An Analysis of the Columbia and Snake River Anadromous Fish Runs

by

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Introduction

The history of the Columbia and Snake River anadromous fish runs since the first dams were built on these rivers is of significant interest to policy makers in the Pacific Northwest. The records of the fish passage have a story of their own to tell, and this paper attempts to shed some light on what has happened since the first dam was built and made operational in 1938. The focus of this study is directed toward the eight dams built on the Columbia River and Snake rivers between 1938 and 1975. The fish run records evaluated extend from 1938 to 1994. The study is divided into three parts. The first part deals with the impact of the Columbia River dams on fish runs. The second part deals with the impact of the Snake River dams on fish runs. And, the third part deals with the overall results of dam construction on these fish runs.

The construction of the first dams built on the Columbia river by the U.S. Army Corps of Engineers was begun in the mid 1930's. This was the Bonneville Dam located on the lower Columbia River approximately 60 miles east of Portland, Oregon. Dam construction continued from the 1930's until the late 1960's when the John Day Dam on the Columbia River was completed. Dam construction was begun in the late 1950's on the Snake River and continued until 1975 when Lower Granite Dam was completed. In all there are four major dams on the Columbia River down stream from the mouth of the Snake River, and there are four dams on the Snake River down stream from Lewiston Idaho. All of the anadromous fish spawning in Idaho, eastern Oregon, and eastern Washington must pass these dams to reach their spawning redds.

The history of the dam construction can be read as a series of hurdles which these fish must over come in order to ensure the survival of their species. Not all of the dams were put in place at the same time. As the dams were constructed 85 fish hatcheries and satellite facilities have also been built and operated as mitigation for the impact which the dams would have on these anadromous fisheries. Nine of these fish hatcheries are operated by the Idaho Fish and Game Department, 29 by the Oregon Department of Fish and Wildlife, 14 by the US Fish and Wildlife Service, 16 by the Washington Department of Fisheries, and 17 by the Washington Department of Wildlife. From the very beginning, it was known that the dams would have a negative impact on the Columbia River anadromous fisheries. In addition to the fish hatcheries, various other systems have been added to aid in upstream and downstream fish passage over the years. Fish ladders were added to each dam during construction. Later when problems emerged for down

stream migrants traveling screens were added to divert the fish away from the turbines. Flip lips were added to the dams to prevent the deep plunging of water which entraps nitrogen and causes a form of bends in smolts as they pass the dams. Eventually, barging was also added to the mix and smolts were barged from Lower Granite Dam to below Bonneville Dam where they were released. All of these practices and the new ones now being offered as solutions to the problems of the anadromous fisheries are all forms of mitigation for losses which have been known about since the first dam was built on the main stem of the Columbia River.

To demonstrate the impact of these dams over time it is necessary to chart the history of fish passage since the first dam was built. Several simple analytical techniques were used in this study. The first was a charting of the actual fish runs. Second, the average fish run for the period between the time the initial dam was built and the next dam was built was calculated, and so on for each of the dams on the Columbia and Snake rivers. Lastly a trend line was fitted to the data. The initial starting point for the Columbia River analysis was in 1938 when Bonneville Dam was made operational. The starting point for the Snake River was 1962 when Ice Harbor Dam was made operational. Finally, the fish runs evaluated in this study are: 1) chinook salmon, sockeye salmon, and steelhead trout.

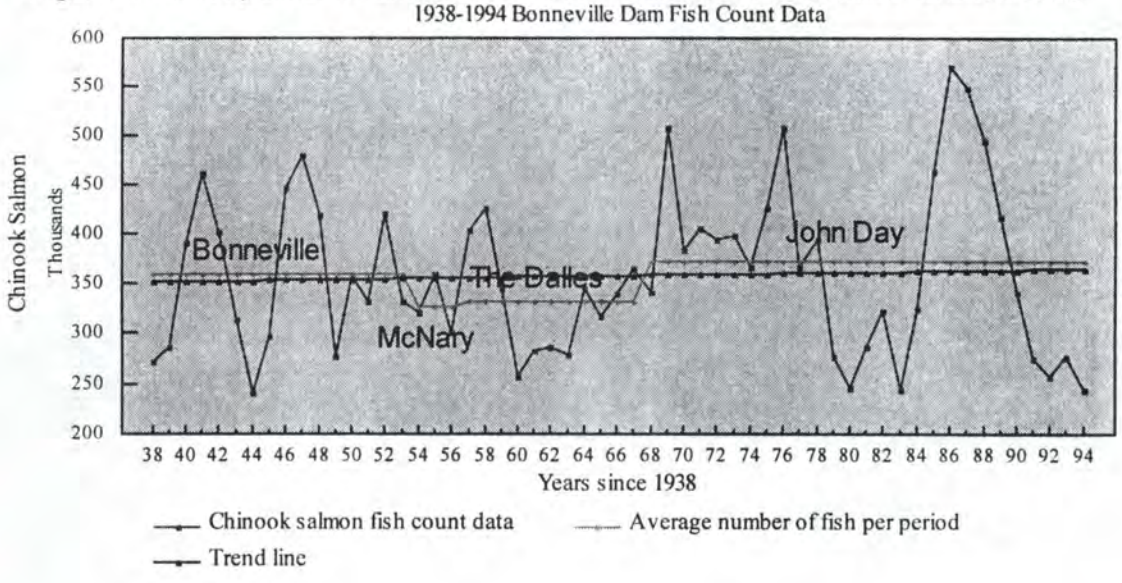
The U.S. Army Corps of Engineers has maintained fish ladders and counting facilities at all its dams on the Columbia and Snake rivers since they were first constructed. The actual fish counting is done by the Washington Department of Fisheries under contract to the U.S. Army Corps of Engineers. An annual publication entitled "Annual Fish Passage Report" is published in the spring of the current year. These reports are the source of the information used in this analysis.

Fish Passage

Chinook Salmon:

Looking at the Columbia River experience first, the chinook salmon fish passage at Bonneville Dam is used to chart the health of the fishery. Figure 1 shows what has happened between 1938 and 1994 to the chinook salmon. The variability of the annual fish runs is evident in this chart, and will also be seen in every other chart presented in this paper. The second curve plotted is the average runs over the time period before the next dam was built on the lower Columbia River. This charts the impact of dam construction on the fish runs. The third line is the estimated trend line for the chinook salmon fish runs on the lower Columbia River.

