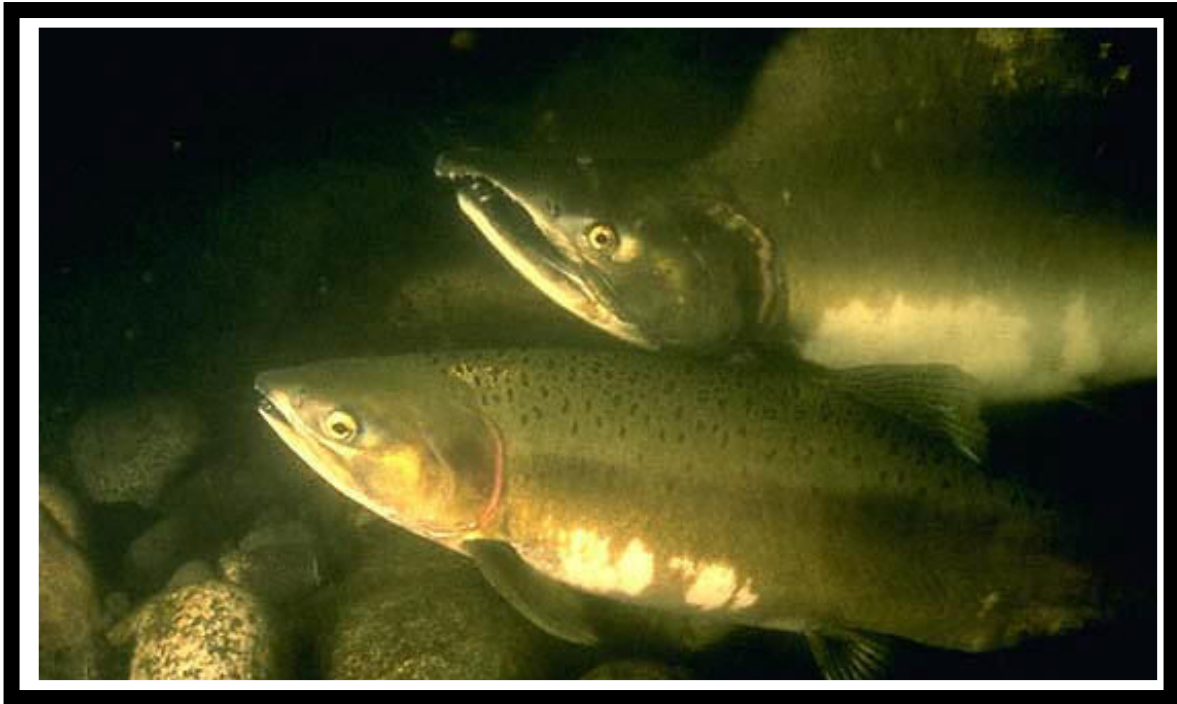


Tsolum River

Limiting Factors to Pink Salmon Production



Abstract

Pink salmon (*Oncorhynchus gorbuscha*) production in the Tsolum River has declined from a high of 100,000 pink salmon adults returning per year in 1935 and 1936 to a record low of ten pink salmon returning to the river in 1984.

Copper leaching from the mine site was identified as a threat to all salmon species in the river in 1986, however historical escapement data shows that pink salmon stocks declined sharply in 1957; ten years before the opening of the Mount Washington copper mine.

Stocks continued to decline after the mine was closed and despite hatchery enhancement efforts there has been only a limited recovery of odd year pink salmon stocks, and no recovery of even year stocks.

The Tsolum River Restoration Society (TRRS) has been successful in seeking funding for projects to reduce copper leaching from the mine site. These efforts include directing flow from the Mt. Washington mine site through the Spectacle Lake wetland in 2003 and the covering of the mine site with a geotextile membrane in 2009.

Restoring productivity of pink salmon in the Tsolum River will require the reduction of copper levels from the Mount Washington Mine as well as habitat restoration, changes to hatchery enhancement strategies, and development of estuary habitat.

The goal of this report is to identify the limiting factors that must be addressed to restore pink salmon productivity in the Tsolum River after the copper concentrations in the river are reduced to levels that are no longer threaten salmon survival.

Table of Contents

Abstract.....	i
Table of Contents.....	ii
List of Figures.....	iii
List of Tables.....	iv
List of Appendices.....	v
Acknowledgements.....	vi
The Tsolum River.....	1
TRRS Restoration Goals and Objectives	2
Identifying Limiting Factors in the Tsolum River.....	3
Historic and Present Pink Salmon Production.....	3
Comparing Tsolum Return to Quinsam & Puntledge River Data	6
High Water Temperature and Gamete Viability.....	7
Physical Barriers to Migration.....	9
Water Flow Effects on Salmon Production	12
Availability of Estuarine Habitat.....	14
Coordination of Successful Enhancement Programs	17
Restoring Even Year Pink Salmon Stocks	20
Control of Copper Leachate and Mine Site Restoration	21
Development of an Atlas of the Tsolum River Watershed	23
Recommendations	27
References	29
Appendices	31

List of Figures

Figure 1. Tsolum River Watershed Map.....	1
Figure 2. Tsolum River Salmon Escapement 1935 – 2009.....	3
Figure 3. Tsolum River Pink Salmon Escapement 1935 – 1958.....	4
Figure 4. Tsolum River Pink Salmon Escapement 1959 -1982.....	5
Figure 5. Tsolum River Pink Salmon Escapement 1983 – 2009.....	5
Figure 6. Odd Year Escapement to the Puntledge, Quinsam and Tsolum Rivers.....	6
Figure 7. Even Year Escapement to the Puntledge, Quinsam and Tsolum Rivers.....	7
Figure 8. Pink Salmon Egg Mortality vs. Adult 21 Day Temperature Exposure.....	8
Figure 9. Tsolum River Barrier Fence.....	10
Figure 10. Gravel Bar Upstream of Rees Bridge, Tsolum Mainstem.....	11
Figure 11. Gravel Accumulation at the Confluence of Murex Creek & Tsolum River.....	12
Figure 12. Pink Salmon Development Stages vs. Peak River Flows.....	13
Figure 13. Courtenay River Estuary Sampling Sites.....	15
Figure 14. Tsolum and Puntledge River Even Year Escapement 1958 to 1982.....	17
Figure 15. Tsolum and Puntledge even year Escapement 1984 – 2008.....	17
Figure 16. Tsolum River even year pink salmon escapement 1954 – 2008.....	20
Figure 17. Geotextile Membrane covering Mt. Washington Mine Site.....	22
Figure 18. Pink and Chum escapement in the Tsolum River 1998 – 2008.....	23
Figure 19. ArcView 3.1 map of Reach 1, Lower Tsolum River.....	24
Figure 20. Google Earth Image of Reach 1, Lower Tsolum River.....	26

List of Tables

Table 1. Objectives of the Tsolum River Restoration Society.....	2
Table 2. Puntledge and Tsolum River temperature monitoring sites	8
Table 3. L.Tsolum River and Headquarters Cr. Hatchery Temperatures 1998	9
Table 4. L. Tsolum River and Headquarters Cr. Hatchery Temperatures 2009	9
Table 5. Pink Salmon Fry Collected at Courtenay River Estuary Sample Sites	16
Table 6. Return for Effort of Odd Year Fry Produced at Headquarters Hatchery.	19
Table 7. Return for Effort of Even Year Fry Produced at Headquarters Hatchery.....	20

Appendices

Appendix 1. Headquarters Creek Pink Salmon Releases and Returns.....	36
Appendix 2. Water Temperatures Recorded at Headquarters Creek Hatchery.....	37

Acknowledgements

For the past decade Directors and Members of the Tsolum River Restoration Society (TRRS) have worked diligently to restore the Tsolum River Watershed and to mitigate damage done to the river by acid rock drainage, residential development and resource extraction.

These efforts have been assisted by professional advice provided by TRRS Directors as well as Bev Bravender, James Craig, John Deniseger, Dominico Iannidanardo, Dave Gooding, Dave Lindsay, and Jack Minard.

Funding from the BC Conservation Foundation, the BC Transmission Corporation, Marine Harvest Canada, and local citizens have supported the Tsolum River Restoration Society and the completion of this work.

