conservation Biology 10:1403-1412
Hepworth, D.K., M.J. Ottenbacher, and L.N. Berg. 1997. Distribution and abundance of native Bonneville cutthroat trout (*Oncorhynchus clarki utah*) in southwestern Utah. Great Basin Naturalist 57(1):11-20.
Hilderbrand, R. H., and J. L. Kershner. 2000. Conserving inland cutthroat trout in small streams: how much stream is enough? North American Journal of Fisheries Management 20:513-520.
Hirsch, C.L., S.E. Albeke, and T.P. Nesler. 2006. Range-Wide Status of Colorado River Cutthroat Trout (Oncorhynchus clarkii pleuriticus): 2005. Status update Colorado River cutthroat interagency coordination group (unpublished report).
Hudy, M., D. M. Downey, and D. W. Bowman. 2000. Successful restoration of an acidified native brook trout stream through mitigation with limestone sand. North American Journal of Fisheries Management 20:453-466.
Hudy, M., T. M. Thieling, N. Gillespie, and E. P. Smith. 2005. Distribution, status, and perturbations to brook trout within the eastern United States. Final report to the Eastern Brook Trout Joint Venture. http://www.easternbrooktrout.org
Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: The Physical Science Basis – Summary of Policy makers. http://www.ipcc.ch/SPM2feb07.pdf
Japhet, M. 2007. South West Region Senior Aquatic Biologist, Colorado Division of Wildlife. Personnel communication.
Johnson, K. M. and M. Beale. 2002. Non-metro Recreation Counties: Their identification and Rapid Growth. Rural America 17: 12-19.

Johnson, O. W., M. H. Ruckelshaus, W. S. Grant, F. W. Waknitz, A. M. Garrett, G. J. Bryant, K. Neely, J. J. Hard. In press. Coastwise Status Review of Coastal Cutthroat Trout (Oncorhynchus clarki clarki) by the National Marine Fisheries Service for listing under the Endangered Species Act. North American Journal of Fisheries Management.

Johnson, O. W., M. H. Ruckelshaus, W. S. Grant, F. W. Waknitz, A. M. Garrett, G. J. Bryant, K. Neely, J. J. Hard. 1999. Status review of coastal cutthroat trout from Washington, Oregon, and California. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-37, 292 p.

Jordan, D. S. 1891. A reconnaissance of the streams and lakes in the Yellowstone National Park, Wyoming, in the interest of the United States Fish Commission. Bulletin U. S. Fish Commission. Vol. 41-63.

Keleher, C.J. and F.J. Rahel. 1996. Thermal limits to salmonid distributions in the Rocky Mountain region and potential habitat loss due to global warming: A Geographic Information System (GIS) approach. Transactions of the American Fisheries Society. 125:1-13.

Kelly, G. A., J. S. Griffith, and R. D. Jones. 1980. Changes in distribution of trout in Great Smoky Mountains National Park, 1900-1970. U.S. Fish and Wildlife Service Technical Paper 102.

Kershner, J. L., C.M. Bischoff, D. Horan. 1997. Population habitat and genetic characteristics of Colorado River cutthroat trout in wilderness and nonwilderness stream sections in the Uinta Mountains of Utah and Wyoming. North American Journal of Fisheries Management. 17(4):1134-1143.

Kershner, J.L. 1995. Bonneville cutthroat trout. M.K. Young, technical editor. Pages 28-35. In: A conservation assessment for inland cutthroat trout. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins. General Technical Report RM-GTR-256.

King, W. 1937. Notes on the distribution of native speckled and rainbow trout in the streams of Great Smokey Mountains National Park. Journal of the Tennessee Academy of Science 12:351-361.

King, W. 1939. A program for the management of fish resources in Great Smokey Mountains National Park. Transaction of the American Fisheries Society 68:86-95.

Krueger, C.C. and B. May. 1991. Ecological and genetic effects of salmonid introductions in North America. Canadian Journal of Fisheries and Aquatic Sciences. 48(1):66-77. 123.

Kruse, C. G., W. A. Hubert, and F. J. Rahel. 2000. Status of Yellowstone cutthroat trout in Wyoming waters. North American Journal of Fisheries Management 20:693-705.

Kruse, C. G., W. A. Hubert, and F. J. Rahel. 2001. An assessment of headwater isolation as a conservation strategy for cutthroat trout in the Absaroka Mountains of Wyoming. Northwest Science 75:1-11.

Larson, G. L., and S. E. Moore. 1985. Encroachment of exotic rainbow trout into stream populations of native brook trout in the southern Appalachian Mountains. Transactions of the American Fisheries Society 114:195-203.