Figure 1. The Impact of Columbia River Dam Construction on Chinook Salmon Runs



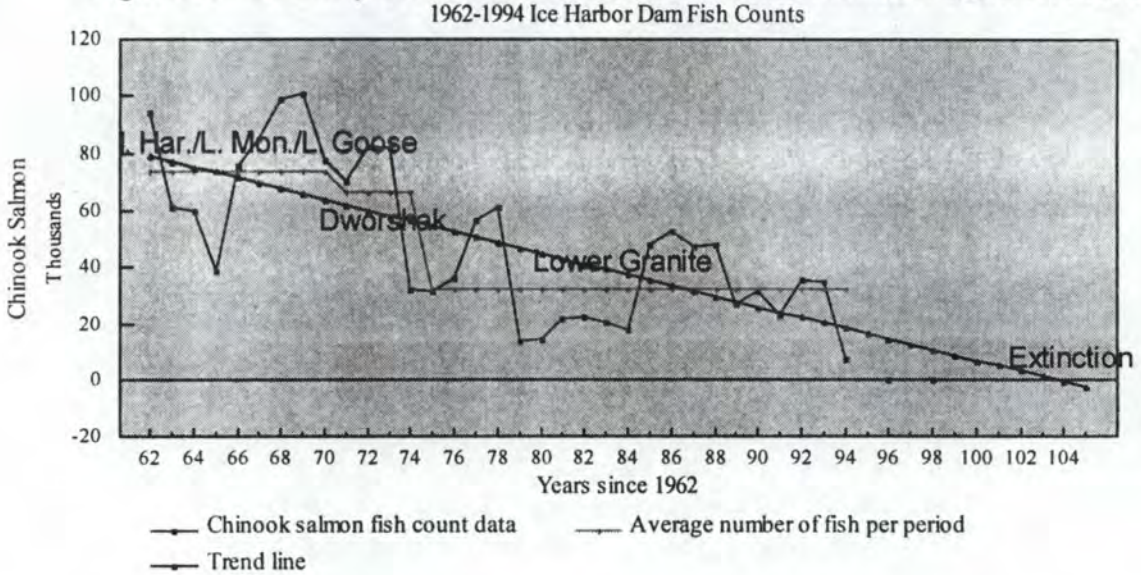
The obvious conclusion is that the chinook runs at Bonneville Dam have maintained themselves at approximately the same level as when they were first counted in 1938. In fact the trend line indicates that the chinook as a whole have tended to increase slightly over the 54 years that the dams have been in place. The questions that need to be answered are, 1) how was this done, and 2) what has been the impact on the overall fishery? To answer the first of these questions one has to look beyond the fish runs themselves, and at the hatchery activity which has also developed over the years. The percentage of hatchery fish compared to wild fish has increased over the years. It is clear that the hatchery fish have been the mainstay in maintaining the chinook salmon runs since 1938. The second question is more complicated in that one needs to look at the three sub species to see if there is a difference in their responses to dam construction. It is clear that summer and spring chinook have not done as well as the fall chinook under the dam regime. But again much of the loss of spawning has been offset by the hatcheries.

It is interesting to look at the impact of the individual dams on fish passage. The average fish passage between 1938 and 1953 counted at Bonneville dam was approximately 360,000 fish annually. When McNary Dam was added to the system in 1954 the average fish passage dropped to about 327,000 fish for the next three years until The Dalles Dam was added to the system. When The Dalles Dam was added to the system the fish passage actually showed an increase to approximately 331,000 fish for the next 13 years. When John Day was added to the system the average fish passage again increased to approximately 373,000 fish annually. The increases in fish passage correlate closely with the construction and operation of fish hatcheries in the Columbia basin. The impact of

dam construction on the chinook salmon seems to be minor according to the fish passage data. However, the chinook fish passage data do not tell the whole story.

On the lower Snake River the chinook salmon runs have not fared as well as they have on the lower Columbia River. This is clearly show in figure 2. It is

Figure 2. The Impact of Dam Construction on Chinook Salmon Runs



clear that the chinook salmon runs on the lower Snake River are in serious decline. This is shown by all of the curves fitted to the fish passage data. The decline shows up most clearly in the trend line fitted to the data. However it is also clearly shown in the average runs between the periods when dams where being built. Finally, if the decline in chinook salmon runs continues, the last fish will pass over Ice Harbor Dam in the year 2004. Of course one needs to take this date with a grain of salt. But what the trend analysis does indicate is that the chinook salmon are in serious danger of becoming extinct sometime in the twenty first century.

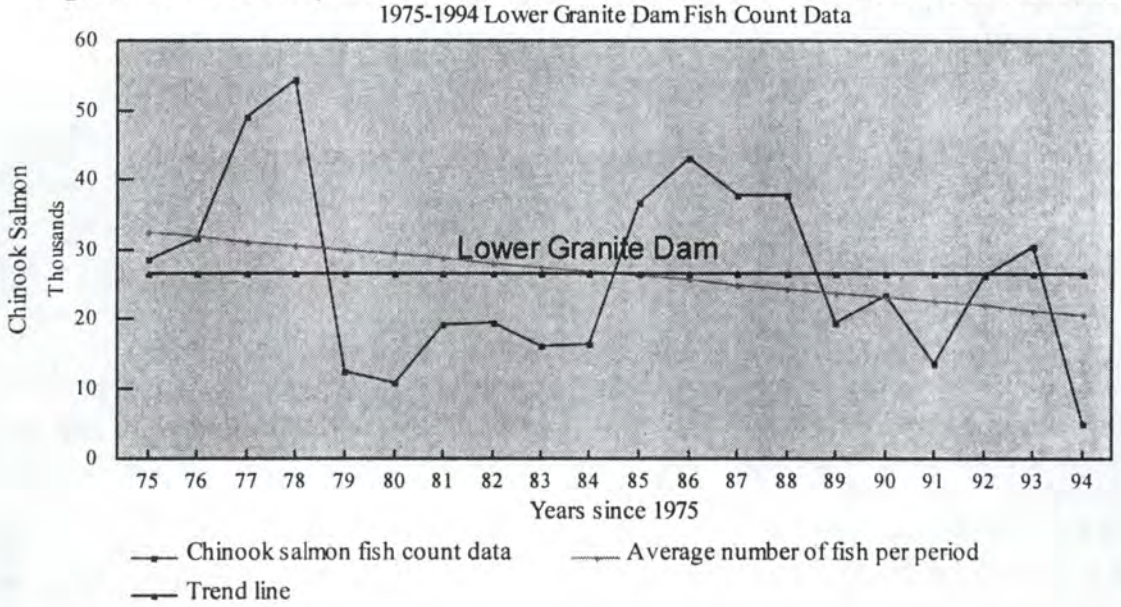
When the average runs over each dam as it was added to the system are examined, it is clear that they have had a negative impact on fish passage. It is interesting that the first three dams which were constructed prior to 1971 had little if any impact on the chinook runs on the lower Snake River. It is only after Dworshak Dam was added to the system that the chinook runs began to seriously decline in terms of the fish count at Ice Harbor Dam. The causes of this decline is not clear, and that will become evident when the Lower Granite Dam fish counts are examined.

