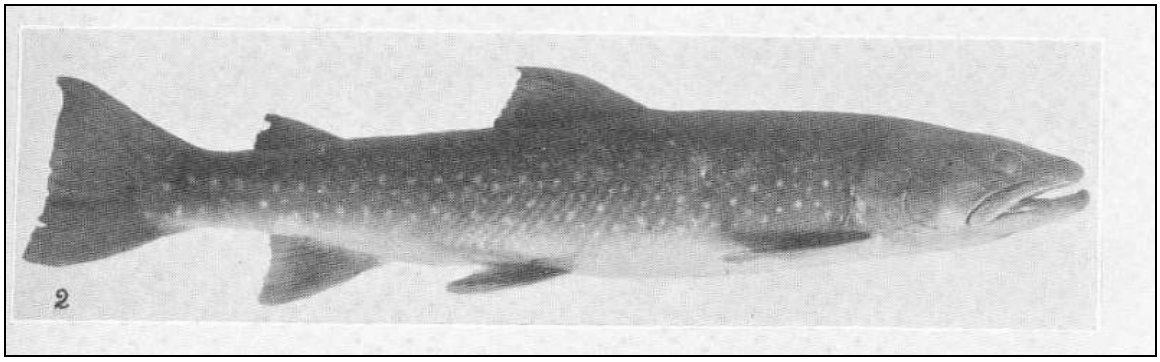
U.S. Fish and Wildlife Service

What Happened to Bull Trout in Lake Chelan?

An Examination of the Historical Evidence



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On the cover: "American trout from Lake Chelan, Washington, USA: Dolly Varden Trout" by Cranford. Figure 40-2 in Game Fishes of the World by Charles Frederick Holder, London England 1913. Image courtesy of the Freshwater and Marine Image Bank of the Digital Collections in the University of Washington Libraries

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Introduction

Bull trout *Salvelinus confluentus* were native to Lake Chelan but are no longer found in the basin and are most likely extirpated. Once commonly caught by anglers, the last verified observation occurred on July 16, 1957, when two "Dolly Varden"[1] were caught in the Stehekin River, preserved, and sent to the Oregon State University Museum. Since then several surveys in the watershed have not located any bull trout (Brown 1984; DES 2001; Archibald 2002; Halupka et al. 2002; Kelly-Ringel 2004), but anecdotal sightings by anglers are occasionally reported (Brown 1984; Halupka et al. 2002). Although the reason for the disappearance of this major indigenous predator is not known, several possibilities have been suggested, with flooding of spawning grounds, an introduced pathogen, and subsequent over-fishing the most commonly cited (Leman 1969; Buckner and Campbell 1977; Brown 1984; WDFW 2002).

The restoration of bull trout into Lake Chelan was first proposed by Brown (1984). Transplantation of adfluvial bull trout into the lake was suggested in the draft bull trout recovery plan (USFWS 2002) and a state fisheries management plan recommended that fluvial bull trout be translocated into the Stehekin River (WDFW 2002). Before any reintroductions occur, however, a rigorous examination of the factors that may have led to the demise of bull trout in the lake is required. Several questions need to be addressed, including: How intense was the fishing pressure in Lake Chelan and did fishery management activities contribute to the loss of bull trout? How severe were the floods that are assumed to have degraded the spawning grounds? Is there evidence of the pathogen other than anecdotal accounts? What pathogens were known to occur in the Columbia River basin during the period, what was the likely cause of the epizootic, and how could it have spread? What role did ecology and geology play in the extirpation? In short- What happened to bull trout in Lake Chelan?

Geologic history of Lake Chelan

Lake Chelan, located in Chelan County of north central Washington, is the largest natural lake in Washington and one of the deepest lakes in the world. It averages about one mile in width and extends for about 50 miles from its principal inlet, the Stehekin River, to its outlet, the Chelan River near the City of Chelan (Figures 1 – 3). This ultraoligotrophic body of water was formed by glacial activity and consists of two major basins, the deep Lucerne Basin of the upper lake and the shallower Wapato Basin of the lower lake. The maximum depth of the lake is 1,486 feet, lake volume is 25 billion cubic yards (92% in the Lucerne Basin), and hydraulic retention time is 10.6 years (Kendra and Singleton 1987). The majority of water flowing into Lake Chelan is from the Stehekin River (65%) and Railroad Creek (10%) while approximately 50 small streams contribute the rest. Most of the tributaries are short and relatively steep.

[1] Bull trout were commonly called Dolly Varden until they were identified as two separate species in 1978 (Cavender 1978). Although "Dolly Varden" disappeared in Lake Chelan before 1978, we know they were in fact bull trout because these 2 specimens were included in an analysis by Haas and McPhail (1991) that showed only bull trout are present in the Columbia River basin. Interestingly, the first written descriptions of bull trout in Lake Chelan did not call them Dolly Varden, evidently because the writers were familiar with the fish from Idaho, where bull trout was the accepted name (e.g. Durham 1891; Evermann 1899).

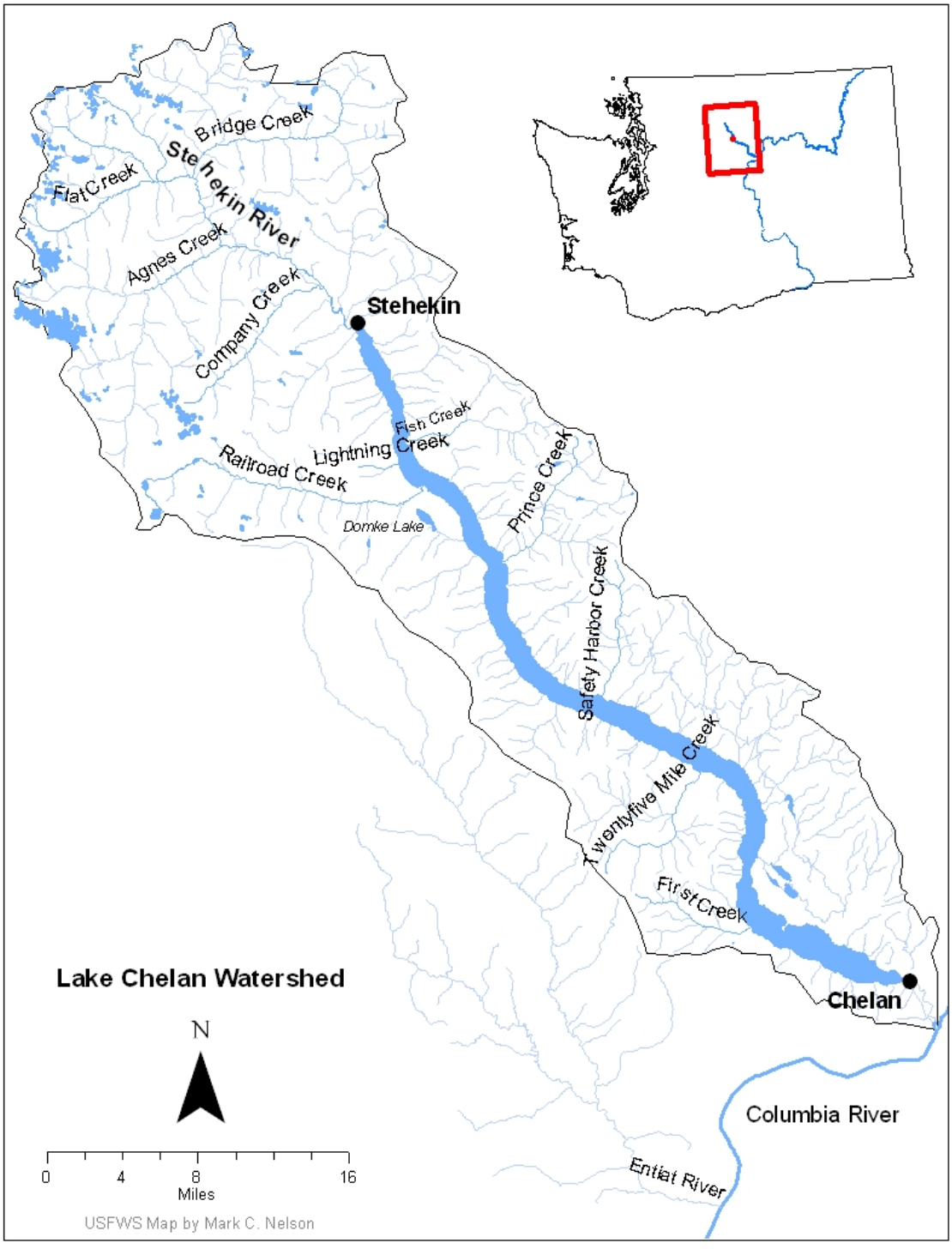

Figure 1. Map of the Lake Chelan watershed, Chelan County, Washington.