Lee, D.C. and 21 other authors. 1997. An assessment of the ecosystem components in the Interior Columbia Basin and Portions of the Klamath and Great Basin. Volume 3. Broad scale Assessment of Aquatic Species and Habitats. USDA Forest Service Technical Report PNW-GTR-405. Portland, Oregon.

Lennon , R. E. 1967. Brook trout of Great Smokey Mountains National Park. U.S. Fish and Wildlife Service Technical Paper 15.

Li, H.W. and P.B. Moyle. 1981. Ecological analysis of species introductions into aquatic systems. Transactions of the American Fisheries Society. 110:772-782.

MacCrimmon, H. R. and J. S. Campbell. 1969. World Distribution of Brook Trout, *Salvelinus fontinalis.* Journal of Fisheries Research Board of Canada 26(7):1699-1725.

Marschall, E. A. and L.B. Crowder. 1996. Assessing Population Responses to Multiple Anthropogenic Effects: A Case Study with Brook Trout. Ecological Applications 6(1):152-167.

Master, L. L., S. R. Flack, and B. A. Stein, editors. 1998. Rivers of Life: Critical Watersheds for Protecting Freshwater Biodiversity. The Nature Conservancy, Arlington, VA.

May, B.E., W.Urie, and B.B. Shephard. 2003 Range –Wide Status of Yellowstone Cutthroat Trout (Oncorhynchus clarki bouvieri): 2001. Status update Yellowstone cutthroat interagency coordination group (unpublished report). 201 pp.

Meehan, W.R. (ed.). 1991. Influence of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special publication 19. Bethesda, MD.

Meisner, J. D. 1990. Effect of climatic warming on the southern margins of the native range of brook trout, *Salvelinus fontinalis*. Canadian Journal of Fisheries and Aquatic Sciences 47:1065-1070.

Moore, S. E., B. Ridley, and G. L. Larson. 1983. Standing crops of brook trout concurrent with removal of rainbow trout from selected streams in Great Smoky Mountains National Park. North American Journal of Fisheries Management 3:72-80.

Moore, S. E., G. L. Larson, and B. Ridley. 1986. Population control of exotic rainbow trout in streams of a natural area park. Environmental Management 10:215-219.

Nature Serve. 2007. An online encyclopedia of life. http:// www.natureserve.org/explorer (July 2007).

Nehlsen, W., J.E. Williams, and J.A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2): 4-21.

Nislow, K. H., and W. H. Lowe. 2003. Influences of logging history and stream pH on brook trout abundance in first-order streams in New Hampshire. Transactions of the American Fisheries Society 132:166-171.

Noon, J. 2003. Fishing in New Hampshire: A history. Moose Country Press, Warner, NH.

Pritchard, V.L., K. Jones, J.L. Metcalf, A.P. Martib, P. Wilkinson, and D.E. Cowely. 2007. Characterization of tetranucleotide microsatellites for Rio Grande cutthroat trout and rainbow trout, and their cross-amplification in other cutthroat trout subspecies. Molecular Ecology Notes 7: 594-596.

Propst, D.L. J.A. Stefferud and P.R. Turner. 1992. Conservation and status of Gila trout *Oncorhynchus gilae.* Southwestern Naturalist. 37: 117-125.

Rieman, B. E., D. C. Lee, and R. F. Thurow. 1997. Distribution, Status, and Likely Future Trends of Bull Trout within the Columbia River and Klamath River Basins. North American Journal of Fisheries Management 17:1111-1125.

Rieman, B.E., and J. B. Dunham. 2000. Metapopulation and salmonids: a synthesis of life history patterns and empirical observations. Ecology of Freshwater Fish 9:51-64.

Roghair, C. N., C. A. Dolloff, and M. K. Underwood. 2002. Response of a brook trout population and instream habitat to a catastrophic flood and debris flow. Transactions of the American Fisheries Society 131:718-730.

Shepard, B. B., B. Sanborn, L. Ulmer, and D. C. Lee. 1997. Status and risk of extinction for westslope cutthroat trout in the upper Missouri River Basin, Montana. North American Journal of Fisheries Management 17:1158-1172.

Shepard, B.B., B.E. May and W. Urie. 2003. Status of Westslope Cutthroat Trout (Oncorhynchus clarki lewisi) in the United States: 2002. Status update to the westslope cutthroat interagency conservation team. (Unpublished report), 94 pp.