What is interesting is that the average analysis indicates that Lower Granite was the dam that caused the most damage to the chinook salmon. This conclusion may be misleading in that the major losses on the Snake River have been downstream from Lower Granite Dam on the Tucannon River in eastern Washington. It is also interesting

that most of this loss shows up after 1974 which is before Lower Granite Dam was closed on the Snake River.

The situation for chinook salmon on the upper Snake River above Lower Granite Dam is shown in figure 3. The rate of decline as measured by the trend lines much lower over the Lower Granite Dam than it was over the Ice Harbor

Figure 3. The Impact of Dam Construction on Chinook Salmon Run

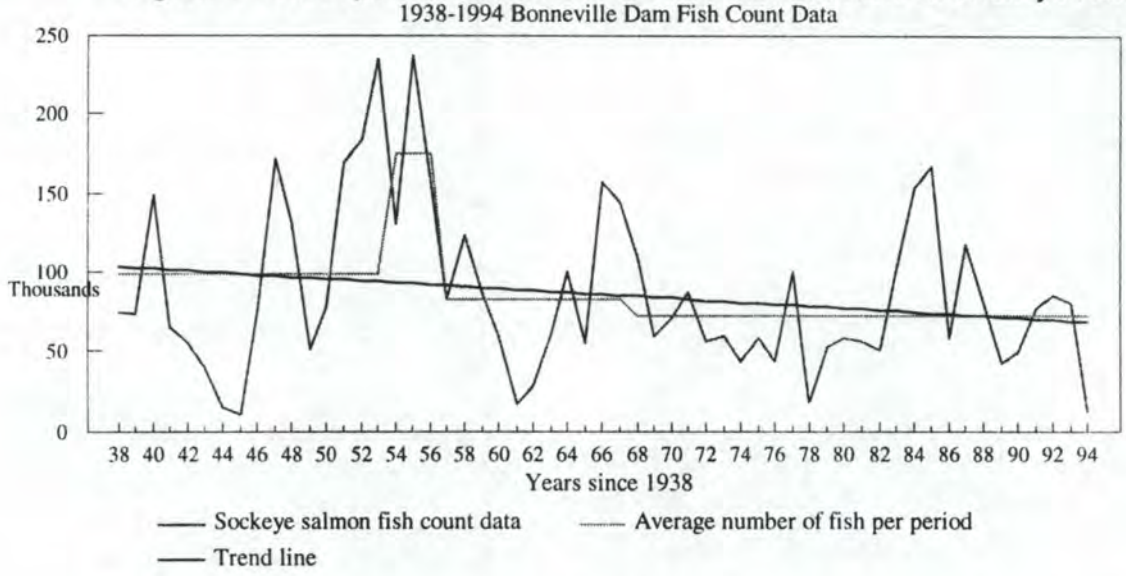


Dam. The variability in the fish runs is similar to that of the down river dams, but the magnitude is less. The trend line begins at about 33,000 fish in 1975, and is about 24,000 fish in 1994. This indicates an overall decline of fewer than 10,000 fish compared to almost 50,000 fish at Ice Harbor Dam. It will take many more years for the chinook to become extinct upriver than the projections for the lower river chinook salmon.

Sockeye Salmon:

The history of the sockeye salmon fish passage on the lower Columbia river is somewhat similar to that of the chinook salmon. The history of fish passage indicates that this species has been in decline since 1938, as shown in figure 3. In the case of sockeye salmon the long run trend line is slightly negative. The rate of decline is relatively slow, and if the conditions represented by the trend line continue to hold this species will become extinct sometime in the middle of the 24th century. Of course this is a far out projection, and should again be taken with a grain of salt much smaller than that for the chinook salmon example discussed above. However, the sockeye salmon are interesting in that very few if any of these fish are reared in fish hatcheries. In this sense they are an indicator wild species. If this is the case then the long term trend line probably is indicative of the future for all wild species of anadromous fish.

Figure 4. The Impact of Columbia River Dam Construction on Sockeye Runs



When looking at the impact of dams by observing the average runs of sockeye salmon for the periods each dam has been in operation it is interesting to note that the increase in average numbers which occurred between 1954 and 1956 the period after the McNary Dam was added to the Columbia River system. This only lasts until The Dalles Dam was completed and made operational in 1957. After 1957 it is all down hill for the sockeye salmon on the Lower Columbia River. Note that the 1994 run has dropped to a level on observed once before during the past 54 years, and that was in 1945, three years after Grand Coulee Dam was added to the system.

On the Snake River the story is a sorry one for the sockeye salmon. This is clearly shown in figure 5. The trend line analysis shows the sockeye salmon on the Snake River becoming extinct in 1990. One needs to recognize that there never were many sockeye in the Snake River to begin with. The maximum number of fish counted over the Ice harbor dam was 1,276 in 1963 the year after the Ice Harbor Dam was added to the Columbia River system.