The Tsolum River

The headwaters of the Tsolum River originate from Blue Grouse Lake. The river flows 30 km in an easterly direction parallel to the east coast of Vancouver Island and provides habitat for chinook, coho, chum, pink and steelhead salmon, cutthroat trout and many species of non-salmonid fishes.

Development along the 258 km² of the watershed includes privately owned forest lands upstream of Headquarters Creek, and a mix of agricultural and rural residential lands in the area between Headquarters Creek and Dove Creek. The lower watershed is surrounded by a mix of agricultural, commercial and residential properties, with limited riparian buffering along the property boundaries.

The Tsolum and Puntledge Rivers flow into the Courtenay River, and fish from both watersheds share the limited habitat available in the Courtenay River estuary.

Air photo and flow data analysis completed by D. Gooding (2009) show that the course of the river has changed over time and that erosion and flooding threaten properties and salmon habitat in the lower watershed.

Tsolum River Watershed Map



Figure 1: Map of the Tsolum River watershed, major lakes and tributaries.

TRRS Restoration Goals and Objectives

Since the establishment of the Tsolum River Restoration Society in 1998, the goal of the society has been to restore the Tsolum River “to restore the river to historic levels of health and productivity.”

The Society has identified the following objectives and is working with its partners to protect habitat and enhance salmon stocks.

Table 1: Objectives of the Tsolum River Restoration Society

Reduce Copper Concentrations	Reduce dissolved copper concentrations to below seven micrograms per litre in the Tsolum River below its confluence with Murex Creek.
Achieve Minimum Flow	Achieve minimum flows that support the upstream migration of returning adult salmon.
Enhance Salmon Stocks	Salmon stocks will be enhanced using hatchery technology until stocks have reached capacity.
Restore and Protect Habitat	To protect the Tsolum River from activities that may damage the health of the Tsolum River Ecosystem. Protect the meander corridor of the Tsolum River and its tributaries
Promote Stewardship	The Society will promote sustainable stewardship of the Tsolum River watershed.

Although objectives have been defined for water quality and copper concentration, the Society has not defined specific objectives for flows, stock enhancement, habitat protection or stewardship promotion. In order to measure achievement and to improve specific conditions, TRRS should define measurable targets for each of the categories listed above.

The goal of “Restoring the Tsolum River to Historic Levels of Health and Productivity” also needs to be refined. Over the past 150 years, development in the watershed has caused changes in river flows and available instream habitat. A hydrological analysis completed by Gooding (2009) shows that river conditions have changed significantly. It may not be possible to achieve the level of productivity that was recorded when pink salmon returns reached historic high levels because instream and upland habitat has been degraded.

Identifying Limiting Factors to Pink Salmon Production

Consistent and sustainable production of pink salmon in the Tsolum River is dependent on:

- Control of Copper Leachate and Mine Site Restoration
- High Water Temperature and Gamete Viability
- Water Quantity/Stable Seasonal Water Flow
- Availability of Estuarine Habitat
- Climatic and Ocean Conditions
- Removal of Physical Barriers to Migration
- Access to of Instream Refuge Habitat
- Coordination of Successful of Enhancement Programs
- Control of Predation

Historic and Present Pink Salmon Productivity

Despite the focus that has been placed on damage done to stocks by the Mt. Washington Copper mine, the greatest decline in pink salmon stock strength occurred before the copper mine opened in 1965. Fisheries and Oceans escapement data for the Tsolum River has not had a return of pink salmon greater than 70,000 fish since 1958 (DFO Mapster V.2 database)

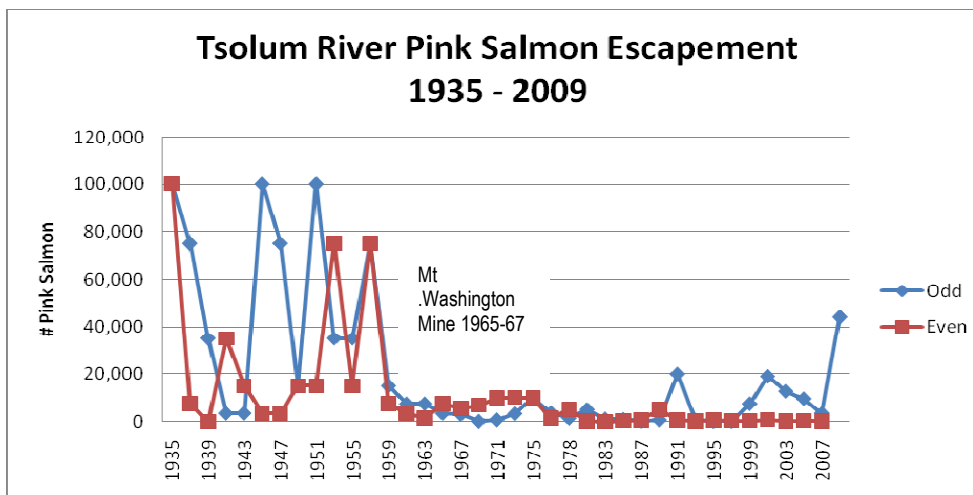


Figure 2. Tsolum River Pink Salmon Escapement 1935 - 2009

Sixty-five years of salmon escapement records from 1935 to 2009 (Figure 2) show that numbers of odd and even run fish have declined from 100,000 adults, reported returning in 1935 and 1936 to 10 adults reported in 1986.

Over the decades the method of gathering escapement data has changed. From 1923 to 1998 data was reported using the BC16 data range format that assigned a letter code to a range of abundance. In many instances this data was collected after brief visits were made to selected reaches of the river. Prior to 2003, escapement data was collected by DFO staff or patrolmen who walked select regions of the watershed. The nuSEDs database reports the median value from the abundance range (Appendix 1).

BC16s were replaced by the Stream Inspection Log (SIL) in 1999. The SIL is the system presently used for reporting salmon escapement. Prior to 2003 escapement data was collected by DFO staff or patrolmen who walked select regions of the watershed.

From 2003 to present, pink salmon escapement data has been collected by teams of Tsolum River Restoration Society volunteers. The advantage to this system is that volunteers are walking more of the watershed area and are collecting a body of local knowledge. The disadvantage is that volunteers are not paid for their time and the present system puts pressure on TRRS to coordinate volunteers and compile data.

The following graph series displays the changes in pink salmon reported over time. During the period between 1935 and 1958 abundance levels ranged from 100,000 to 3,500 with no data (reported as zero return) available for 1940.

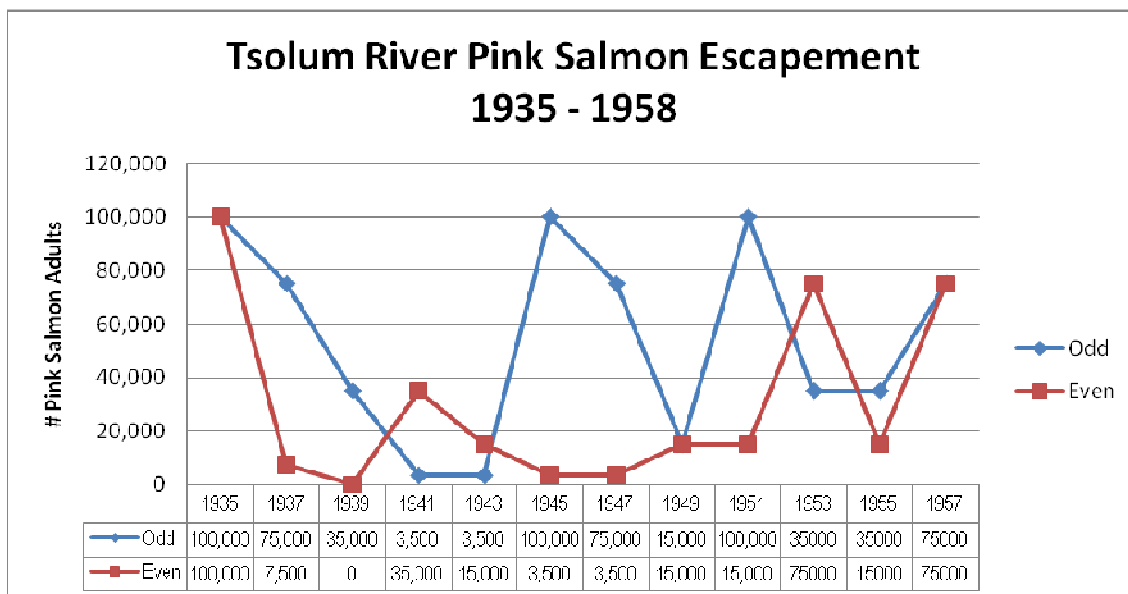


Figure 3. Tsolum River pink salmon escapement 1935 – 1958.