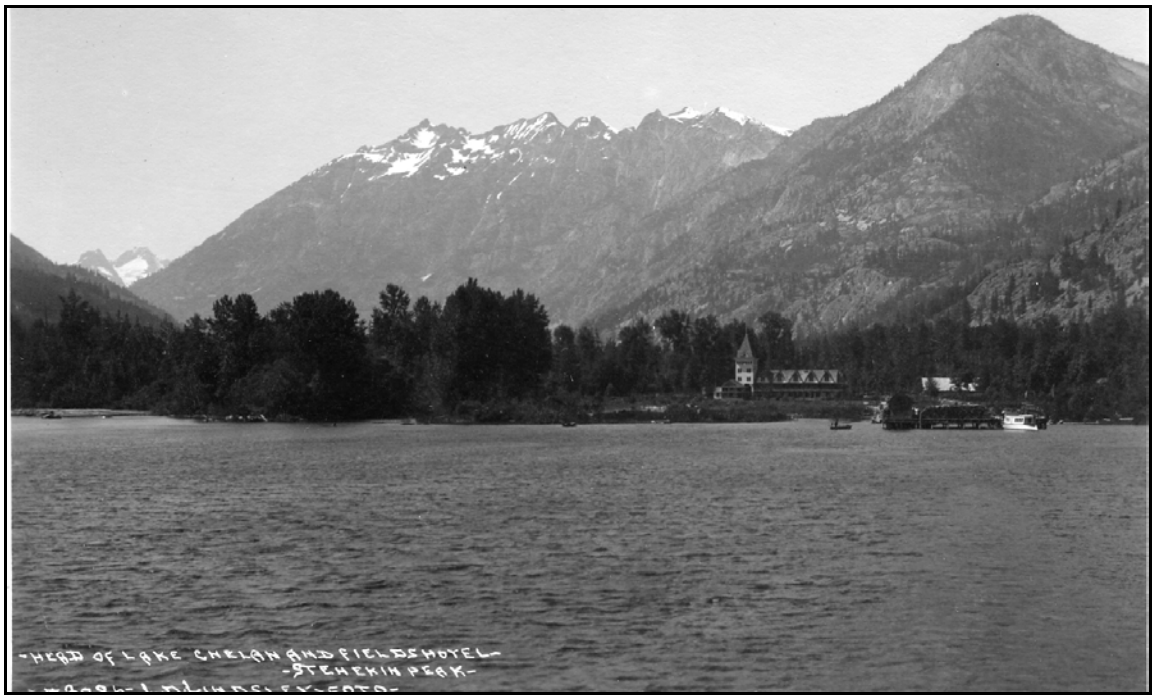

Figure 2. "Head of Lake Chelan and Fields Hotel – Stehekin Peak" (L.D. Lindsley photograph #3086, courtesy of Lake Chelan Historical Society).

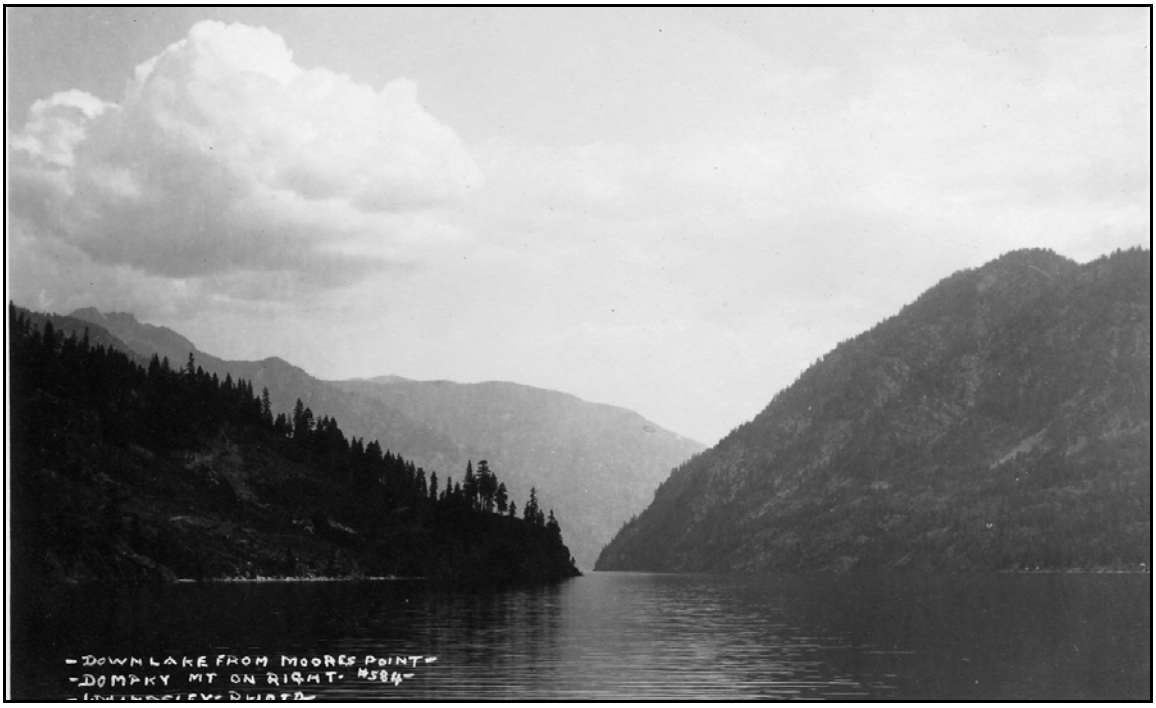

Figure 3. "Downlake from Moores Point – Dompky Mt on Right" (L.D. Lindsley photograph #584, courtesy of Lake Chelan Historical Society).

Pre-glacial Chelan Valley had a length of about 75 miles, which is represented now by the Stehekin River, Lake Chelan and the Chelan River. Lake Chelan was carved and shaped by the processes of glacial erosion and deposition from the Chelan Glacier and the Okanogan lobe of the Cordilleran Ice Sheet during the Wisconsin glaciation of about 18,000 years ago (Freeman 1944). The Chelan Glacier was over 4,000 feet thick and may have extended from the Cascade Crest to almost the Columbia River, but it apparently retreated rapidly before it maintained itself for a considerable time at a point near Twenty-Five Mile Creek. Simultaneously, the Okanogan lobe moved down the Columbia River to beyond the Chelan Valley, blocking the valley end and damming the melt water to create Glacial Lake Chelan between the two glaciers. Two former outlets and numerous terraces of this glacial lake exist between Twenty-Five Mile Creek and the foot of Lake Chelan. When the glaciers receded, the original outlet of the Chelan River had become completely blocked with fluvial glacial deposits left by the Okanogan lobe and modern Lake Chelan was formed. A new outlet was excavated through granite bedrock by the Chelan River, which now descends 400 feet in three miles through a steep and narrow gorge before entering the Columbia River (Figure 4).

Native and introduced fish

The native fish community of Lake Chelan was typical of post-glacial refugia in the upper Columbia Basin headwaters (Brown 1984). The occurrence of these isolated native fish populations was probably the result of repeated massive flooding when ice dams forming glacial Lake Missoula periodically burst (Behnke 1992). Descriptions of the native assemblage of Lake Chelan include bull trout *Salvelinus confluentus*, westslope cutthroat trout *Onchorhynchus clarki lewisi*, burbot *Lota lota*, largescale sucker *Catostomus macrocheilus*, longnose sucker *C. catostomus*, bridgelip sucker *C. columbianus*, northern pikeminnow *Ptychocheilus oregonensis*, peamouth *Mylocheilus caurinus*, redside shiner *Richardsonius balteatus*, mountain whitefish *Prosopium williamsoni*, and pygmy whitefish *P. coulteri* (Evermann 1899; BioAnalysts, Inc. 2000; Wydoski and Whitney 2003; Matthews et al. 2004).

Several non-native fish species have been introduced into Lake Chelan (USCFF 1903; Brown 1984; Matthews et al. 2004). Salmonids that were purposely stocked during fisheries management activities include Yellowstone cutthroat trout *O. clarki bouvieri* (stocked in 1903), rainbow trout *O. mykiss* (in 1913)[2], kokanee *O. nerka* (in 1917)[3], brook trout *S. fontinalis* (in 1934)[4], Chinook salmon *O. tshawytscha* (in 1974), and lake trout *S. namaycush* (in 1980). Washington State Department of Fisheries attempted to

[2] The first transplantation of *O. mykiss* in the watershed occurred in 1904, when steelhead fry were introduced into previously fishless Domke Lake above Lucerne. Then, in one of the first experiments on the fisheries of the Lake Chelan watershed, cutthroat trout were introduced into Domke Lake in 1908 and the resultant hybrids were considered "the best and gamest trout in the world". So in 1911, plans were made to install a hatchery substation to produce hybrids to stock around the state (Brown 1984).

[3] The year 1917 is usually cited, and Brown (1984) indicates the stocking may have occurred in 1916, but a newspaper account in 1920 quotes the State Fish Commissioner that it was "five or six years since we started planting" (Anon. 1920). Thus the introduction may have happened as early as 1914.

[4] Accurate WDFW stocking records do not exist prior to 1934, but brook trout were first introduced into eastern Washington in 1896 (USCFF 1898) and into other waters of Chelan County in 1913 (Anon. 1913), therefore probably were stocked into the Lake Chelan watershed much earlier than 1934.