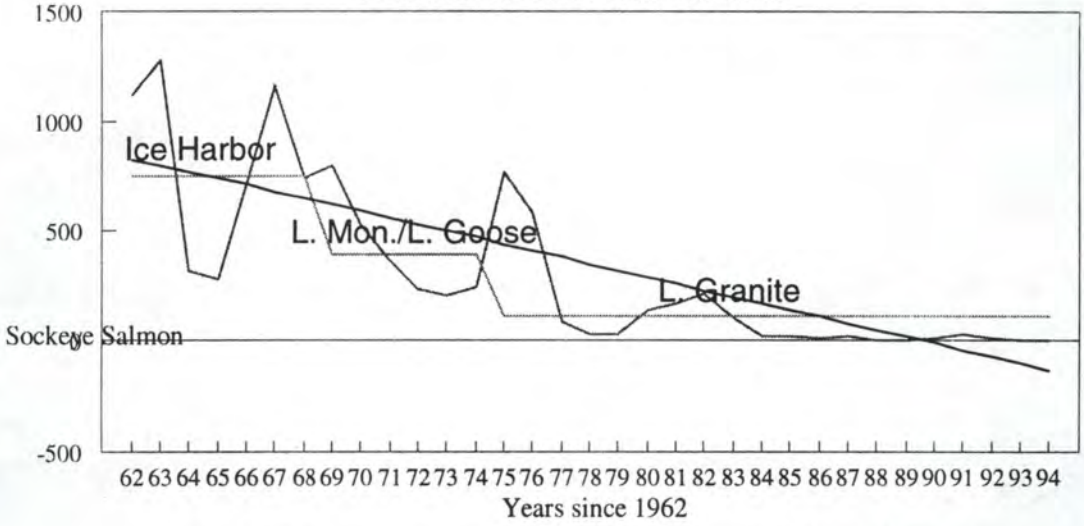
The average run data indicated a steady decline over the past 30 years for the sockeye salmon on the Snake River. There was a year when the average increased and that was wen Lower Monumental Dam was added to the Snake River System. This appears to be a statistical aberration. The overall trend is negative as is clearly shown by the trend analysis.

The outlook for the sockeye salmon on the Snake River is bleak to say the least. Unless some dramatic way can be found to enhance this fishery it appears that it is doomed. However one should point out that even though the analysis is discouraging, that every year since 1990 there have been some sockeye in the Snake River. In 1994 they were not counted at Ice Harbor Dam, but were counted at Lower Granite Dam. It

appears that unless hatchery fish are provided, that there is no future for the sockeye salmon in the Snake River.

Figure 5. The Impact of Dam Construction on Sockeye Salmon

1962-1994 Ice Harbor Dam Fish Count



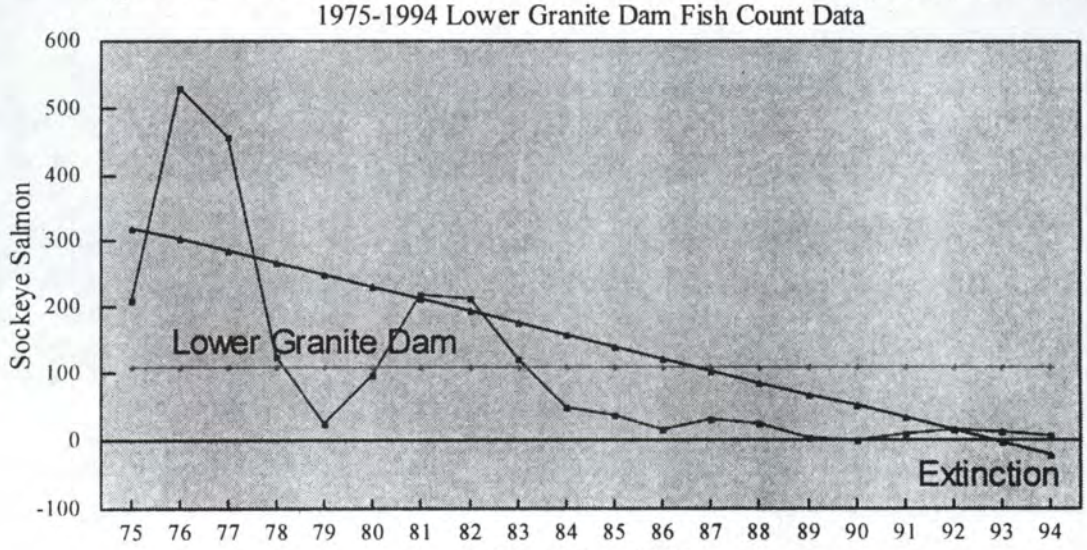
Sockeye salmon fish count data — Average number of fish per period

Trend line

The picture for the sockeye salmon at Lower Granite Dam is even more drastic than it was at the Ice Harbor Dam. In Figure 6 the sockeye salmon are

Figure 6. The Impact of Dam Construction on Sockeye Salmon Runs

1975-1994 Lower Granite Dam Fish Count Data



Sockeye salmon fish count data — Average number of fish per period

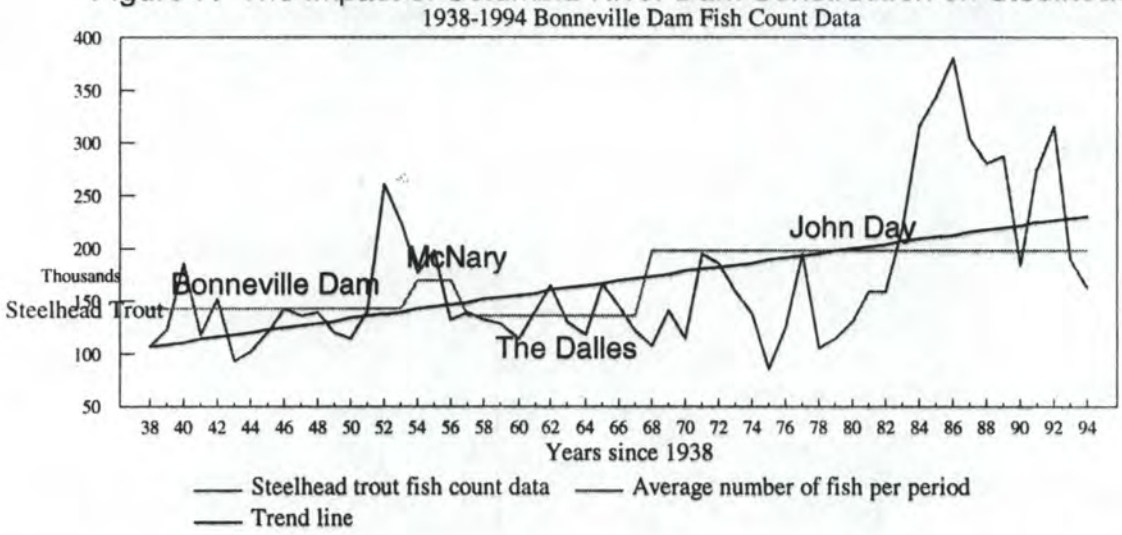
Trend line

in at least as bad condition as indicated at Ice Harbor Dam. There were only 531 fish passing Lower Granite Dam in 1976, and since then the number has gone for all intents to zero. It is clear that without augmentation that the sockeye salmon are history on the Snake River.