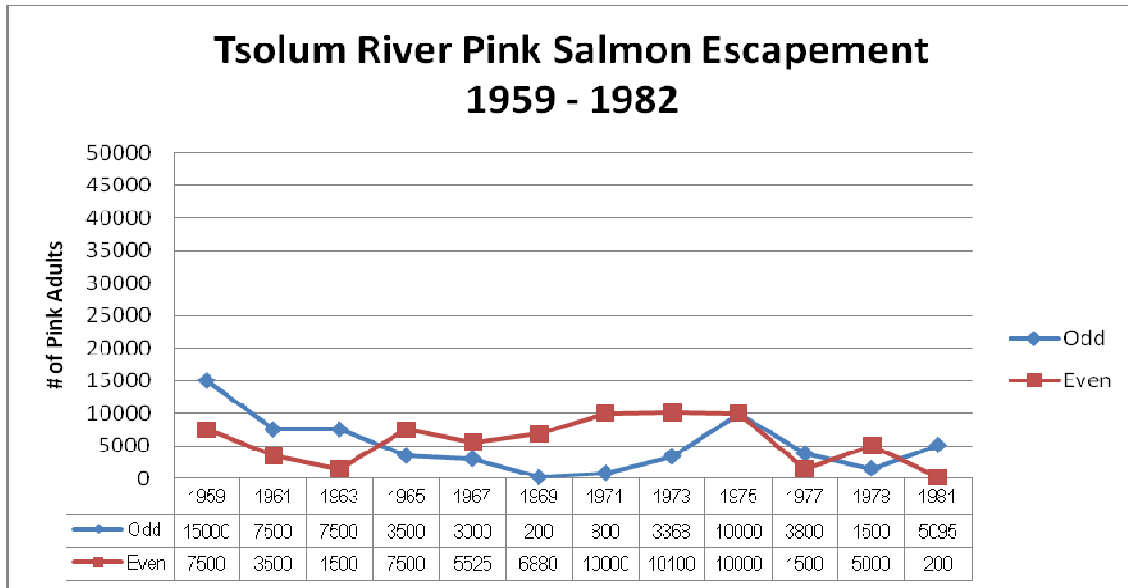


Figure 4. Tsolum River Pink Salmon Escapement 1959 -1982.

After 1983 even year returns to the river fell to less than 5% of average returns reported before 1959. Enhancement techniques presently being used for even year pink salmon stocks have not improved returns to the Tsolum River.

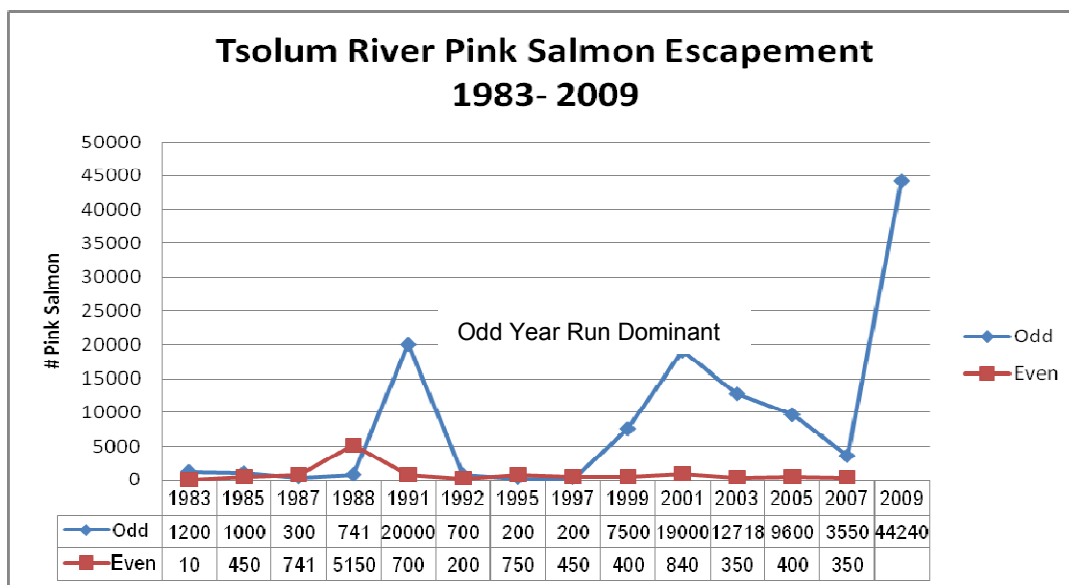


Figure 5. Tsolum River Pink Salmon Escapement 1983 – 2009.

The dominance of odd and even year pink salmon stocks is not well understood. Over the past seventy years there has been a change from equal dominance (1935 – 1936 and 1957-1958) to even year dominance (1965 – 1975) to the present odd year dominant cycle (1997-2007) in Tsolum River stocks.

This shift in even to odd year dominance is also evident in data reported for the Quinsam and Puntledge Rivers with even year stocks showing stronger returns prior to 1995 and all dominant odd year returns in both rivers since 2000.

The Tsolum River even year pink salmon returns are presently so low that they warrant being listed as a stock requiring urgent restoration. The plan should include selecting a donor or Tsolum stock for even year enhancement, use of net pen rearing to release fed fry and a habitat survey to determine if even year stocks are spawning in different areas of the river and tributaries.

There is also a need to determine why there was a shift in even-odd year dominance and how changes in freshwater habitat contributed to this shift. If there is to be a recovery of stocks to equivalent abundance of odd and even year runs TRRS will need to understand how these stocks use freshwater and estuary habitat.

Comparing Tsolum Returns to Quinsam & Puntledge River Data

An examination of returns to the Quinsam, Puntledge and Tsolum rivers from 1997 to 2007 shows that odd year returns to the Puntledge, Tsolum and Quinsam Rivers show a very strong correlation in escapement numbers between odd year returns to the three systems despite very different instream conditions (Tsolum:Puntledge .712, Tsolum:Quinsam .638, Puntledge:Quinsam .838).

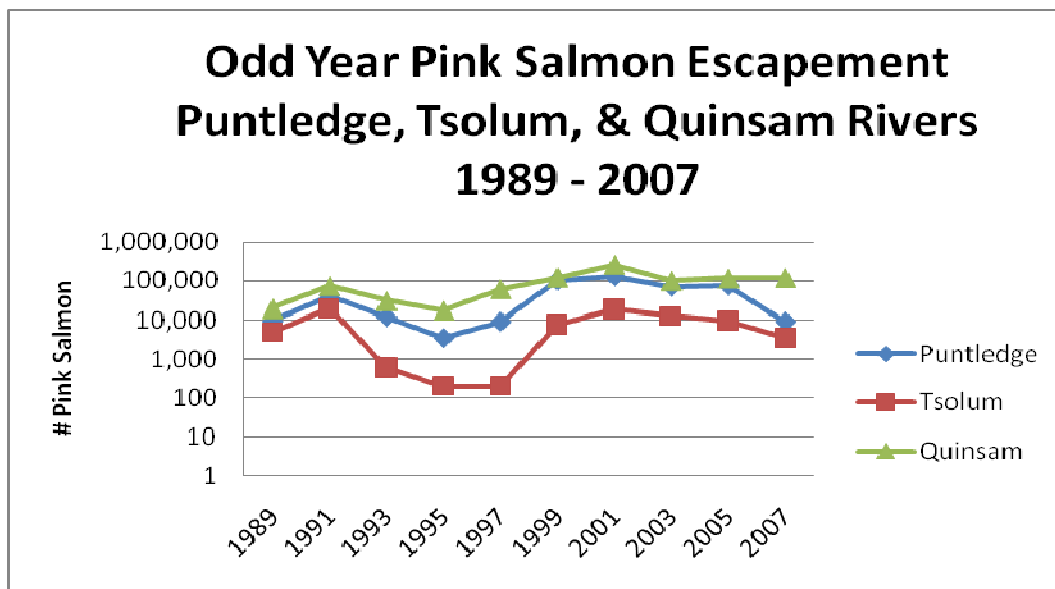


Figure 6. Odd Year Escapement to the Puntledge, Quinsam and Tsolum Rivers 1989 to 2007.