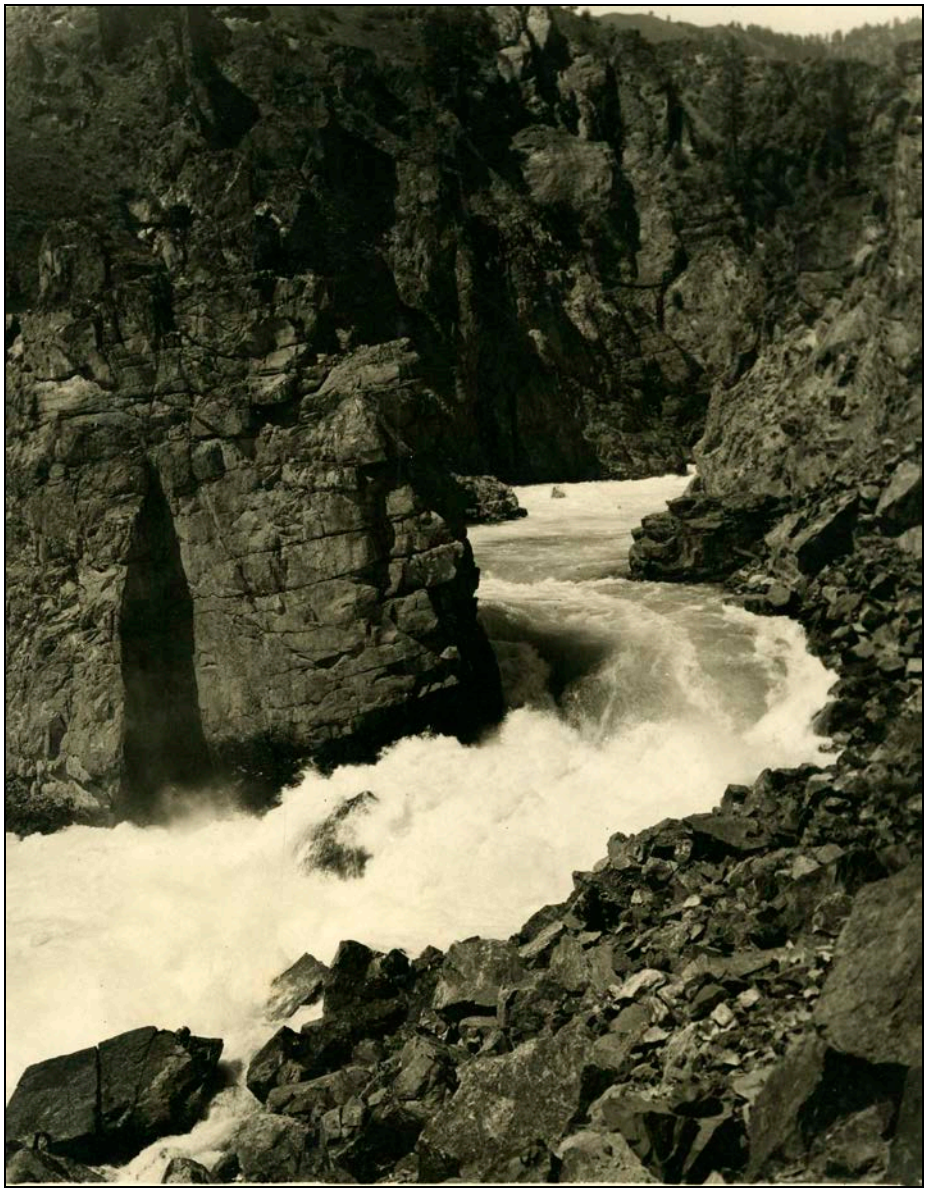

Figure 4. The Chelan River Gorge (photograph courtesy of Lake Chelan Historical Society).

establish a run of sockeye salmon *O. nerka* in Lake Chelan in the early 1950s when 100,400 fry were planted in 1952 (USFWS 1952a), 477 adults were planted in 1953 (USFWS 1953) and 862 adults and 50,900 fry were planted in 1954 (USFWS 1954)[5].

[5] I discovered the sockeye salmon introductions while researching this paper and am not aware of any other published records of this attempt. Thus, details of this program are scarce, but it appears from the Leavenworth NFH annual reports that adult sockeye salmon were trapped by WDF in the Rock Island Dam fish ladders and hauled to Lake Chelan in tank trucks loaned by the hatchery, who also supplied the fry. I suspect the plantings were a response by WDF to criticisms from local sportsmen's groups to "improve" the fishing, and although WDF had "urged the fishermen to be satisfied with keeping the lake a silver trout lake", they "promised to continue to experiment with Lake Chelan" (Anon. 1950).

Arctic grayling *Thymallus arcticus* were unintentionally planted in Lake Chelan in 1946 during an aborted attempt to aerially stock alpine lakes in the upper watershed (Anon. 1949). Dolly Varden *S. malma* obtained from coastal Alaska were planted in 1966 (Brown 1984). The plantings of these last three species apparently did not take and no adult sockeye salmon, grayling or Dolly Varden were later recorded.

A review of historical records indicated anadromous salmonids were not present in Lake Chelan prior to stocking (Hillman and Giorgi 2000). In addition, an analysis of potential barriers to anadromy concluded that several bedrock falls and cascades in the Chelan River Gorge are impassable to steelhead and therefore to all migratory fish (R2 Resource Consultants and Ichthyological Associates, Inc. 2000). Thus native fish populations in the lake were isolated in a unique ecosystem for several thousand years before it was altered by anthropogenic activities. This conclusion is supported by Chelan Indian legend accounts of the lake: "*When he came to the animal people along the Chelan River, he said to them, "I will send many salmon up your river if you will give me a nice young girl for my wife." But the Chelan people refused. They thought it was not proper for a young girl to marry anyone as old as Coyote. So Coyote angrily blocked up the canyon of the Chelan River with huge rocks and thus made a waterfall. The water dammed up behind the rocks and formed Lake Chelan. That is why there are no salmon in Lake Chelan to this day."* (Clark 1953); and *"Coyote noticed the very beautiful daughter of a Chelan chief fishing for salmon in Lake Chelan, so he decided to ask for her hand in marriage. When Coyote asked the girl's father if he could marry his daughter the chief refused in no uncertain terms. This so enraged Coyote, that he immediately threw huge boulders into the Chelan River. The boulders created rapids and falls that have ever since prevented the salmon from navigating upriver to the lake."* (Hackenmiller 1995).

Early Lake Chelan fisheries

Cutthroat trout- By all accounts, the cutthroat trout was the fish to catch in Lake Chelan and large numbers of big trout were taken (Leman 1969) (Figures 5 and 6). Early newspaper stories reported on the successful outings of local citizens as well as tourists who traveled long distances to fish the lake (Anon. 1891; Anon. 1893). Of the newspaper stories the most detailed was an account of a steam boat trip (Durham 1891), which described the great numbers of fish and the preferred technique of fishing at the mouths of tributary streams (*see also* Leman 1969). Commercial fisheries also exploited the abundance of native trout and began supplying markets in Waterville and Coulee City as well as resorts and hotels all around the lake (Durham 1891; Pershall 1959). Although cutthroat trout were the target of most fishermen, some bull trout were also caught (Figure 7).

Bull trout- Bull trout had enthusiasts and angling for them occurred primarily at the head of the lake (Figures 8 and 9) and in the Stehekin River (Figure 10). Most of what is known about fishing for bull trout came from two longtime local residents: Harry Buckner, an orchardist and rancher who moved to the Stehekin Valley in 1911, and Randy Morse, owner and operator of Camp Stehekin fishing resort (Morse 1957, Leman 1969; Buckner and Campbell 1974; Buckner and Campbell 1977; Brown 1984).

Figure 5. A display of ninety trout caught by six fishermen in Lake Chelan, December 11, 1906 (photograph courtesy of Lake Chelan Historical Society).

Figure 6. "Fishing on Lake Chelan" (L.D. Lindsley photograph #2067, courtesy of Lake Chelan Historical Society).

Figure 7. A day's catch of cutthroat trout (upper stringer) and bull trout (lower stringer- note light spots and white leading edge on ventral fins) from Lake Chelan (Dr. L.O. Bernard photograph courtesy of Lake Chelan Historical Society).

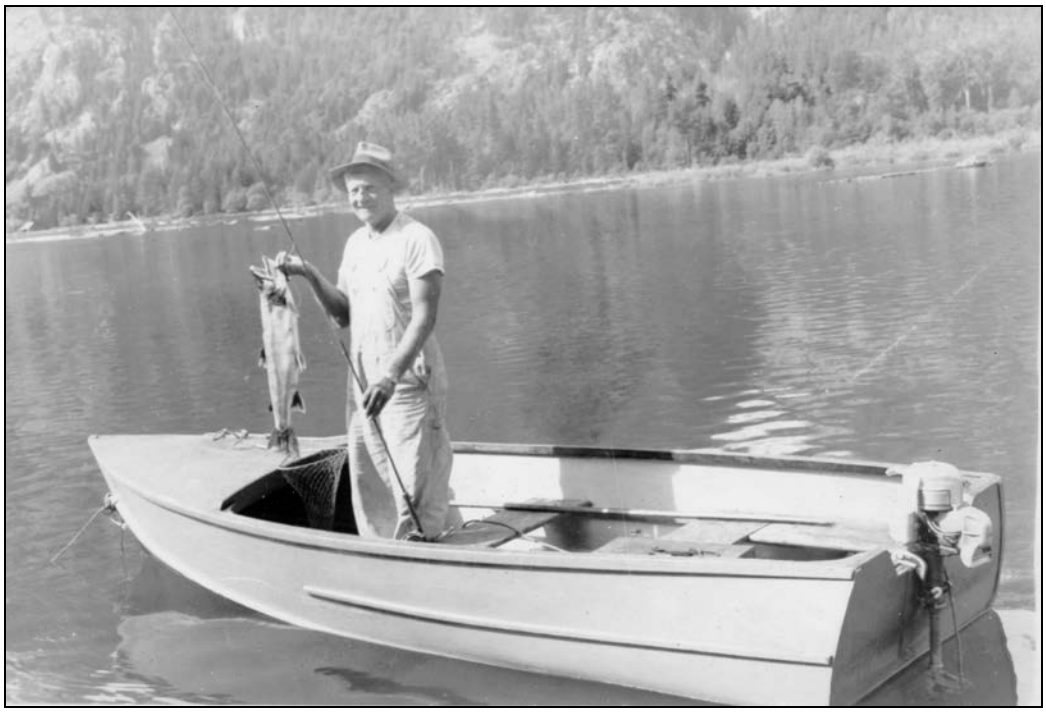

Figure 8. A bull trout caught in upper Lake Chelan 1948 (photograph courtesy of Lake Chelan Historical Society).