Steelhead Trout:

The case for the steelhead trout on the Columbia and Snake rivers is quite different that that for the chinook and sockeye salmon. This species has fared better under the dam regime on these rivers. In both rivers steelhead have managed to increase in number compared to the salmon species, Figure 1, shows the fish passage record for steelhead trout since 1938. There has been

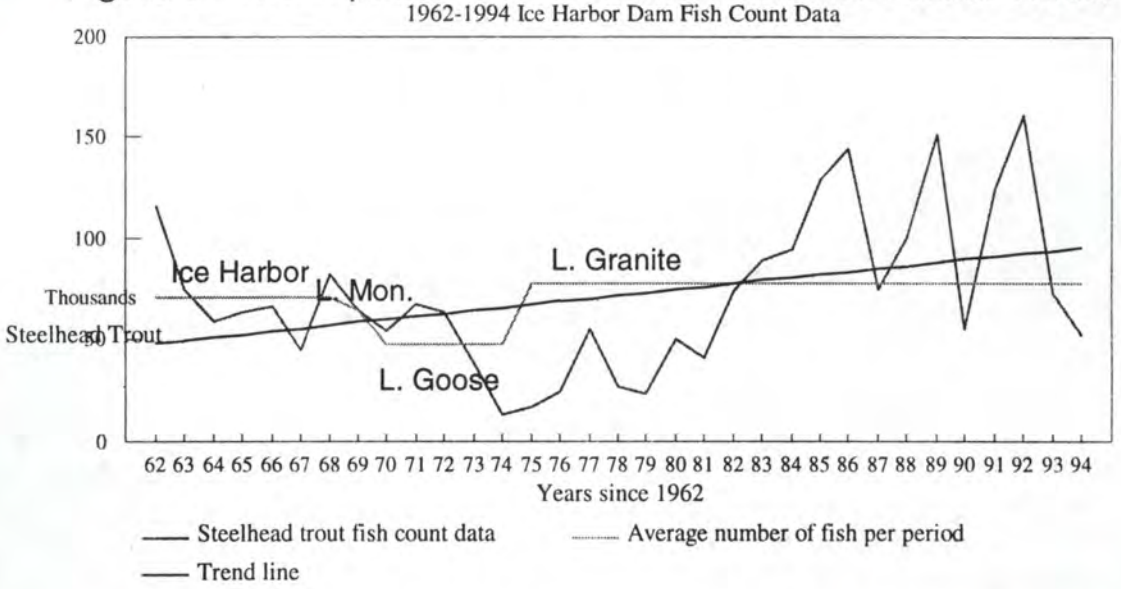
Figure 7. The Impact of Columbia River Dam Construction on Steelhead



a slow but steady persistent increase in the number of fish counted over Bonneville Dam since this time. This increase has persisted in spite of additional dams being added to the system. It is interesting to note that the steelhead runs more or less held their own up until 1968 when the John Day Dam was added to the lower Columbia River system. This date corresponds reasonably well to the time that major steelhead trout hatcheries were added to the system. It seems that the steelhead trout are either tougher fish than the salmon, or that they are not subjected to as much predation or fishing pressure as the salmon. There are obviously other reasons why the steelhead trout have adapted better to the dam system on the river than have the salmon.

In the case of the Snake River steelhead trout runs, they have also reacted in a similar manner to fish passage as have the lower Columbia River steelhead. The rate of increase is less for the Snake River than for the

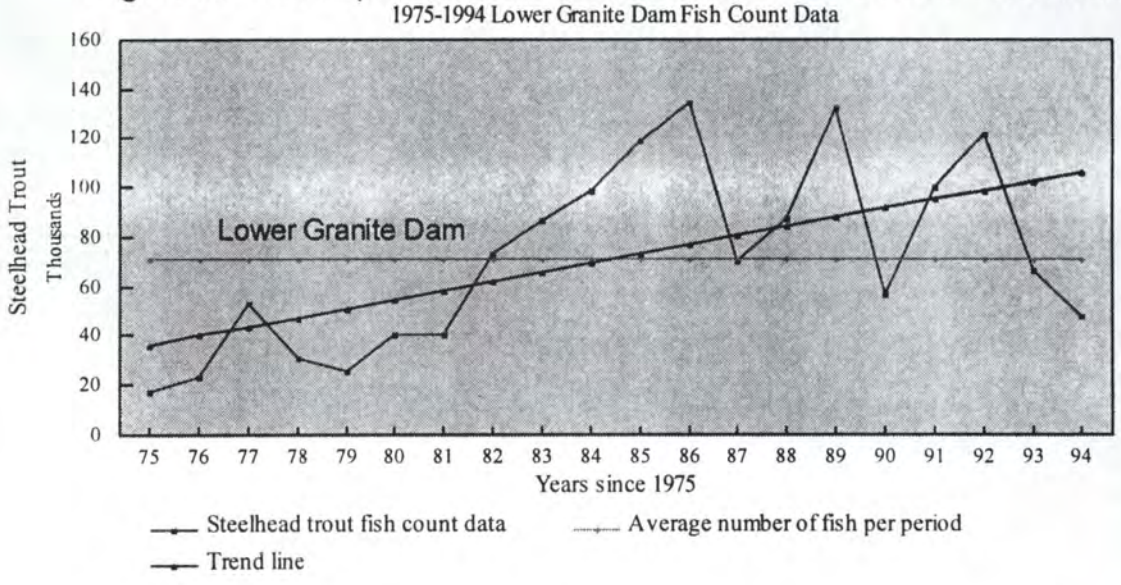
Figure 8. The Impact of Dam Construction on Steelhead Trout Ru



Columbia River steelhead trout, but it still strongly upward in direction. The reason that this condition exists can largely be explained by the development of steelhead hatcheries in the Snake River basin. The more recent years tend to clearly show this phenomenon. To a large extent, most the increase in the production of steelhead has come from the Ashaka, Idaho fish hatchery which was built to offset the loss related to the construction of the Dworshak Dam on the North Fork of the Clearwater River.