Tsolum and Puntledge Rivers (Tsolum:Puntledge .899) but weak for Tsolum and Quinsam stocks (Tsolum: Quinsam .335, Puntledge: Quinsam .547). This correlation suggests that marine survival is a controlling factor of survival in the three watersheds.

From 1985 to 1995 even year stocks were dominant. From 2000 onward, the Quinsam River has produced stronger even year stocks (Figure 7).

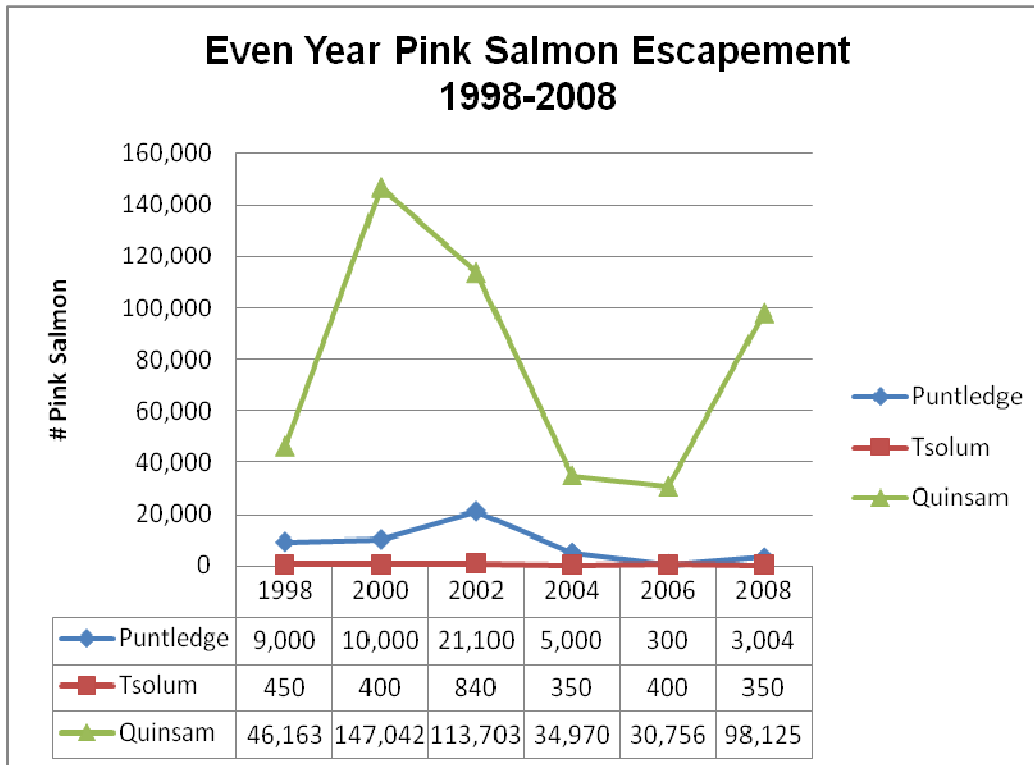


Figure 7. Even Year Escapement to the Puntledge, Quinsam and Tsolum Rivers.

High Water Temperature and Gamete Viability

In 2004, a study conducted at Puntledge Hatchery compared egg mortality between adult pink salmon exposed to three temperature regimes. Results showed that temperatures found in the Puntledge and Tsolum River during August and September (during the time of pink salmon spawning) are above optimum for egg viability and adversely affect the final stages of pink salmon maturation. The consequence of high temperature stress is increased adult mortality, delayed maturation rate, and reduced gamete viability.

Other research conducted in the Pacific Northwest determined that high temperatures are detrimental to all life stages of salmon including spawning, embryo development, growth, maturation, and resistance to disease (Cairns et al., 2005). Elevated temperatures can also affect swimming performance (Farrell, 2002) affecting the ability of Tsolum and Puntledge pink salmon adults and juveniles stocks to avoid seal predation.

The following graph illustrates the correlation between high water temperatures and pink salmon egg mortality as recorded during the 2004 Puntledge River Hatchery study.

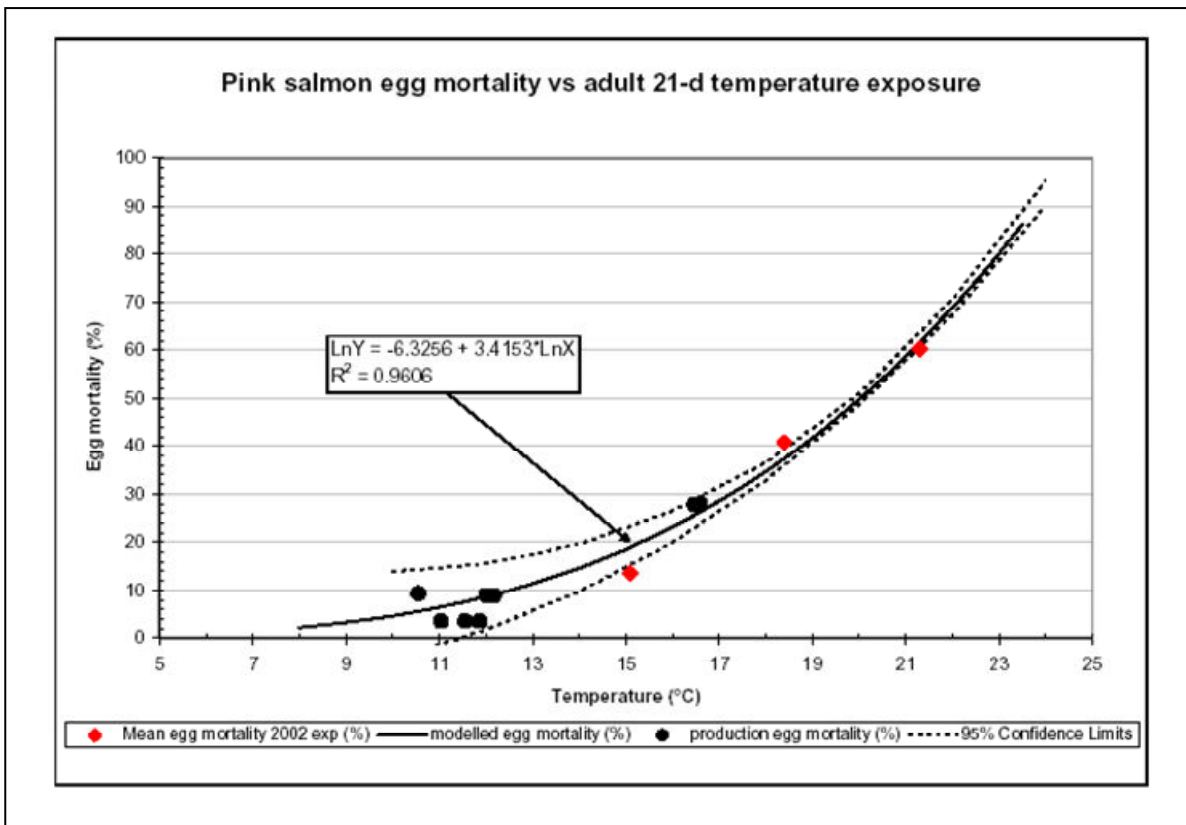


Figure 8 : Pink Salmon Egg Mortality vs. Adult 21 Day Temperature Exposure.

Data from the Puntledge River Hatchery study shows increased egg mortality when pink salmon adults were exposed to temperatures between 16.6 °C and 24°C. A study of temperatures in the Puntledge and Tsolum Rivers completed between May 14 and October 1, 1998 measured temperatures at the following sites along the rivers.

Table 2. Puntledge and Tsolum River temperature monitoring sites.

Puntledge River Temperature Monitoring Sites Jenkins et al. 2000	Tsolum River Temperature Monitoring Sites Jenkins et al. 2000
1 Comox Lake Outlet	1 Wolf Lake Outlet
2 Puntledge Hatchery Upper Site	2 Headquarters Creek
3 Pink Side Channel	3 Yew Tree
4 Puntledge Powerhouse Pool Puntledge Hatchery Lower Site	4 Lower Tsolum
5 Fence	
6 Fifth Street Bridge	

The study showed a similar temperature range between sites in both rivers, (12°C to 20°C) in the Puntledge River and (12°C and 18°C) recorded in the Tsolum River. Average temperatures in the Puntledge and the Lower Tsolum rivers vary by less than 3°C in August and by less than 1°C in September. Given this small temperature variation between the two rivers it is not likely that salmon would avoid migrating into the Tsolum River due to differences in temperature.