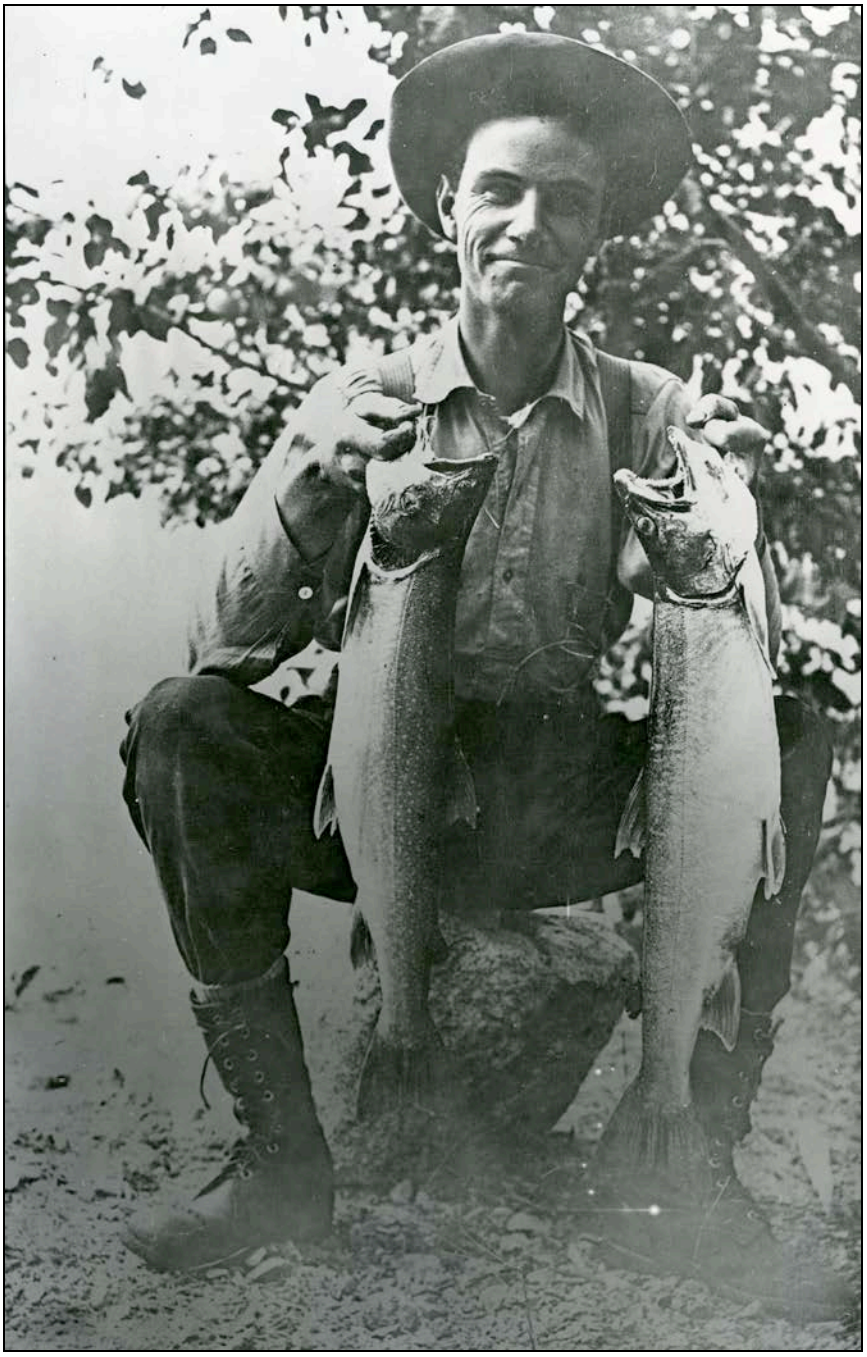

Figure 9. Two bull trout caught at the mouth of Lightning Creek (photograph courtesy of Lake Chelan Historical Society).

Figure 10. Mrs. J.K. Appleby of Seattle holding two large bull trout taken from the Stehekin River in 1910 (photograph courtesy of Lake Chelan Historical Society).

From their recollections it appears anglers targeted the spawning run, particularly at the famous Dolly Hole upstream of High Bridge at about river mile 11 on the Stehekin River (Buckner and Campbell 1977; Brown 1984) (Figures 11 – 13). Migratory bull trout congregated in this pool downstream of the waterfall (considered by Buckner to be impassable at low water due to his estimate of a 15 foot drop) and large numbers of big bull trout were taken by local anglers and tourists alike (Buckner and Campbell 1977; Brown 1984). Bull trout caught at the Dolly Hole averaged about 9 pounds and the largest was 18 pounds. Prior to the planting of kokanee, Buckner estimated that bull trout averaged only about 3 pounds (Buckner and Campbell 1977). However, other accounts written before the establishment of kokanee reported that bull trout caught in the lake weighed 10 to 12 pounds (Eaton 1917).

Kokanee- Washington State Fish Commission introduced kokanee into Lake Chelan around 1917 (Leman 1969) and by 1920 they were spawning in several tributaries (Anon. 1920), including the Stehekin River and Company Creek (Brown 1984). For the next sixty years, these "silver trout" as they were then called, were the mainstay of the Lake Chelan fishery and accounted for over 80% of the annual recreational fishery harvest (Brown 1984). Historical creel census data indicates kokanee populations have been erratic- the highest catch rates occurred in the mid 1940s and have crashed and rebounded several times since (Brown 1984; Keesee et al. 2009). Several coincident ecological events have been noted with these population cycles, such as major floods and fisheries management activities, including introduction of opossum shrimp (*Mysis relicta*) and Chinook salmon (Brown 1984), but the causes of the cycles are unclear.

Regulations and fisheries management

Historical fisheries management strategies had major impacts on bull trout populations. For many years bull trout were viewed as vermin and fishery managers treated them as competitors to be eliminated throughout their range. In 1914, Washington State Fish Commissioner L.H. Darwin decided that because "*Dolly Varden trout are one of the greatest enemies of young salmon*" they were exempted from the game laws of the state and could be sold[6] (Anon. 1914a). That same year the game fishing regulations specifically exempted "*Dolly Varden or Bull trout*" from the seasons and catch limits that were established for all other varieties of trout (Anon. 1914b). In 1921 the attitude towards bull trout was succinctly summarized by a Chelan County Game Commissioner: "*You sportsmen know what a dolly will do to a bunch of small fish and want to see the dollies all caught out. They are a worthless fish*" (Anon. 1921). In 1925 the state legislature defined the fishes considered to be "game fish" and Dolly Varden or bull trout were not included (Sec. 4, Chap 178, Ex. Session Laws, 1925 *as cited in* WDGGF 1926). By 1938, managers issued regulations that shortened the season for game fish but specifically stated that "*Dolly Varden may be taken throughout the year in Lake Wenatchee and Lake Chelan with no limit to the number taken*" (WDG 1938); this special regulation for the two lakes was in effect through at least the 1957 season (WDG 1957). In the 1970 season Dolly Varden were included as a game fish (WDG 1970) and in 1984, bull trout were finally added to the list in the annual fish pamphlet (WDG 1984).

[6] However, Dolly Varden or bull trout were never classified as food fish and regulated by the state as were other fishes that could be sold such as salmon.