The situation at Lower Granite mirrors that at Ice Harbor Dam. The time span is shorter, but the impact of the fish hatchery is clearly evident. Over all

Figure 9. The Impact of Dam Construction on Steelhead Trout Runs



it appears that the steelhead trout have adapted themselves to the dam construction better than the various species of salmon have.

Estimated Value of Columbia and Snake River Fisheries

The question arises as to the worth of these fish which are part of the natural environment, and which existed prior to the building of the dams on these rivers. This question has become even more pressing with the threat of naming some of these fish endangered species. Arguments are being made that the economic losses from the strategies being proposed far outweigh the value of these fish, but little evidence is presented on the side of the fish. The approach will be to estimate the value of the salmon and steelhead fisheries in the Snake River system. The approach used to estimate fishery value was based on the American Fisheries Society document entitled "Monetary Values of Freshwater Fish and Fish-Kill Counting Guidelines published in 1982. The "Monetary Values of Freshwater Fish Committee" and the "Pollution Committee" set forth procedures and estimated the value of each specie of freshwater fish.[2] The values developed in the above study have been updated from 1982 to 1993 using the producer price index. [3] The Value per fish are shown in Table 1 along with the average weight, the estimated

value per fish, and the capitalized value per fish. This latter value may be interpreted as that amount of money which would have to be set aside to generate the corresponding cash flow generated by the fish value. A four percent "social discount rate" was used to determine the capitalized value of these fish. Recognizing that the choice of discount rate

Table 1. Monetary Values of Colombia and Snake River Anadromous Fish, 1993.

Species	Weight lb.	Value* per lb. $	Value per fish $	Capitalized value $
Chinook Salmon	33	$.4.96	$163.68	$4,092
Sockeye Salmon	10	$4.96	$49.60	$1,240
Steelhead trout	17	$4.96	$84.32	$2.108

Source: American Fisheries Society. "Monetary Values of Freshwater Fish and Fish-Kill Counting Guidelines." American Fisheries Society . Special Publication No. 13, 1982.

Adjusted by the Producer Price Index to update the values from 1982 to 1993.

[2] The Monetary Values of Freshwater Fish Committee and the Pollution Committee. "Monetary Values of Freshwater Fish and Fish-Kill Counting Guidelines." American Fisheries Society, Special Publication No. 13. 1982.

[3] USDA. "Agricultural Outlook." March 1992/AO-183.

is arbitrary, and that one could argue for higher or lower discount rates, this discount rates should not be considered to be set in concrete, but rather as a first step in the process of determining the value of these fish.

The average replacement cost of each species is shown in table 1. Each chinook salmon was valued at $163.68, sockeye salmon at $49.60, and steelhead trout at $84.32. The capitalized value of each fish for spawning using the 4 percent discount rate was: 1) chinook salmon $4,092, 2) sockeye salmon $1,240, and 3) steelhead trout $2,108.

Columbia River Fisheries

The next step was to calculate the value of the fishery based on the numbers of fish shown in the Corps of Engineers fish count data. These values are shown in table 2 for Bonneville Dam. The values shown are based on the trend analysis for each species of fish over the time period covered by the fish counting procedure. The beginning and the ending values are shown in table 2 and the differences are were computed. At Bonneville Dam the trend for chinook salmon and steelhead trout was increasing, and that for the sockeye salmon was decreasing. The changes in the fisheries over time have tended to be increasing in the aggregate. The total number of all anadromous fish over Bonneville Dam has increased from an estimated 567,865 fish in 1941 to 685,741 fish in 1993. This represents an overall increase of over 114,000 fish, or a 20% increase over 51 years. The economic values were computed using the values in table 1. The annual value of all of the fisheries at Bonneville Dam was estimated to have increased between 1941 and 1993 by $14.3 millions. The total stock value in 1941 was $71.1 millions and it had increased to $85.4 millions by 1993. The stock value (or capitalized value) of these fisheries had increased by $230 millions. The total stock value in 1941 was estimated at $1.8 billions, and this increased to $2 billions by 1993.

In terms of the individual species between 1941 and 1993: 1) the annual value of the chinook salmon increased from $57 millions to $62.5 millions, 2) the annual value of sockeye salmon declined from $5.1 millions to $3.5 millions, and 3) the annual value of steelhead trout increased from $9.0 millions to $19.4 millions. The net gains were: 1) chinook salmon, $ 5.5 millions, 2) sockeye salmon, a negative $1.6 millions, and 3) steelhead trout, $10.4 millions. The stock value of the individual fisheries also changed between 1941 and 1993 as follows. Chinook salmon increased by $137.5 millions from $1.425 billions in 1941 to $1.562 billions in 1993. The sockeye salmon's stock value declined by $40 millions from $127.5 millions in 1941 to $87.5 millions in 1993. The steelhead trout which showed the largest gain increased by $260 millions from $225 millions to $485 millions in 1993. The general conclusion is that the aggregate value of these fisheries has increased slowly since Bonneville Dam was completed. It is also true

that most of this increase has resulted from the mitigation in terms of hatcheries, barging, and fish passage improvements that have been added to the systems since 1938.

Table 2. Estimated Economic Value of Selected Columbia River Fisheries, 1941-93.

Dam / species	Year	The number of fish	Average Value per fish	The annual value of fishery	Capitalized value of fishery*
			$	**mil. $**	**mil. $**
Bonneville					
Chinook	1941	348,133	$163.68	$57.0	$1,425.0
	1993	381,881	(same)	$62.5	$1,562.5
	Difference	33,748	NA	$5.5	$137.5
Sockeye	1941	103,126	$46.90	$5.1	$127.5
	1993	74,058	(same)	$3.5	$87.5
	Difference	(29,068)	NA	($1.6)	($40.0)
Steelhead	1941	106,562	$84.32	$9.0	$225.0
	1993	229,802	(same)	$19.4	$485.0
	Difference	123,240	NA	$10.4	$260.0
Totals	1941	567,876	NA	$71.1	$1,777.5
	1993	685,741	NA	$85.4	$2,007.5
	Difference	114,865	NA	$14.3	$230.0

- A four percent discount rate was used in this study.