As pink salmon enter the Tsolum River they encounter cooler temperatures the further they travel up the river. Temperatures found in Headquarters Creek are lower than temperatures found in the lower river, but are still above optimum temperatures for pink salmon survival.

Table 3. Temperatures Recorded in the Lower Tsolum River and at Headquarters Creek Hatchery in 1998.

Tsolum River 1998 Temperature Records					Difference	
	Lower Tsolum		Headquarters Creek		Tsolum - Headquarters	
	Maximum	Average	Maximum	Average	Maximum	Average
August	23.1	20.8	20.6	18.7	2.6	2.1
September	21.3	17.8	20.9	17.0	0.4	0.8

Table 4. Temperatures recorded in the lower Tsolum River and at the Headquarters Creek hatchery in 2009.

Tsolum River 2009 Temperature Records					Difference	
	Lower Tsolum		Headquarters Creek		Tsolum - Headquarters	
	Maximum	Average	Maximum	Average	Maximum	Average
August	23.6	21.0	22.0	20.3	1.6	0.8
September	20.5	17.7	20.2	16.8	0.3	0.9

Although there is a variation in water temperature between different years, cooler temperatures are always found further up the watershed. Water temperatures decline as pink salmon migration progresses, but are commonly above the optimum temperatures for survival.

Physical Barriers to Migration

As returning adults return to the Tsolum River they may be held in the warm shallow pools downstream of the Rees bridge by a barrier fence that was constructed in 1951 (Fish Resource Board Technical Bulletin 1951).

On September 13, 1951 fisheries inspectors were called to investigate pink salmon dying in the Tsolum river. The adults were moving up the river on the high tide and were then trapped in shallow pools the as the tide dropped. To prevent

pink salmon from moving up the river during times of low water a barrier fence was constructed.

This fence is still in place and hinders adult pink salmon migration. During low tide the fish must hold in shallow pools below the fence. These pools are warm, low in oxygen and within the range of seal predation. Removal of the fence would allow pink salmon unrestricted passage to refuge habitat in the upper watershed.



Figure 9. Barrier fence located near the community fairground downstream of the Rees Bridge (UTM 10 E0355043 N5507820) Photo K. Campbell September 2009

Gravel accumulating in the lower reaches of the river is accumulating in pools that used to be available as refuge habitat. As the gravel builds up it causes water to flow sub-surface during times of low water. The exposed gravel beds become a heat sink that adds further stress to migrating salmon.

Low water levels in tributaries limit available spawning habitat. Pink salmon are thus restricted to spawning in the Tsolum mainstem, and in Dove and Headquarters Creek. During most years other tributaries such as Smit-Forsythe, Towee and Portuguese Creeks do not have enough water flow to allow fish passage until mid October.

Upstream of the barrier fence gravel accumulations near Rees Bridge also inhibit the passage of pink salmon. Spawner surveys conducted during August and September, 2009 (a year of abundant escapement) reported few redds located between this barrier fence to the Rees bridge. Also noted was gravel that was laden with silt and algae.



Figure 10. Gravel bar located upstream of Rees Bridge in the lower Tsolum River watershed. D. Gooding photo 2009.

The gravel bar upstream of the Rees Bridge is a challenge to pink salmon migration. Stream surveys conducted in 2009 showed that pink salmon do not hold in this area, preferring to migrate upstream to deeper pools at the Burkhart property at the end of Stephen Road. Although this gravel is an appropriate size for pink spawning this reach is not utilized by pink salmon.

Low water flows in many tributaries of the lower Tsolum River limit the available refuge and spawning habitat available to pink salmon. During August and September many of the tributaries such as Portuguese Creek, Dove Creek, Towee Creek and Spirit Creek are not passable due to low water conditions.

Gravel bars in the Tsolum mainstem also challenge migrating pink salmon and need to have channels maintained to allow the fish to travel upstream.

In September 2009 pink salmon were observed swimming into the Murex Creek tributary when water rose to allow access past the gravel bar that had accumulated at the confluence of Murex Creek with the Tsolum River. (D. Gooding, personal communication 2009)



Figure 11. Gravel accumulation at the confluence of Murex Creek and the Tsolum River. Note the larger gravel size as compared to the Rees Bridge gravel accumulation in the previous figure.

Removal of gravel is often seen as habitat destruction however when gravel was removed from the Tsolum River in 1943 for the construction of the Comox Airport stock numbers increased the following year suggesting that pink salmon production may benefit from gravel removal.

Water Flow Effects on Salmon Production

Pink salmon spawn in the Tsolum River from August to October and remain in the river until they migrate to the Courtenay Estuary during March and April.

The earliest spawners enter the river during the time of lowest flow and are unable to access refuge habitat because of lack of water in the tributaries. Water from Wolf Lake is added to Headquarters Creek and has a variable effect on increasing water flow in the lower reaches of the river. During dry years when groundwater levels are low much of the Wolf Lake water flows to ground before increased flows are notable at the Lower Tsolum flow station.

Peak spawning of pinks has been recorded to occur from October 10 – October 15th. Using average temperature data recorded at the Headquarters Creek Hatchery from 1997 to 2006 eggs deposited during the first two weeks of October would reach the eyed stage between November 1st - 8th.

Hatching occurs between January 5th and January 21st and fry swim up occurs between April 1st - 8th. Historical flow records report highest winter flows occur in the Tsolum River in November, December and January.

These peak flows move gravel down the watershed and can cause flooding, bank erosion and siltation of spawning gravel. This bed load movement also has the potential to kill or displace salmon eggs and alevins.

Although low flows and high temperatures impede spawning and migration, a hydrologic study of low and peak flows in the Tsolum River indicates that high water flows have a greater adverse effect on pink salmon survival than low flows (Gooding 2009). Pink salmon deposit their eggs in shallow redds, selecting gravel sizes of smaller diameter than other salmon species. This light gravel is moved easily by high velocity flows making pink salmon eggs particularly vulnerable to high flow events. Time series aerial photography has shown that high water flows that cause movement of gravel in the watershed is affecting access to tributary habitat and displacing redds.

Peak flows have become larger and more frequent as more of the watershed has been cleared and developed, and restoration of riparian vegetation is a multi-decade process. It is expected that gravel bars in the upper watershed will continue to travel downstream for decades to come.

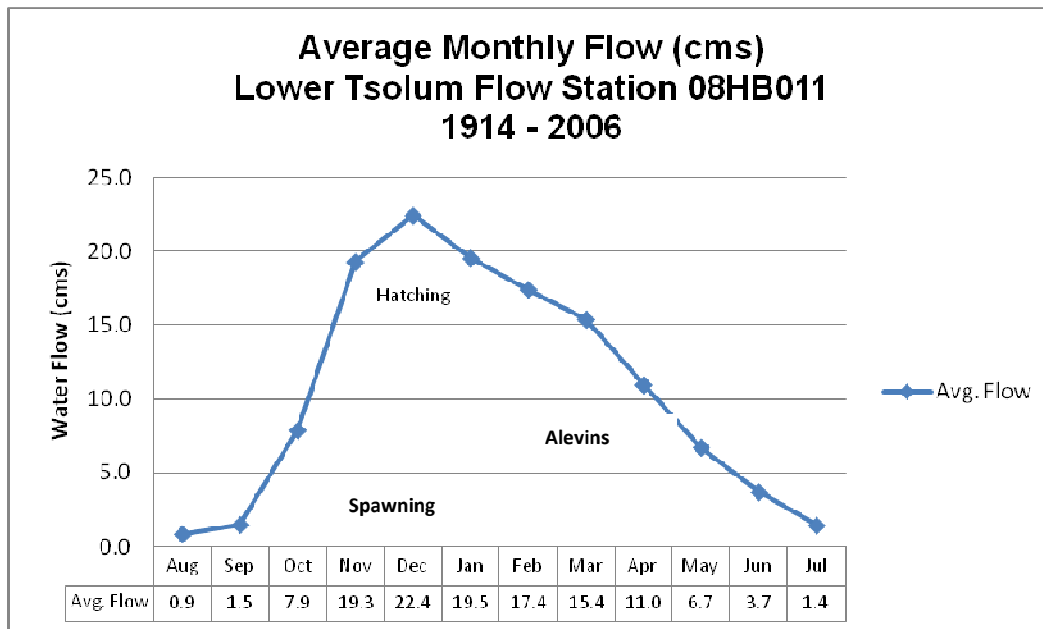


Figure 12. Pink salmon are at their most sensitive stages of development during the time of peak flows in the Tsolum River.