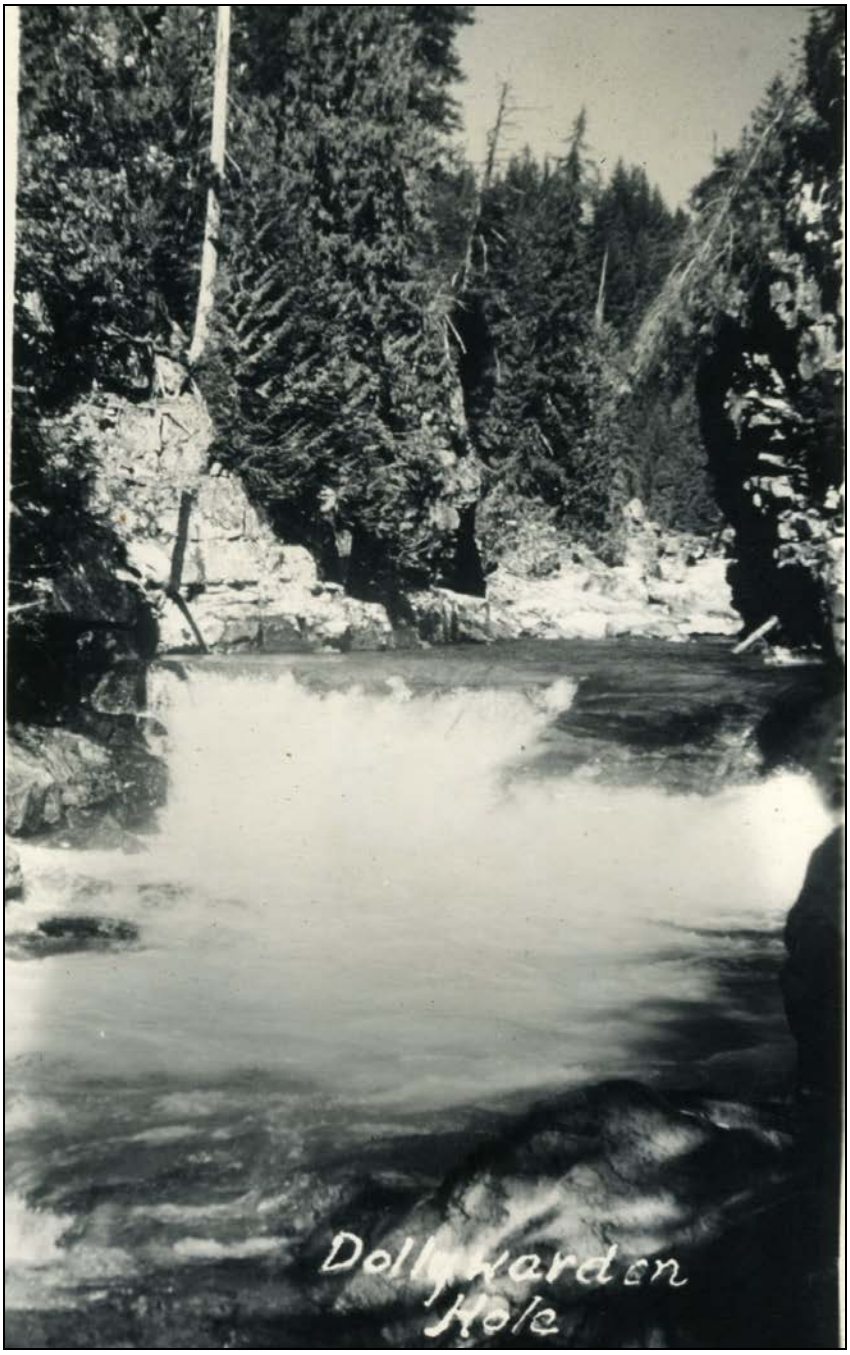

Figure 11. The "Dolly Varden Hole" on the Stehekin River (photograph courtesy of Lake Chelan Historical Society).[7]

[7] Note that this image is reversed in comparison to the Dolly Hole photograph in Figure 12.

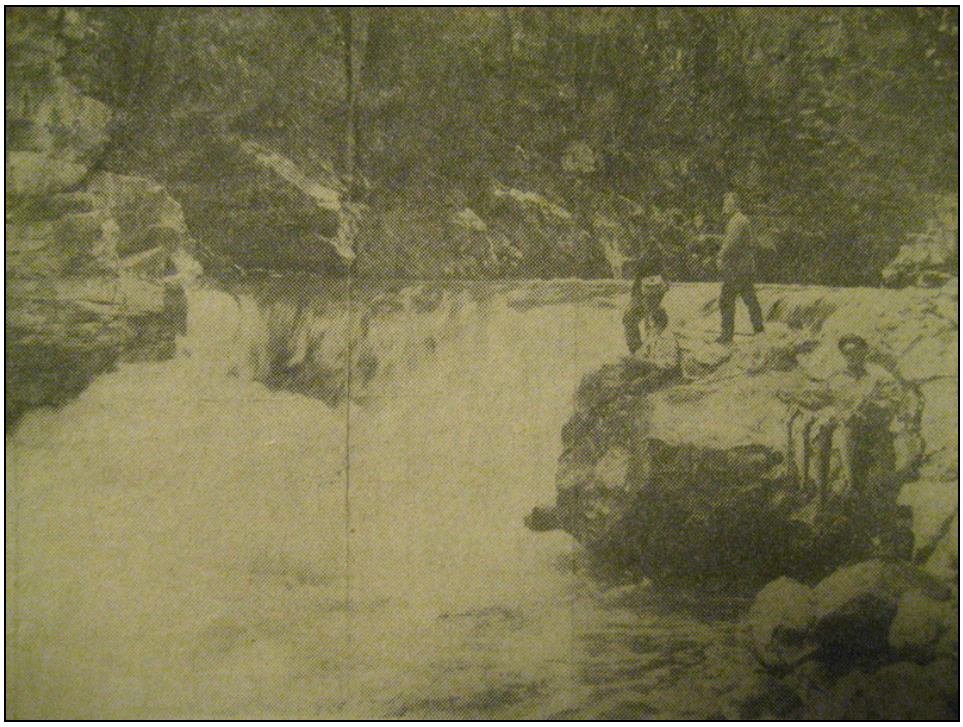

Figure 12. Original caption: "The Dolly hole of the Stehekin is rated one of the most famous fishing holes in the Pacific Northwest" (Photograph taken of clipping provided by Stan Morse from his family archive; newspaper unknown, ca. 1948).

Figure 13. Randy Morse, owner/operator of Camp Stehekin fishing resort, displaying a trophy bull trout he caught in the Dolly Hole, ca. 1948 (photograph courtesy of Stan Morse).

After bull trout disappeared from Lake Chelan, several accounts stated that, in general, overfishing had not been a problem (Leman 1969; Buckner and Campbell 1974; Brown 1984). From the very start of the fishery in Lake Chelan, however, observers issued warnings about the dangers of overfishing: *"Market fishermen are already at work supplying the Waterville and Coulee City markets. Some of the Chelan people flout the idea of the lake ever being fished out, but after the market fishermen have been at work for a few years they will think and talk quite differently. Here lies what will eventually prove one of the lake's greatest attractions, and it is to Chelan's interest to guard it in every possible manner."* (Durham 1891); and "*Last season seines, gillnets, setlines, and even explosives were used to capture fish in the lake and hundreds of pounds were shipped to market…This lake is no better home for trout than Coeur d'Alene or Pend Oreille were, but even at this early date fishing for trout in these waters is poorly rewarded even by the most skillful angler. It is true the lake is deep; so are the others, but the fish are not so numerous as one might suppose, and once the fish are caught and the game killed or scared away, the greatest attractions for the tourist are gone."* (Armstrong 1892).

In the early days of the fishery, there were no seasons or limits and large numbers of trout were routinely caught by sport and market fisherman in Lake Chelan (Figure 14). After regulations were established in Chelan County, for many years the fishing season was May 1 to December 31 and the legal limit was 50 trout per day (Anon. 1914b). In 1922 the bag limit was lowered to 25 fish per day (State of Washington 1922). By 1938, the limit was reduced to 20 fish per day and the season was shortened to October 31, but these limits were still not sustainable by modern management standards. In addition, by the 1940s, most of the fishing pressure was applied to kokanee and the high creel limits probably increased the susceptibility of bull trout to unintentional harvest (Wright 1992), which further impacted a bull trout population already under pressure of an open season. Bull trout are a slow growing species with late maturity, low fecundity and high catchability (Brown 1992) and have low sustainable levels of fishing effort and harvest. It may take decades for adfluvial bull trout populations to recover from over-fishing and only if unexploited (Post et al. 2003).

Of all the fishery management actions, hatchery operations and introduced fish probably had the greatest long-term impacts on the fish community of Lake Chelan. In 1902, the Washington Legislature appropriated money for a fish hatchery at Stehekin and it apparently began operations in 1903. The primary purpose of the hatchery was to trap cutthroat trout from the Stehekin River and ship the eggs and fry to other waters in Washington. With up to thirteen traps in operation at a time, the river essentially was treated as an egg factory and millions of eggs were shipped but few juveniles were returned to the lake. By 1927, the take of eggs, in conjunction with the ecological effects of introduced kokanee and overfishing, resulted in only 9 females caught (Brown 1984). The hatchery closed and the era of cutthroat trout ended. With the loss of cutthroat trout, the native fish community of Lake Chelan was forever altered by man. Fishery management then shifted totally towards hatchery-reared introduced species and from 1933 to 1951, 35.5 million kokanee and 2.2 million rainbow trout fry were planted in the Lake Chelan watershed, with unknown numbers planted prior to 1933 (Brown 1984).

Figure 14. Market fishermen, as evidenced by the large boat and packing boxes, with a day's catch of fish (photograph courtesy of Lake Chelan Historical Society).

Floods

In 1948, floods in the Columbia Basin were the most disastrous in the recorded history of the river at that time and property loss was conservatively estimated at $100,000,000 (Church and Schallert 1949). Prior to 1948, only the floods of 1876 and 1894 had higher discharge since record keeping began at The Dalles on the Columbia River in 1857. The 1948 floods were due to a deep snow pack in the mountains that was increased by an unusually cold and snowy April, a cold and rainy early May that saturated the snow-free soils at lower elevations, and a rapid increase in temperatures with warm wet air in late May that culminated in two very heavy rain on snow events (Church and Schallert 1949). The resultant flooding also struck the Stehekin River of Lake Chelan, when a discharge of 18,900 ft^3/s was recorded on May 29, 1948 (Figure 15). Flooding of the Stehekin River also occurred in the fall of the next year, when discharge was recorded at 18,400 ft^3/s on November 27, 1949 (Figure 15). Each of these floods was about 6,000 ft^3/s more than the previous high water discharge of 12,900 ft^3/s recorded on June 2, 1936. In 1950, the spring runoff was very high and matched this previous record.