Lower Snake River Fisheries

The next point at which values were measured was at Ice Harbor Dam near the mouth of the Snake River. Idaho, Oregon, and Washington up river chinook salmon, sockeye salmon, and steelhead trout all pass through this dam. The major contributors to this value were the chinook salmon and steelhead trout. The major loss in value was that related to the decline in the number of chinook salmon in the river. The total number of chinook declined by 54,534 fish over this time period, or a loss of 70 percent. The number of steelhead trout has increased by almost 60,000 fish in the same time period, or an increase of 153 percent. The sockeye salmon the loss was not economically significant, but was environmentally a disaster for this fishery because for all purposes the run has been lost..

The value of the Snake River fishery is shown in table 3. The estimated value of the Snake River fisheries in 1965 was $397.8 millions in terms of its stock value, and it generated an annual flow worth $16.3 millions. In 1993 the estimated stock value of these fisheries had declined $297.5 millions, a loss of $100.3 millions, and the annual flow to $11.9 millions. In terms of the individual fisheries the greatest decline occurred to the chinook salmon which declined in terms of its estimated stock value from $315

millions to $90 millions. The annual value of the chinook salmon fishery declined $225 millions in terms of its stock value, and $9 millions in terms of its annual value.

The sockeye salmon on the Snake River never was a large fishery, and it declined to zero by 1988. There has been a complete loss of this fishery which had a stock value in 1962 of $0.8 millions and annual value of $0.4 millions.

Table 3. Estimated value of Selected Lower Snake River Fisheries, 1965-93.

Dam /species	Year	Average number of fish	Value per fish	The annual value of fishery	Capitalized value of fishery*
			$	**Mil $**	**Mil. $**
Ice Harbor					
Chinook	1962	76,889	$163.68	$12.6	$315.0
	1993	22,355	(same)	$3.6	$90.0
	Difference	(54,534)	NA	($9.0)	($225.0)
Sockeye	1963	710	$49.60	$0.4	$0.8
	1993	(0)	(same)	$0.0	$0.0
	Difference	(710)	NA	($0.4)	($0.8)
Steelhead	1962	39,131	$84.32	$3.3	$82.0
	1993	98,939	(same)	$8.3	$207.5
	Difference	59,808	NA	$5.0	$125.5
Totals	1962-3	116,730	NA	$16.3	$397.8
	1993	121,294	NA	$11.9	$297.5
	Differences	4,564	NA	$4.4	$100.3

* A four percent discount rate was used in this study.

The steelhead trout on the other hand are a very different picture. The numbers The steelhead trout on have increased dramatically on the Snake River since 1962. The estimated stock value of these fish has increased from $82 millions in 1962 to $207.5 millions in 1993, and the estimated annual value from $3.3 millions to $8.3 millions over the same period. The net increase in terms of stock value has increased by $125.5 millions, and the annual value by $5 millions.

In the case of the Lower Snake River the total number of fish over the Ice Harbor Dam increased between 1962/63 and 1993. The reason for this was the large increase of steelhead trout which occurred. The total number of steel trout increased from approximately 39,000 to over 98,000 fish during the 30 year period, a net gain of 59,000 fish. At the same time the number of chinook salmon declined by over 54,000 fish, and the sockeye salmon disappeared from the river. The percentage increases in decreases were: 1) chinook salmon decreased by 29 percent , 2) sockeye 100 percent, and 3)

steelhead increased by 250 percent. The lower Snake River fisheries lost value during this time, mainly because the economic value lost by the decline of the chinook fishery was greater than the gain in terms of the number steelhead trout fishery.

Lower Granite Dam and the Up River Snake River Fisheries

The last dam to be considered is the Lower Granite Dam on the Snake River. Lower Granite dam is the gateway to Idaho and the upriver Oregon and Washington fisheries. The results of this analysis are interesting in that the chinook salmon runs over Lower Granite although declining over time are not nearly as reduced as those over Ice Harbor Dam. The value of the upstream Idaho, Oregon, and Washington fisheries are shown in table 4. In terms of stock value the chinook salmon have declined by about 20 percent, from a high of $122.5 millions in 1978 to $102.5 millions in 1993. The annual value of the chinook fishery has declined from $4.9 millions to $4.1 millions. This should be compared to the loss at Ice Harbor dam which was approximately 70 percent.

Table 4. Estimated Value of Selected Upper Snake River Fisheries, 1978-93.

Dam /species	Year	The number of fish	Average value per fish	The annual value of the fishery	Capitalized value of the fishery*
			$	Mil. $	Mil. $
Lower Granite					
Chinook	1975	29,794	$163.68	$4.9	$122.5
	1993	24,964	(same)	$4.1	$102.5
	Difference	(4,830)	NA	($0.8)	($20.0)
Sockeye	1975	134	$49.60	$0.007	$0.2
	1993	(0)	(same)	$0.0	$0.0
	Difference	(134)	NA	($0.007)	($0.2)
steelhead	1975	35,416	$84.32	$3.0	$75.0
	1993	114,736	(same)	$9.7	$242.5
	Difference	79,320	NA	$6.7	$167.5
Totals	1975	65,344	NA	$7.9	$236.6
	1993	139,700	NA	$13.8	$345.0

* A four percent discount rate was used in this study.

In the case of the sockeye salmon the results are quite similar to those at Ice Harbor Dam. The number of sockeye passing Lower Granite Dam was even smaller that that for Ice Harbor Dam. The last sockeye passing Lower Granite Dam was counted in

1989. The loss in term of stock value was estimated at $0.2 millions, and in terms of annual value approximately $70,000.

The steelhead trout follow the pattern established at Ice Harbor Dam. The number of fish has increased over 300 percent. The net increase in stock value for steelhead was $167.5 millions, from $75 millions in 1978 to $242.5 millions in 1993. The annual value increased from $3.0 millions in 1978 to $9.7 millions in 1993. The main factor behind this increase is the Ashaka steelhead hatchery on the Clearwater River.