Smith, G.R., W.L Stokes, and K.F. Horn. 1968. Some late Pleistocene fishes of Lake Bonneville. Copeia 4:807-816.

Soulé, M. E. 1980. Thresholds for survival: maintaining fitness and evolutionary potential. Pages 151-169 in M. E. Soulé, and B. A. Wilcox, editors. Conservation biology: an evolutionary-ecological perspective. Sinauer, Sunderland, MA.

Stephens, S.J. , C. McGuire and L. Sims. 2004. Conservation Assessment and Strategy for the California Golden Trout (Oncorhynchus mykiss aquabonita) Tulare County, California. U.S. Fish and Wildlife Service, Sacramento, California. 91 pp.

Strange, R. J., and J. W. Habera. 1998. No net loss of brook trout distribution in areas of sympatry with rainbow trout in Tennessee streams. Transactions of the American Fisheries Society 127:434-440.

Thieling, T.M. 2006. Assessment and predictive model for brook trout (*Salvelinus fontinalis)* population status in the eastern United States. Master's thesis. James Madison University, Harrisonburg, Virginia.

Thurow, R.F., D.C. Lee, and B.E. Rieman. 1997. Distribution and status of seven native salmonids in the Interior Columbia River basin and portions of the Klamath River and Great Basins. North American Journal of Fisheries Management 17:1094-1110.

U. S. Army Corps of Engineers. 1998. National Inventory of Dams data. http://crunch.tec.army.mil/nid/webpages/nid.cfm (November 2004).

USFWS (U.S. Fish and Wildlife Service). 1983. Arizona Trout Recovery Team. Albuquerque, New Mexico.

USFWS (U.S. Fish and Wildlife Service). 1994. Lahontan cutthroat trout, Oncorhynchus clarki henshawi, Recovery Plan. U.S. Fish and Wildlife Service, Portland , Oregon. 147 pp

USFWS (U.S. Fish and Wildlife Service). 1998. Greenback cutthroat trout recovery plan. U.S. Fish and Wildlife Service, Denver Colorado. 62 pp.

USFWS (U.S. Fish and Wildlife Service). 1999a. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for Bull Trout in the Coterminous United States. 50 CFR Part 17, RIN 1018-AF01. Federal Register Vol (64), No. 210, November 1, 1999.

USFWS (U.S. Fish and Wildlife Service). 1999b. Status review for westslope cutthroat trout in the United States. U.S. Fish and Wildlife Service, Portland , Oregon and Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 2001. Status review for Bonneville cutthroat trout (Oncorhynchus clarki utah). Portland, Oregon and Denver Colorado. 143 pp.

USFWS (U.S. Fish and Wildlife Service). 2003. Gila trout recovery plan (third revision). Albuquerque, New Mexico. 78 pp.

USFWS (U.S. Fish and Wildlife Service). 2004. Revised Recovery plan for the Paiute cutthroat trout (Oncorhynchus clarki seleniris). Portland , Oregon. 105 pp.

USFWS (U.S. Fish and Wildlife Service). 2005. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Bull Trout; Final Rule. 50 FCR Part 17, RIN 1018-AJ12; 1018-AU31, Federal Register Volume (70), No. 185, September 26,2005.

USGS (U. S. Geological Survey). 2004. National Land Cover Dataset 1992 (NLCD 1992). http://landcover.usgs.gov/natllandcover.asp. (June 2004).

Varley, J. D. and R. E. Gresswell. 1988. Ecology, status, and management of Yellowstone cutthroat trout. In: Status and Management of Interior Stocks of Cutthroat Trout. American Fisheries Society Symposium 4:13-24.

Warren, M. L., Jr., P. L. Angermeier, B. M. Burr, and W. R. Haag. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the southeastern United States. Pages 105-164 in Benz, G. W. and D. E. Collins (editors). Aquatic Fauna in Peril: The Southeastern Perspective. Special Publication 1, Southeast Aquatic Research Institute, Lenz Design and Communications, Decatur, GA.

Williams, J. D., M. L. Warren, Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6-22.

Yarnell, S.L. 1998. The Southern Appalachians: A history of the landscape. United States Department of Agriculture, Forest Service, Southern Research Station, General Technical Report SRS-18, Asheville, North Carolina.

Young, M.K. 1995. Colorado River cutthroat trout. M.K. Young, technical editor. Pages 16-23. In: A conservation assessment for inland cutthroat trout. USDA Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins. General Technical Report RM-GTR-256.