Time series aerial photography has shown how gravel has migrated from the upper reaches of the Tsolum River and it is expected that this migration will result in continual changes in habitat for decades to come.

To improve pink salmon productivity despite extreme high and low flows, passage to refuge habitat must be maintained. Providing access to refuge and tributary habitat by clearing gravel away to allow pink salmon passage is a task that needs to be undertaken each fall due to changing instream conditions. This can be done as a small scale volunteer project with teams working to keep river passage chutes open from August to October.

Present regulations do not require changes in upslope land use or in riparian buffer width to compensate for hydrologic changes in a watershed, so it is important that hatchery production is improved and that off channel habitat be developed to protect incubating fish from extreme flows.

Present regulations to not restrict development in order to maintain flow conditions favorable to salmon. The Society must work with landowners to maintain wide riparian buffer zones, retain upslope vegetation and reduce the amount of impervious surface in the watershed in order to minimize the effect of run off and high water flows that threaten salmon survival.

Availability of Estuarine Habitat

Pink salmon produced in the Puntledge and Tsolum Rivers both rear in the Courtenay River Estuary. The estuary has been dredged and development around the estuary has eliminated much of the riparian habitat (Morris 1979). The Courtenay River Estuary provides rearing grounds for salmon from the Puntledge River and its tributaries (Browns, Cruikshank, Morrison & Arden Creeks) and the Tsolum River watershed (Murex, McKay, Pyrrhotite, Headquarters, Dove and Portuguese Creeks). The combined area drained by these systems is 859 km² (Riddell and Bryden 1996).

The Trent and Tsable Rivers, Brooklyn Creek and Millard and Piercy Creeks also produce salmon that rear in this estuary, although they are not major pink salmon producing systems. Most pink salmon enter the Courtenay River estuary from the Puntledge and Tsolum watersheds.

All salmon face physiological stress when entering the marine environment. Pink salmon run strength is established or destroyed during the first few weeks after migration from freshwater. Salmon that have access to estuary refuge habitat and rich food sources should be able to minimize this stress, avoid predation and grow faster than fish facing competition for limited food and habitat.

The 2001 DFO survey of the Courtenay River Estuary found that most of the fish captured were found in man-made refuges (such as the Comox Marina) and that the available rearing habitat in the estuary was not adequate for the number of salmon fry utilizing the estuary. Researchers also noted that pink fry were in the estuary before their sampling began and that there is a need for further research to determine pink salmon fry usage of the estuary from February to the end of April.

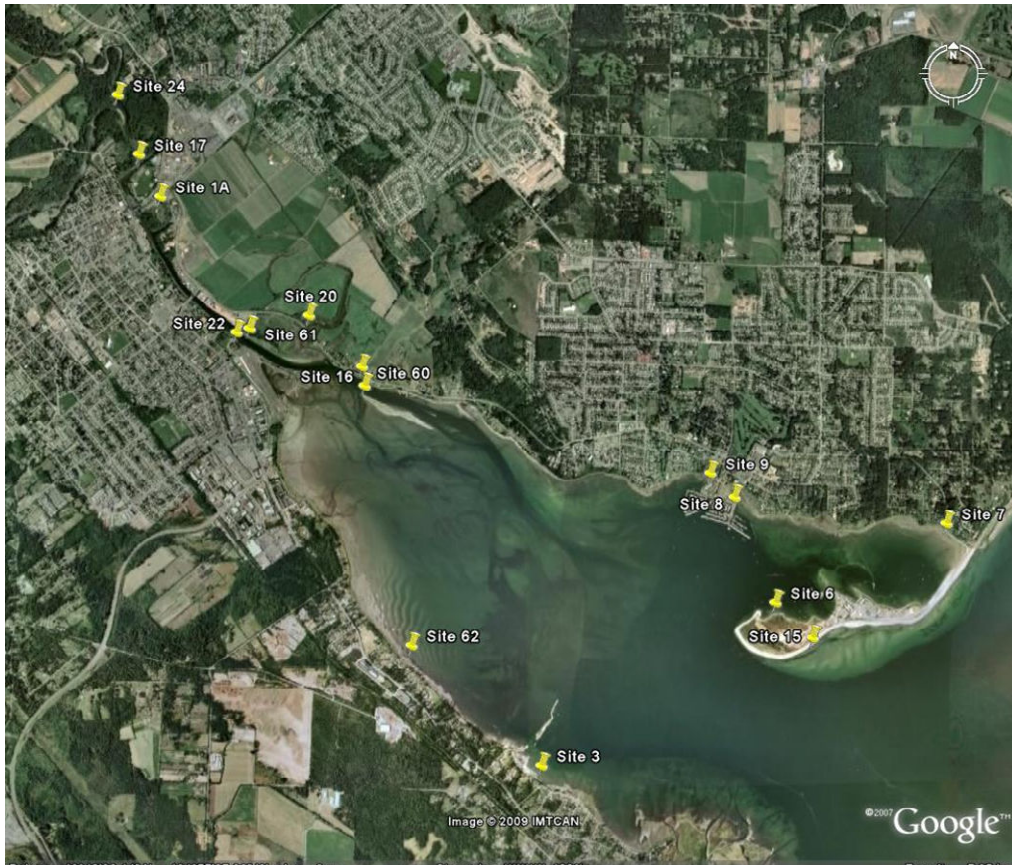


Figure 13. Sample sites in the Courtenay Estuary Hamilton et al. 2002

The study noted that temperatures at many of the sample sites were above 20°C, above the optimum temperature for salmon survival. The highest catches of salmon were found in dredged and man-made habitats - which are the deepest parts of the estuary.

No studies have been completed to define the productivity of habitat in the estuary for pink salmon; the number of pink salmon chosen for enhancement is not determined by available estuarine habitat.

Further study is needed to determine if even and odd year pink salmon stocks utilize the same areas of the estuary. Restoration projects that enhance nursery areas for pink salmon fry should be considered as a tool to improve pink salmon productivity.

Table 5. Pink Salmon Fry Collected at Courtenay River Estuary Sample Sites.

Courtenay River Estuary Study 2001		Total # Pink
Site #	Location	Juveniles
1A	Groove Millennium Park	7
3	Royston Pier	32
6	Inside Goose Spit	20
7	Mouth Brooklyn Creek	1
8	Comox Marina (dredged)	2,646
9	Bay west of Comox Marina	14
15	Outside Goose Spit	64
1	Dredged boat slough	1
17	Lewis Park	17
20	Duck Slough flood gate	16
22	Betty's Marina	5
24	Punt-Tsolum confluence	1
61	Across from Betty's Marina	1
62	South of site 40	2
16	Slough by sewage lagoon	2
60	Large tree in river	2
Total		2,831

Several recommendations from the Hamilton 2002 report may benefit pink salmon in the Tsolum River.

2002 Estuary Report Recommendations:

1. Investigate the extent of the salt marsh historically present in the upper estuary and the possibility of returning a portion of the former flood plains to marsh.
2. Increase off-channel rearing areas, especially in the upper, mid and lower river zones.
3. Explore the opportunities to create more low tide refuges, especially in the lower river and eastern estuary zones.
4. Investigate the possibility of creating new marsh habitat and dredged pools in the former sewage lagoon at the head of the estuary.
5. Collaborate with B.C. Hydro to maximize flows as much as possible during the warmer summer months and to investigate the potential benefits of constructing a system to allow the release of cold water from the depths of the lake.
6. Assess the levels of copper in the water and sediments in the estuary to ascertain historic and present levels.

Coordination of Successful Enhancement Programs

Stocks of Tsolum and Puntledge pink salmon share similar freshwater and marine rearing habitats. Historically the Tsolum River even year pink salmon stock was the more productive than the Puntledge River even year stock.