The 1948 flood apparently washed out spawning gravels, shifted large boulders downstream, and reportedly destroyed a large portion of the spawning areas used by kokanee and trout in the Lake Chelan watershed (Leman 1969). In particular, the better gravels in the historical kokanee spawning areas of 25 Mile Creek and Company Creek

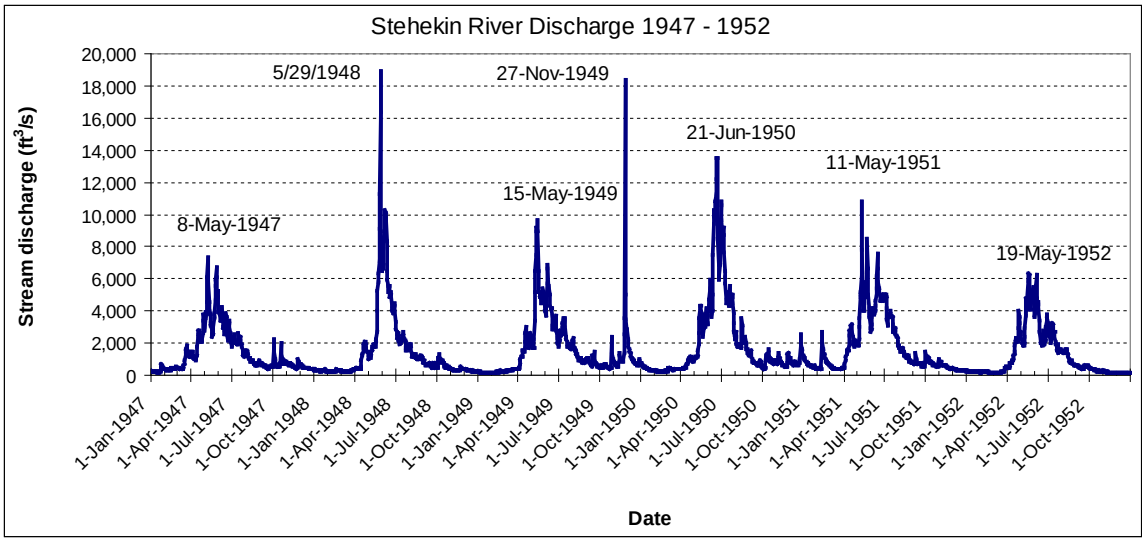

Figure 15. Stehekin River daily discharge, 1947 to 1952.

were reportedly scoured or covered with gravels too large for kokanee to utilize (Leman 1969). It has been suggested that the resultant lower populations of kokanee as well as presumed loss of bull trout spawning habitat were factors that contributed to the decline and disappearance of bull trout in Lake Chelan (Brown 1984). While flooding appears to be a plausible factor in the decline, it is unlikely that flooding alone was responsible, as the 1948 and 1949 floods occurred in all of the mid Columbia River tributaries without the disappearance of other populations of bull trout. Also, larger floods in the Columbia basin occurred in 1876 and 1894, but bull trout in Lake Chelan survived those events.

Flooding may have been merely coincidental with the decline of kokanee and bull trout in Lake Chelan and it is possible something else was actually responsible. In Lake Wenatchee, for example, fishing for kokanee was considered good through the spring of 1948 but after the flood in June of that year, the population apparently disappeared for an unknown reason and no fish were caught during the 1949 and 1950 seasons (USFWS 1952a). One could naturally conclude that the flood was the cause if not for the fact that in 1947, before the flood occurred, no kokanee were observed spawning and no redds were found during surveys in the Lake Wenatchee watershed, and it was not until 1952 that kokanee spawning was again documented (USFWS 1952a). Thus, another factor such as disease may have been involved.

Disease

Epizootic- Fishing for bull trout in Lake Chelan was considered by local anglers to be good until the late 1940s and early 1950s, when apparently an outbreak of a disease nearly wiped them out. Only two published accounts of the event exist- Randy Morse's recollection that was recorded in 1961 (Leman 1969; Brown 1984)[8] and Harry Buckner's

[8] Brown (1984) stated that Morse's description was written in a letter to Washington Department of Game in 1961, but I could not determine if that letter still exists. Leman (1969) recorded Morse's description and cited it in a footnote as "Morse, Randy. Personal notes, 1961." However, Stan Morse provided to me a fish planting chart his father maintained and in an entry for 1951, the bull trout die-off was noted (Morse 1957). Thus, there is an unpublished contemporaneous record of the event and may be the source Leman cited.

that was recorded in 1974 (Buckner and Campbell 1974). The timing of the mortality event differs between the two accounts; Morse stated it was the fall of 1951 while Buckner recalled that it occurred in late summer or fall of 1949[9]. Both men described sick and dying fish: *"They were seen in great numbers along the shores at Stehekin, covered with a grey fungus, sick and dying"* [Morse] and *"There were large ones floating around sick at the head of the lake, there were dead ones laying in the shallow water along the road there at the head of the lake. I had heard one of the game wardens remark that they probably had some- he named it fungus disease- but I don't know"* [Buckner]. Although fungus appears to be implicated in both accounts, the pathogen allegedly responsible for the mortality was never identified. Brown (1984) hypothesized that the unknown pathogen was introduced along with the many plantings of non-native fish into the lake.

Pathogens and epizootics occur in wild fish populations, but they are usually not documented or studied. In the summer of 1952, however, another apparent epizootic of an unknown origin occurred in wild Chinook salmon in the Entiat River, the adjacent watershed on the Columbia River downstream of the Chelan basin. As recorded by fishery research biologists at the Entiat Salmon Cultural Laboratory, *"During the forepart of August a tremendous mortality was observed in the wild chinook fingerling in the river. Every eddy and shoal area in the stream contained dead and dying fish. When it is considered that moribund fish fall easy prey to predators the mortality must have been terrific. Examination of these fish disclosed an infection with a stalked, ciliated protozoan. Colonies of these protozoans were found on all fish examined but the incidence of infection varied from light to extremely heavy. In view of the fact that all fish examined were moribund and the incidence of the stalked ciliate infection was so variable it is doubtful if this organism was responsible for the epidemic. No other animal parasites were found. In view of the fact that large eroded areas were visible on the surface of the fish without any animal parasites it is believed that the primary invader was a bacterial infection and the ciliate was a secondary infection"* (USFWS 1952b). This episode supports the contention that bull trout in Lake Chelan also suffered a large outbreak of an epizootic and illustrates the difficulty in determining the cause, even for trained fishery biologists, who could only speculate it was bacterial. In fact, many of the fish diseases were initially baffling to early fish biologists when they first encountered them.

Possible candidate pathogens- By the early 1950s the study of fish disease in the United States was rapidly developing but there were few trained fish pathologists (Lagler 1956). Most of what was known about fish diseases was learned from fish culture where early investigations of infectious diseases in trout had identified several etiological agents

[9] Buckner associated his memory of the die-off with a specific event: "*these Dollys disappeared before the flood of '49, which we had at Stehekin but nobody else knows much about*" (Buckner and Campbell 1974). This flood occurred in November 1949. However, I could not find any written documentation or contemporaneous newspaper accounts to corroborate Buckner's date. Morse, on the other hand, recorded his observation in 1951 "*Nov.-Dec.- Dolly Varden in great numbers appeared at Stehekin along shores and apparently sick*" (Morse 1957). It is possible there were die-offs in two separate years, with each man describing a different one, or perhaps the passage of time clouded Buckner's memory of the timing of the event when he recalled it 25 years later.

including trematodes, fungi, protozoa, and bacteria (Davis 1946). Contemporaneous annual reports of the federal salmon facilities comprising the Grand Coulee Fish Maintenance Project indicate that diseases present in local hatcheries at this time included bacterial gill disease, bacterial kidney disease, columnaris, costiasis, furunculosis, ichthyophthiriasis, octomitiasis, saprolegniasis, and sockeye salmon disease[10]. Of these possible candidates, several lines of evidence indicate that sockeye salmon disease (now known as IHN) was most likely the cause of the bull trout die-off that was observed in Lake Chelan. Before that case can be made, however, a review of the disease is required.

Infectious hematopoietic necrosis (IHN)- Sockeye salmon disease was first recognized in 1951 (Rucker et al. 1953). Initially the etiological agent was thought to be bacterial but during a series of experiments the agent was demonstrated to be a virus (Watson et al. 1954). After similar hemorrhagic viral diseases were reported in other species of salmon, all were renamed as infectious hematopoietic necrosis in 1970 (Post 1987). Outbreaks of the disease apparently occurred in hatcheries for several years before it was recognized, in part because viral diseases of fishes were largely unknown at the time. Several times during the 1940s, very high mortality was noted among the juvenile kokanee and sockeye salmon but all efforts to treat with therapeutants were ineffective (USFWS 1947). The mortality outbreaks so mystified biologists that they could only speculate it was due to anemia or a bad supply of beef liver in the fish feed (USFWS 1947). Interestingly, their hunches were somewhat on the right track, for eventually it was discovered that the virus was spread in the feed, which contained infected salmon by-product supplied by canneries. At that time the fish feed used in hatcheries contained unpasteurized viscera from sockeye salmon and pink salmon or eggs from Chinook salmon and chum salmon caught in waters of Alaska, British Columbia, or Washington (Watson et al. 1954).