Young, M.K., R.N. Schmal, T.W. Kohley, and V.G. Leonard. 1996. Conservation status of Colorado River cutthroat trout. General Technical Report RM-GTR-282. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experimental Station. 32p

Table 1. Summary of assessment data for 15 inland trout species (status under the Endangered Species Act (Federal endangered = FE; Federal threatened = FT; Species of concern = SOC; Estimated extirpated/historic; % of historic habitat extirpated; references).

Species	**Federal Status: historic, current, Or pending**	**Recovery Plan**	**Estimated: extirpated/historic (units)**	**% of historic habitat extirpated**	**Primary References**
Apache trout *Oncorhynchus gilae apache*	FE 1967 FT 1975	1979 1983	570/600 stream miles (1:24000)	> 90 %	USFWS 1983; Behnke 1992; Behnke 2002
Brook Trout *Salvelinus fontinalis*	None		1,451/5,001[1] subwatershed (6th HU)	28 %	MacCrimmon and Campbell 1969; Behnke 2002; Hudy et al. 2005
Bonneville cutthroat trout *Oncorhynchus clarki utah*	None; Petitioned 1998; Finding: Not warranted 2001		4,378/6,758 stream miles (1:24000)	65 %	Behnke 1992; Kershner 1995; USFWS 2001
Bull trout *Salvelinus confluentus*	FT 1999	Various 2002 -2004	2,484/4,462[2] subwatershed (6th HU)	56 %	Rieman et al. 1997; Thurow et al. 1997; USFWS 1999a; USFWS 2005
California Golden trout *Oncorhynchus mykiss aguabonita*	Candidate 1991 SOC 1996, Petitioned 2000		92/100 stream miles (1:24000)	> 90 %	Behnke 1992; Behnke 2002; Stephens et al. 2004
Colorado cutthroat trout *Oncorhynchus clarki pleuriticus*	None; Petitioned 1999; Finding: No action at this time		18,364/21,386 stream miles (1:24000)	87 %	Behnke 1992; Young 1995; Young et al. 1996; Hirsch et al. 2006
Coastal cutthroat trout *Oncorhynchus clarki clarki*	None; Umpqua Sea-Run FE 1996; Delisted 2000; Petitioned 1997; Finding: Not warranted 2002.		Could not be determined	Could not be determined	Nehlsen et al. 1991; Behnke 1992; Hall et al. 1997; Johnson et al. 1999; Johnson et al. (in press)
Gila trout *Oncorhynchus gilae gilae*	FE 1967 FT 2005	1979; 1984; 1993; 2003	121/144 stream miles (1:24000)	>82 %	USFWS 2003
Greenback cutthroat trout *Oncorhynchus clarki stomias*	FE 1967 FT 1978	1978; 1983; 1998	900/1,000 stream miles (1:24000)	>90 %	USFWS 1998; Behnke 1992; Behnke 2002
Lahontan cutthroat trout *Oncorhynchus clarki henshawi*	FE 1970 FT 1975	1995	3,240/3,600 stream miles (1:24000)	96.6 % lake 80.3 % stream	USFWS 1994
Paiute cutthroat trout *Oncorhynchus clarki seleniris*	FE 1967 FT 1973	1985 2004	0/10 stream miles (1:24000)	0	Behnke 1992; Thurow et al. 1997; Behnke 2002; USFWS 2004
Redband trout *Oncorhynchus mykiss gairdneri*	None; Petitioned 1997; Finding: Not warranted		1,854/5,438[3] subwatershed (6th HU)	>34 %	Behnke 1992; Lee et al. 1997; Thurow et al. 1997; Behnke 2002

Rio Grande cutthroat trout *Oncorhynchus clarki virginalis*	None; Petitioned 1998; Finding: Under candidate status review	5,850/6,660 stream miles (1:24000)	88%	Behnke 1992; Behnke 2002; Japhet 2007
Westslope cutthroat trout *Oncorhynchus clarki lewisi*	None; Petitioned 1997: Finding: Not warranted 2000	23,001/56,5001 stream miles (1:24000)	41 %	Behnke 1992;USFWS 1999b; Shepard et al. 1997; Shepard et al. 2003
Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri*	None; Petitioned 1998; Finding : Not warranted 2001	9,869/17,397 stream miles (1:100000)	57 %	Jordan 1891; Hanzel 1959; Behnke 1992; May et al. 2003

1 Does not include the native range of brook trout in the states of MI, WI, MN

2 Only includes bull trout range within the Interior Columbia River Basin and portions of the Klamath and Great Basins

3 Only includes redband trout range within the Interior Columbia River Basin and portions of the Klamath and Great Basins