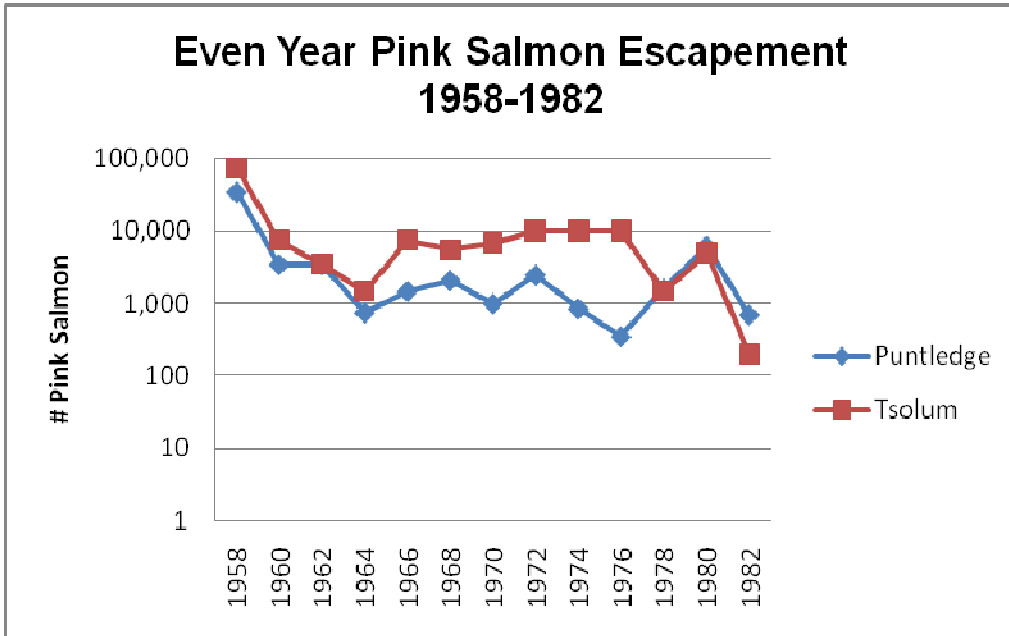


Figure 14. Logarithmic graph comparing even year salmon escapement to the Tsolum and Puntledge Rivers from 1958 to 1982.

After 1982 the Puntledge River even year production exceeds production from the Tsolum River.

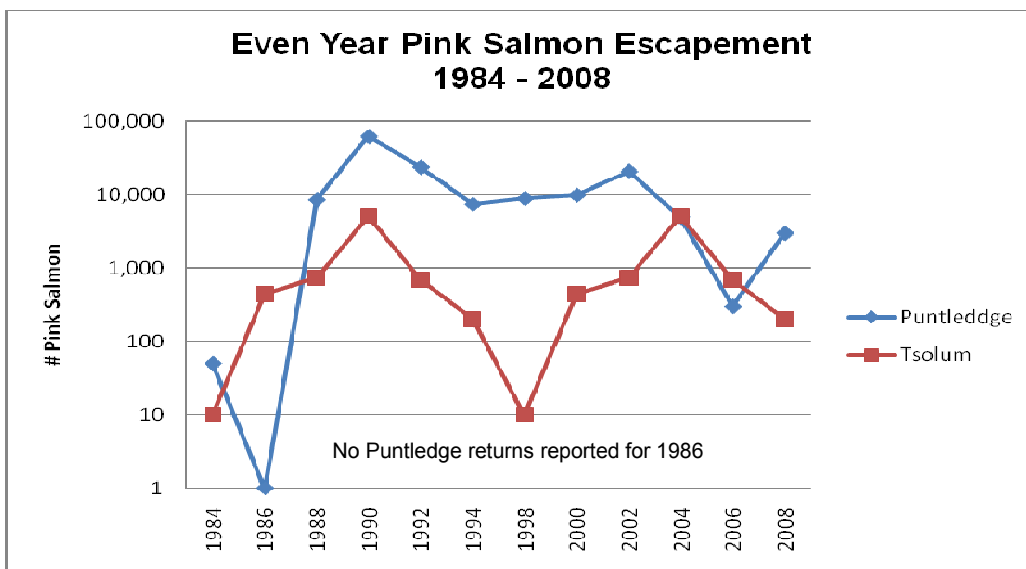


Figure 15. Logarithmic graph comparing Tsolum and Puntledge even year pink salmon production from 1984 – 2008.

In 1998 Puntledge Hatchery renewed their enhancement efforts at the Headquarters Creek hatchery by placing 1,000,000 pink salmon eggs into a keeper-channel style incubation system in the hatchery rearing channels. The Headquarters hatchery program has been in operation for 11 years and has produced variable returns of odd and even year stocks.

Egg-to-fry survival of Headquarters hatchery pinks is estimated to be 80 to 90% for all years. Despite using the same donor stocks and enhancement techniques for odd and even year enhancement programs, there has been no recovery of even year stocks. Return for effort spent on odd year enhancement brings 47 times the return that is realized from enhancing even year pinks. The historic productivity of the Tsolum River even year pink salmon stocks has been lost during the last 30 years, and should now be considered to be an endangered stock.

There may be an advantage to pink stocks in coordinating production from both rivers to reduce competition for estuary rearing habitat. There is also an opportunity to enhance early marine survival of Tsolum stocks by using net pens in the Courtenay Estuary to produce fed fry before release. Holding the fry in net pens and monitoring plankton activity in the estuary would allow the fry to be released at the time when food resources are most abundant.

The use of netpens for pink enhancement is a controversial strategy as increased pink salmon survival may initiate a recreational fishery and increase pressure on Puntledge River Chinook stocks that inhabit the Courtenay River Estuary. However by using fisheries closures for pink and chinook stocks we can avoid this conflict and review the potential for a recreational fishery after both stocks show strong recoveries.

Since 2000, four times as many summer chinook have returned to the Puntledge River than even year pink salmon returning to the Tsolum River (9,704 summer chinook, 2,340 even year pinks). The majority of summer chinook migrate into the Puntledge River before the pink salmon return in mid August. Fishing is closed in the Courtenay Estuary until September 1st and fishing in the Puntledge River does not open until October 1st. As long as the even year pink salmon are not being enhanced to create a fishery there should not be a conflict with summer chinook.

It is important to maintain the hatchery program as the the hatchery provides stable rearing conditions. During years of major high flows the hatchery produces the majority of fry surviving to migration. It is also important to focus the enhancement program to target improvements in even as well as odd year stocks.

It is difficult to know how many of the pink salmon returning to the Tsolum River are descendents of the original Tsolum River stock as none of the fry are marked before release. The Society is planning to work with Puntledge Hatchery staff to transport the Headquarters Creek hatchery fry below the fry-trapping site at the base of Stephen Road. With all of the enhanced fry downstream of the trap the pink fry that do enter the rotary screw trap can be assumed to be wild stock.

During the past 10 years the majority of odd and even run pink adults returning to the Tsolum River have been observed spawning in Headquarters Creek and escapement surveys report that over 70% of the pinks returning to the Tsolum migrate into Headquarters Creek (J. Minard, personal communication 2009). The fact that the fish are choosing the Headquarters system suggests that enhancement efforts have been successful in bringing fish back to the area that they migrated from. However, unless the fry are marked this cannot be proven.

Table 6: Return for Effort of Odd Year Fry Produced at Headquarters Hatchery.

Headquarters Creek Pink Salmon Enhancement			Odd Year		
Year	Donor Stock	#	Returned	#	Return/
		Released	in Year	Returned	Effort
1999	Quinsam	500,000	2001	19,000	3.80%
2001	Puntledge/ Quinsam	1,000,000	2003	12,718	1.27%
2003	Quinsam	1,000,000	2005	9,600	0.96%
2005	Quinsam	1,000,000	2007	3,550	0.36%
2007	Quinsam	1,000,000	2009	50,000	5.00%
Total		4,500,000		94,868	2.28%

Table 7. Return for effort of even year fry produced at Headquarters Hatchery.