IHN is an acute to subacute hemorrhagic disease caused by a rhabdovirus that replicates in the cytoplasm of the infected cell. The hematopoietic tissue of the spleen and anterior kidney is primarily infected, but other tissues of the body are targeted as the disease progresses (Post 1987). Descriptions of the progression of the disease noted hemorrhagic and eroded areas on the body, usually at the base of the fins (Watson et al. 1954). Before the cause of the disease was identified, hatchery reports commented on a fungus growth on various parts of the body on some of the infected fish (USFWS 1949; USFWS 1950).

The major routes of transmission are oral and by contact either direct or through flowing water (Post 1987). Fish feeding on infected fish can develop the disease (Yasutake and Amend 1972) and the IHN virus (IHNV) can be shed in the urine and feces (Post 1987). Studies on transmission determined direct contact to be more efficient than indirect contact through infected water, but mortality levels in either case were between 70 and

[10] These reports are the only ones currently available to me for review so it must be emphasized that the diseases were not unique to those facilities. Their reports, however, often contained detailed descriptions of the problems encountered because fish pathologists on staff at the Western Regional Office of the Division of Hatcheries in Seattle were routinely consulted on issues of nutrition and disease. Several other federal and state hatcheries were in operation at the time and eggs and fry of several salmonines were constantly shipped between hatcheries across the region. All hatcheries essentially employed the same techniques of fish culture and received fish feed from the same suppliers. There is no evidence that any one facility was to blame for an epizootic.

90% within 30 days (Watson et al. 1954). In addition to the gills and skin, modern research techniques indicate that the fin bases are a major point of entry of the virus (Harmache et al. 2006). Fish can carry IHNV asymptomatically and the disease can be transmitted from parent to offspring, presumably as egg-associated virus (Amend 1976). IHNV has been found in ovarian fluid, eggs, and milt of carrier brood fish, resulting in its unintentional spread over long distances during fish culture activities (Post 1987).

Morbidity levels among susceptible fishes may reach 100% during epizootics of IHN, with 50% mortality occurring within the first two weeks (Post 1987). During the early outbreaks in the hatcheries it was noted that mortality peaked in the spring and again in the fall, with very little mortality during summer and winter. Subsequent studies showed that IHNV does not survive at relatively high water temperatures and the optimum epizootic potential is at about 10-12°C (Amend 1976). It is thought the disease generally does not occur naturally above 15°C (Post 1987) though it can occur at higher temperatures depending on water quality and other factors. During IHN epizootics mortality rates are observed to be highest among early juveniles, including fry while still in the redd (Post 1987), but even adults are susceptible to the disease (Arkush et al. 2004). Juveniles and adults that survive the infection generally clear the virus, but a small proportion of fish may become carriers of the virus for some period of time (G. Kurath, USGS, pers. comm.). The existence of a life-long carrier state is uncertain and may differ for different host species of fish. There are no treatments for IHN.

The susceptibility of salmonids to IHN varies with geography and the phylogenetics of the virus. IHNV is native to the Pacific Northwest, and research has identified three distinct genogroups: the U clade of the Columbia River basin, coastal Washington and Oregon, Alaska and British Columbia; the M clade of the Snake River and lower Columbia River basins; and the L clade of southern coastal Oregon and California (Kurath et al. 2003). Although both U and M clades infect multiple species in the Columbia River basin, wild populations of sockeye salmon, kokanee, and Chinook salmon are primarily infected with the U clade, while steelhead, rainbow trout, and cutthroat trout are primarily infected with the M clade (Garver et al. 2003). Other fish experimentally infected with IHNV that showed subsequent mortality include brook trout (Bootland et al.1994), Arctic char *Salvelinus alpinus* (McAllister et al. 2000), and burbot (Polinski et al. 2010).

Evidence implicating IHNV- Several lines of evidence implicate IHNV as the pathogen most likely responsible for the bull trout mortalities observed in Lake Chelan in the late 1940s or early 1950s. This evidence includes the timing and season of the outbreaks, shared sources of contaminated feed, transfers of susceptible fish between several hatcheries with known IHN outbreaks and subsequent plantings of these fish, routes of transmission from planted fish to bull trout, virulence of the disease, and known susceptibility of other char species.

1) Timing- IHN was first identified in the Grand Coulee Fish Maintenance Hatcheries in 1951 (Rucker et al. 1953) and unidentified disease outbreaks with similar etiology were reported in their annual reports since at least 1947 (USFWS

1947). It is probable that for several years infected fish were stocked without realizing the virus was being inadvertently spread. Morse recalled that bull trout mortalities in Lake Chelan occurred in 1951 while Buckner remembered the year as 1949, thus the emergence of IHN in Columbia River salmon hatcheries coincides with the timing of the bull trout mortalities observed in Lake Chelan.

2) Seasonality- IHN outbreaks occur during periods of cold water, mostly in the spring and fall. Morse and Buckner both state the die-off in Lake Chelan happened in the fall. Other diseases such as columnaris and furunculosis can result in high mortality rates and were present in the mid Columbia hatcheries in the 1940s and 50s, but these are generally warm-water diseases and highest mortality occurs in the summer. Fungal diseases such as saprolegniasis are secondary to other infections and there are apparently no primary cases among fishes (Post 1987)
3) Carrier fish- IHN was first identified in sockeye salmon and kokanee during the initial outbreaks in the hatcheries. Unpasteurized fish meal and salmon viscera were added to the production feed in the hatcheries during 1941 and the formulation was modified in 1944 (USFWS 1944). The contaminated viscera used in all mid Columbia hatcheries came from common cannery suppliers and the feed was processed and stored in the freezer locker at Leavenworth NFH before distribution to both federal and state hatcheries (USFWS 1951). Millions of kokanee from several sources were planted in Lake Chelan during the late 1940s and many were first transferred to and reared at the Chelan hatchery prior to stocking. From 1952 through 1954 sockeye salmon adults and fry were planted in the lake by the state of Washington. In addition to infected fish that were planted during the beginning of outbreaks, some of the kokanee that survived the disease in the hatcheries may have been carriers when they were later released.
4) Routes of transmission- There were several probable transmission routes of the disease in the Lake Chelan watershed. These include bull trout feeding on infected kokanee fry that were planted in the lake; contaminated water flowing from kokanee spawning tributaries; overlap of spawning sites with imposition of redds; and bull trout feeding on infected kokanee eggs. As a result the virus could have been transmitted to all stages of bull trout, including eggs and fry in the redd, emergent fry, juveniles rearing and feeding in the tributary, and feeding or spawning adults. Kokanee were present in the mainstem Stehekin River upstream to the Dolly Hole (Buckner and Campbell 1974) and their major spawning areas were in tributaries of the lower Stehekin River- thus during concurrent migration and spawning of both species, bull trout would have been exposed to IHN over a large area of the watershed during the fall.
5) Virulence- The morbidity levels of IHN are very high and can approach 100% mortality of infected fish. Although not well understood, it is possible that individual fish that survive the infection may become carriers. Infected adults can pass the virus to offspring through eggs and milt as well as shedding the virus into the water column. Therefore, mortalities may have occurred for a considerable period after the devastating initial outbreak of the disease in Lake Chelan.
6) No resistance- IHN is an anadromous fish disease that the isolated bull trout in Lake Chelan would have never encountered prior to stocking of kokanee and

therefore could not have developed any resistance to the disease. In general, fish populations which have had no previous contact with a pathogen are frequently more susceptible than fish in regions where the pathogen is endemic (Rohovec et al. 1988).

7) Susceptibility- To date IHN has not been documented in wild populations of bull trout, but it is known to be virulent in other species of charr including brook trout and arctic char (Bootland et al.1994; McAllister et al. 2000).

These lines of reasoning support the hypothesis that IHN was most likely the cause of the die-off of bull trout observed in Lake Chelan. Although highly plausible, it is a circumstantial case without direct or indisputable evidence. However, the two bull trout collected in the Stehekin River in 1957 are archived at Oregon State University[11] and may hold some additional clues. Although preserved in formalin, a method unfavorable to preserving viral RNA, the specimens should be examined for signs of IHN.

The spread of any disease in a fish population is dynamic and the prevalence and impact depend upon complex interactions between the host, pathogen and the environment (LaPatra 1998; Reno 1998). Ultimately, the case for IHN depends on the susceptibility of bull trout and controlled laboratory studies are needed. To date, only one project has experimented on bull trout and although some of the exposed fish died of the disease, that unpublished study found them relatively resistant to the virus unless weakened or stressed by factors including other diseases (Engelking 2003). During the 1940s and 50s, bacterial kidney disease (BKD) was prevalent in sockeye salmon and kokanee during the initial outbreaks of IHN at the hatcheries (Rucker et al. 1953) and was likely also introduced into Lake Chelan. Bull trout are weakened by BKD (Jones and Moffitt 2004) and the stress may have increased their susceptibility to IHN.