The situation for the Upper Snake River fish runs is markedly different that that for the Lower Snake River fish runs. In this case the changes are not as dramatic as they were for the lower Snake River fish runs. The chinook salmon runs are declining, but at a much slower rate than for the Lower Snake River. The loss of chinook between 1978 and 1993 amount to just under 5,000 fish during the 15 year period. The loss of sockeye was the same as that which occurred at Ice Harbor Dam because the final destination of the sockeye would have been in the upper reaches of the Salmon River drainage in central Idaho lakes. However, for the steelhead trout, an even more rapid increase was shown than that at the Ice Harbor Dam. Steelhead trout numbers increased by almost 80,000 fish during this period.

Conclusions and Observations

The purpose of this paper was to attempt to develop a methodology for estimating the value of the Columbia River fisheries. The important conclusions to be drawn are: 1) that the aggregate fish runs on the Columbia River as counted at Bonneville Dam have tended to increase since 1938; 2) the fish hatcheries, spills, and transport systems which have been used to maintain the up river fish populations have worked reasonably well to maintain and enhance steelhead trout populations on the Snake River; 3) that the greatest loss of fish has occurred on the lower Snake River; and 4) that the sockeye salmon have virtually disappeared from the Snake River.

There is only one spawning stream between Ice Harbor Dam and Lower Granite Dam, the Tucannon River in Washington State, and the greatest loss of fish is undoubtedly related to the loss of habitat on this river. From an environmental point of view, it is clear that the loss of the Tucannon fishery has been a serious blow to the lower Snake River fishery. The loss of over 50,000 chinook salmon on their spawning journey between 1962 and 1993 needs further research.

This study concludes that the aggregate value of the Columbia River fisheries has increased since the Bonneville Dam was built. It is also true that most of this increase has resulted from the mitigation in terms of hatcheries, barging, and fish passage improvements that have been added to the systems since 1938. In terms of the individual

species between 1941 and 1993: 1) the annual value of the chinook salmon increased from $57 millions to $62.5 millions, 2) the annual value of sockeye salmon declined from $5.1 millions to $3.5 millions, and 3) the annual value of steelhead trout increased from $9.0 millions to $19.4 millions. The net gains were: 1) chinook salmon, $ 5.5 millions, 2) sockeye salmon, a negative $1.6 millions, and 3) steelhead trout, $10.4 millions. The stock value of the individual fisheries also changed between 1941 and 1993 as follows. Chinook salmon increased by $137.5 millions from $1.425 billions in 1941 to $1.562 billions in 1993. The sockeye salmon's stock value declined by $40 millions from $127.5 millions in 1941 to $87.5 millions in 1993. The steelhead trout which showed the largest gain increased by $260 millions from $225 millions to $485 millions in 1993. The aggregate stock value of these fish runs estimated at Bonneville dam in 1993 was just over $2.0 billions, and the annual value generated was estimated to be $85.4 millions.

The situation on the lower Snake River is mixed in terms of the economic value of the fisheries. The chinook and sockeye salmon are in decline, while the steelhead trout are increasing in a significant way. The value of the chinook salmon on the lower Snake river has declined dramatically since 1965. The stock value of this fishery declined $225 millions, and the annual value by $9 millions between 1965 and 1993. In the case of the sockeye salmon the loss of stock value decline $0.4 millions and an annual value loss of $70,000. The steelhead trout runs however were increasing, and the stock value of this resource increased from $82 millions to $207.5 millions. The annual value of the steelhead runs increased from $3.3 millions to $8.3 millions. The aggregate stock value of the lower Snake River fish runs was estimated to be $297.5 millions in 1993, and this was decline of $100.3 millions from the situation in 1965. The annual value of the lower Snake river fisheries was estimated to be $11.9 millions in 1993, down $4.4 millions from 1965.

The upper Snake River fish runs that feed the Idaho, eastern Oregon and Washington fisheries are being maintained in a better form that those of the lower Snake River. The chinook salmon although in decline have not suffered as much as the lower Snake River chinook salmon. The stock value of this resource has declined from $122.5 millions to $102.5 millions since 1978. The annual value declined from $4.9 millions to $4.1 millions. The fate of the sockeye salmon on the upper river is the same as that for the lower Snake River. In the case of steelhead trout, again the resource is increasing. The stock value of the steelhead trout on the upper river has increased from $75 millions in 1978 to $242.5 millions in 1993. The annual value of the fishery increased from $3 millions to $9.7 millions over the same period. The aggregate stock value of the upper Snake River fisheries was estimated to be $345 millions in 1993, which was up $108.4 millions over 1978. The annual value of the fishery was estimated to be $13.8 millions in 1993, which was up $5.9 millions.

Conclusions

Only broad conclusions can be drawn from these data. The first and most important one is that it is the fish hatcheries and improvements in the downstream passage conditions have made it possible for the anadromous fish to survive in these rivers under the dam regime. This can be seen in the data. It is particularly evident for the steelhead trout on the Snake River. It is also evident for the chinook salmon on the Columbia River. In the latter case it is evident in terms of the chinook salmon being able to hold their own or hang on over the long term.

A second conclusion is that statistical analysis of these data is difficult. This is a result of the great variability which exists from year to year in the magnitude of the runs. This is true for all species of anadromous fish. The reasons for this variability are not clearly understood, and they are undoubtedly affected by both biological conditions in the rivers and in the ocean. They may also be affected by ocean and river harvest of these fish as they return to spawn.

The third conclusion is that the aggregate value of these fisheries has increased since Bonneville Dam was completed. It is also true that most of this increase has resulted from the mitigation in terms of hatcheries, barging, and fish passage improvements that have been added to the systems since 1938. However, it is also clear that some individual species have not fared very well during the 55 years since the first dam was built. The sockeye salmon have been in decline on both the Columbia and Snake rivers, and the chinook salmon have been in serious decline on the Snake River. Steelhead trout however have been increasing significantly on both river systems. In conclusion, some of the fisheries on the Columbia and Snake rivers have been impacted negatively by the development of the dams on these rivers. This negative impact has been mitigated by hatcheries, improved downstream fish passage, improved spawning habitat, and downstream barging of chinook salmon and steelhead trout. In the case of the sockeye salmon, the only hope may be to build hatcheries for these fish, if society wants to ensure their survival in the current river system..