Susceptibility tests can be difficult to interpret and negative tests are not necessarily conclusive, particularly given the complex host specificity and virulence of the various IHNV clades (as well as strains within clades). For example, experimental exposure of sockeye salmon to U clade IHNV strains results in high mortality, while exposure to M clade strains causes no disease (Garver et al. 2006). Studies conducted in the early 1950s with the IHNV strain obtained from dying sockeye salmon found that it did not cause disease in either Chinook salmon or rainbow trout (Watson et al. 1954). However, evidence suggests IHNV is capable of adapting to new hosts by mutation. Thus, the M clade is hypothesized to have arisen by adaptation to high virulence in rainbow trout (Troyer and Kurath 2003). Therefore, challenge tests for bull trout conducted with the modern isolates of IHNV may not be comparable to the original form that may have been introduced into Lake Chelan and experiments may not conclusively settle the matter. It would be ideal to use the original strain of IHNV from the first outbreaks, but that genetic isolate was not preserved.

[11] These bull trout were caught by a graduate student from OSU (Tschirley 1958) who gifted them to the museum (specimen no. OS 2803 still labeled under old identification of *S. malma*). Both are small (215 and 244 mm) and may have initially been fixed in 10% formalin and then initially preserved in 36.5% isopropanol (D. Markle, OSU, pers. comm.). Although they are in fair condition and are still soft, there may only be a slight chance of extracting genetic material (B. Sidlauskas, OSU, pers. comm.).

If experiments are conducted on bull trout to test the IHNV hypothesis, it would be vital to use fish from a population that has never been exposed to anadromous fish, such as the resident bull trout population upstream of the waterfall barrier in Early Winters Creek. This population is located in the Methow subbasin and its headwaters arise on the opposite side of Rainy Pass and the headwaters of Bridge Creek and the Stehekin River. The Early Winters Creek resident population may have been isolated almost as long as Lake Chelan bull trout and may also be the closest genetic relative to that lost population.

Periodic crashes of kokanee populations have occurred in the lake after the 1950s, including during the 1960s, 1980s, and the 2000s (Brown 1984; Keesee et al. 2009). These are usually attributed to ecological factors or flooding, but IHN may also have been a contributing factor. Although it is now standard hatchery procedure to conduct fish health screenings prior to stocking fish, most wild populations of fish have not been tested for diseases in Lake Chelan. Therefore, intensive fish health surveys should be conducted to determine if IHNV (or other disease) is present in kokanee and other fish in the lake. Because survivors can clear the virus, it may also be useful to look for antibodies in the blood serum of sampled fish (G. Kurath, USGS, pers. comm.).

Ecology and geology

Ecosystems consist of complex relations with cascading effects and synergistic interactions between biotic and abiotic elements. Ecology and geology did not cause the extirpation of bull trout in Lake Chelan, but they were factors in the loss. The geologic isolation of Lake Chelan increased the population's vulnerability to stochastic and catastrophic events. Without connectivity to the rest of the mid-Columbia basin, there were no refugia from disease or environmental changes and there was no chance of a re-colonization from other bull trout populations immigrating into the lake. Geology limited the number and size of spawning areas available to adfluvial bull trout, as most of the tributaries have steep gradients with only short reaches near the mouth accessible to migratory fish (Brown 1984; BioAnalysts, Inc. 2000; Archibald 2002). There is very little rearing habitat in these lower reaches and if bull trout did spawn in them, most if not all of the age 0 fry would have to disperse to the lake where they likely would not survive (Downs et al. 2006). Most of Railroad Creek is inaccessible to adfluvial fish due to waterfall barriers in the lower river (Archibald 2002; Kelly-Ringel 2004) and within the upper Stehekin River drainage, there are several waterfall barriers to migration and only native cutthroat trout and introduced rainbow trout are found upstream (Ostberg and Rodriguez 2006). Harry Buckner thought that the Dolly Hole waterfall was a migration barrier to bull trout and it may be that spawning only occurred downstream in the mainstem Stehekin River. However, if the waterfall was not a barrier, successful passage at waterfall obstacles is dependent upon large size of bull trout and low stream discharge (Nelson and Nelle 2008). Fishing pressure at the Dolly Hole was highest during the spawning run and targeted the bull trout congregated below the falls as they waited for the flows to decline; thus the large bull trout most able to pass above the falls were likely removed from the population and most of the spawning would have had to occur downstream. Flooding then occurred for several consecutive years and may have reduced survival and recruitment of several year classes of bull trout. Therefore, at the time of the

epidemic, it is likely that the bull trout population in Lake Chelan was relatively small and mostly concentrated in the lower Stehekin River.

As a small population declines, the term “extinction vortex” has been used to describe the theoretical interactions and mutual reinforcement between biotic and abiotic forces that can drive population size downward to extinction (Gilpin and Soulé 1986). An investigation of actual extinction dynamics found that time-to-extinction decreased logarithmically as a function of population size and that both year-to-year rates of decline and variability increased as time-to-extinction decreased (Fagan and Holmes 2006). Of the 10 extinction-bound vertebrate populations in that study, increases in abundance were never observed in four populations once the effective population size dropped below 50 individuals, but in two populations increases were observed even with fewer than 10 individuals; However, those increases were short-lived and the dynamics of all the populations deteriorated as extinction approached.

The final decline of bull trout in Lake Chelan was documented by Randy Morse (1957) and his notes provide a glimpse of an extinction vortex in action (Table 1). The last bull trout recorded in WDFW creel surveys was caught in 1957 (Brown 1984). Perhaps fittingly, what may have been the last bull trout caught in the Stehekin River was landed by Morse’s son Stan: a 6 incher he remembers angling as a young boy in 1959 (S. Morse, pers. comm.). By 1960, bull trout had forever disappeared from Lake Chelan.

Table 1. Excerpt from notes section in Randy Morse's chart of fish plantings (Morse 1957), detailing decline of “Dolly Varden” (bull trout) in Lake Chelan from 1951 to 1957.

Year	Special Notes
1951	*Nov.-Dec. – Dolly Varden in great numbers appeared at Stehekin along shores and apparently sick. 3-spine stickle back have been seen in considerable numbers at Stehekin*
1952	*About 5 lg. Dolly Varden caught this year. Lots of 6" to 8" Dolly’s (very unusual). Only one marked rainbow has been checked in at Camp Stehekin.*
1953	*No lg. Dolly’s. Few 6" to 8" Dolly’s. Few 1 lb. to 1½ lb. Dolly’s. Very few silvers – ave 11". Very few lg. suckers or chubs*
1954	*<u>Very</u> <u>Few</u> Dolly’s of all sizes. No lg. suckers or chubs at Stehekin. Very few silvers – 12" to 14" average. Few ling cod “very thin” caught at Lucerne*
1955	*Ling cod reported gone from Lucerne. Lots of peamouth 10" chub at Stehekin. 6 Dollys caught 3 to 5 lb.*
1956	*No basis for 1954 & 1955 ling cod reports. Ling cod caught / 2½" shrimp in tummy. Stehekin ran out of silvers – very few spawners reported in Stehekin River. 5 Dollys caught 3 to 5 lb.*
1957	[Blank- no entry]

Prior to anthropogenic activities, the ecology of the isolated native community of fishes in Lake Chelan existed in relative harmony. Once the system was altered, however, it was vulnerable to unpredictable fluctuations. Overfishing was the first activity that changed the system, but after the loss of the lacustrine population of the native westslope cutthroat trout, hatchery stocking of non-native fish was the major factor that forever tilted the balance. As each new species was planted, the aquatic community became more unstable. The fate of bull trout irrevocably intertwined with introduced kokanee, which became a source of food and probably disease. The introduction of rainbow trout contributed to the decline of riverine westslope cutthroat trout but also further impacted bull trout by competitive interactions, particularly in streams where bull trout may have existed above waterfall barriers. Eastern brook trout fill the same niche in streams as bull trout and compete for the same resources of food, space, and spawning areas with the additional threat of hybridization. In addition, Lake Chelan has been a "dumping grounds" to get rid of excess or inferior hatchery fish (Brown 1984) and it is not known how many other fish diseases may have been introduced into the lake. Finally, the introduction of opossum shrimp in 1968 (Leman 1969) and lake trout in 1980 permanently changed the trophic dynamics of the ecosystem (see Rieman and Falter 1981; Stafford et al. 2002) and will complicate, if not preclude, the re-establishment of bull trout in the lake (see Donald and Alger 1993).

Although the exact cause of the bull trout die-off may never be known with absolute certainty, the extirpation was clearly related to the management of the fisheries of Lake Chelan. From the beginning there is history of managers who acted without understanding the ecological limits inherent in an ultraoligotrophic lake and then failed to learn from the past. Instead, a constant desire to "improve" the lake resulted in actions that were short-sighted with narrow and selfish goals in mind. One historic management objective was to eliminate bull trout from Lake Chelan and in retrospect we should not be surprised that it happened. With the lake ecosystem now so altered, including the introduction of several new species since bull trout were lost, the question is: If we were to restore bull trout to the lake, could we prevent them from disappearing again?

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Stan Morse graciously provided the photograph of his father holding the Dolly Hole bull trout, the old newspaper clipping of the anglers at the Dolly Hole, and his father's chart of fish plantings and fishing observations in Lake Chelan. Visiting with Stan and hearing his family's history at their resort Camp Stehekin put a human face on this story. While the loss of bull trout from the lake was an ecological tragedy, it was also a sad ending to Randy Morse's fishing resort, which he promoted based on trophy bull trout in the lake.

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