Headquarters Creek Pink Salmon Enhancement			Even Year		
Year	Donor Stock	#	Returned	#	Return/
		Released	in Year	Returned	Effort
1998	Puntledge	1,000,000	2000	400	0.08%
2000	Puntledge	1,000,000	2002	840	0.08%
2002	Puntledge	1,000,000	2004	350	0.04%
2004	Quinsam	1,000,000	2006	400	0.04%
2006	Quinsam	1,000,000	2008	350	0.04%
Total		5,000,000		2,340	0.06%

Present enhancement efforts produce consistently greater returns/effort with odd year stock.

TRRS has been reluctant to change enhancement techniques until there is a proven reduction in copper leachate from the mine site. Once the water quality in the Tsolum River is proven to be within standards below lethal limits for salmon, changes will be made to pink enhancement programs.

Restoring Even Year Pink Salmon Stocks

Despite releasing 1,000,000 fry per year, there have been fewer than 1,000 adults returning for each of the past five even year enhancement cycles. More research and experimentation must be completed to ensure stronger returns of even year stocks.

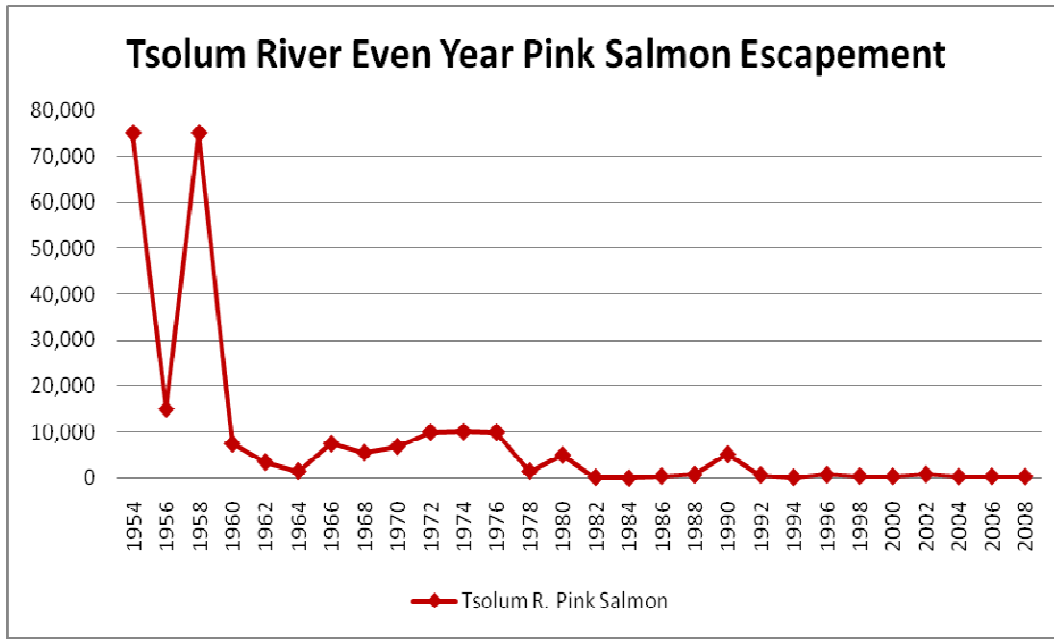


Figure 16. Tsolum River even year pink salmon escapement 1954 - 2008.

Table 8. Even year returns of pink salmon to the Tsolum River

Tsolum River Even Year Pink Salmon Escapement 1998 - 2008					
1998	2000	2002	2004	2006	2008
450	400	840	350	400	350

Examination of even year pink salmon stocks from the Quinsam River and the mainland inlets (Glendale and Kakweiken) do not show the same decline in even year returns.

Since the re-establishment of the pink salmon hatchery program on Headquarters Creek there has been no coordination of production targets between the Puntledge and Tsolum Rivers. It is time to establish pink enhancement as a focused project consider production from both rivers and to investigate how estuary conditions affect returns to both rivers.

By coordinating early/mid and late stock enhancement with stocks enhanced at Puntledge Hatchery, release timings can be extended thereby increasing the possibility that hatchery will encounter zooplankton that will sustain them. Coordinating releases from the two rivers also provides the option of staging or pulsing releases into the estuary to research the optimum productive strategy.

Unless there is an adjustment in the methods used to enhance the even year Tsolum stocks there is a risk of losing a cycle that produced 100,000 fish in 1936 and 75,000 fish in 1958.

Quinsam Hatchery has had success with using net pen rearing to enhance even year pink salmon stocks. When this technique was proposed to Puntledge Hatchery staff and at the Tsolum River Pink Salmon Strategic Review meeting in December 2009, the advisors suggested that it may be wise to wait until copper levels have declined so there is no confusion about the positive effect that may be coming from mine site coverage.

DFO staff also suggested that pink salmon returning to the Courtenay River Estuary may cause extra fishing pressure that would threaten Puntledge Summer Chinook stocks. Further discussion with Puntledge Hatchery staff suggests that using net-pen enhancement for pinks would not negatively impact chinook survival because of a difference in return timings between the two stocks.

Control of Copper Leachate and Mine Site Restoration

Since the establishment of the Tsolum River Task Force in 1997, a primary goal has been to reduce copper levels in the river. Elevated copper concentrations were first noticed by DFO staff in 1986 when, despite using enhancement techniques that were proven successful at other facilities, only 10 pink salmon were reported as returning to the Tsolum River. Investigations revealed that high levels of copper were leaching from the north pit of the abandoned Mt. Washington copper mine (Erickson and Deniseger 1987). Water samples taken downstream of the mine were recorded well above the 7 ppb level recommended for the Tsolum River. In 1986, sampling showed that stream invertebrates were absent in Pyrrhotite Creek and in 1999 bioassays conducted using coho fry held downstream of Murex Creek had 100% mortality in 24 hours (Campbell 1999). Further downstream the concentrations were below lethal concentrations but were still recorded at levels that adversely affect the ability of pink salmon to acclimate to salt water (Erickson and Deniseger 1987). Water quality studies led to remediation plans that recommended covering the mine site. The first cover was completed in 1989 (Galbraith 1992), but it was not until 10 years later that any noticeable reduction in copper concentrations was reported.

In 2003, water from Pyrrhotite Creek was diverted into the Spectacle Lake wetland as a passive treatment for copper leachate from the mine site. At the time of construction, it was estimated that this wetland would be effective for approximately 10 years, after which a permanent solution to reducing dissolved copper levels in the river would have to be found.

In the summer of 2009, the first phase of a three-phase project was initiated to restore the Mt. Washington mine site. During phase 1, the surface of the North Pit was contoured and a series of drains was installed to direct water away from the acid generating rock.

A bituminous geomembrane cover was placed over the North Pit to seal the site against rainwater. Beginning in the summer of 2010 this membrane will be covered with 1 metre of till. The west dump will also be covered with till and both sites will be revegetated. If required, there is a third phase of water treatment that can be developed to lower copper concentrations to below provincial guidelines.



Figure 17. Geotextile membrane covers the Mt. Washington mine site September 2009.
K. Campbell photo

Leachate from the Mt. Washington mine site reaches lethal levels during mid October when fall rains flush the mine site and again in the first two weeks of June when the snow melts at the mine site. Pink salmon enter the river in August and complete spawning by mid October, so adults and fry are not active in the river during the time that the highest concentrations of copper are present. Pink salmon eggs do incubate in the copper-laden water and high copper concentrations may reduce the viability of the eggs (Barry et al. 2000).

Copper levels that were lethal to salmon in the Tsolum River may also inhibit salmon survival in the estuary (Levings et al 2004). The copper levels in the sediments at depth have not been investigated in the estuary and the levels of copper within the surface sediments have not been tested since 1999. Sampling copper concentrations in marine sediments may indicate whether the mine site is also affecting salmon survival out of the river.

Research conducted by Windom (1986) showed that although copper bound to sediments may be stable, copper can also be released into the water column under conditions of low salinity as are found in the Courtenay River Estuary. High copper concentrations also have adverse effects on invertebrates, molluscs and algae (Windom 1986). TRRS volunteers are working with Ministry of Environment staff to determine if the mine site cover is effectively reducing copper levels in the river below 7 parts per billion, the level determined to be safe for salmon in the Tsolum River (Deniseger and Pommen 1995).

Competition with Chum Salmon on Spawning Grounds

Chum salmon enter the Tsolum River in October after most pink salmon have completed spawning. An examination of Fisheries and Oceans escapement records from 1998 to 2008 shows very low escapement numbers for chum in the Tsolum River, suggesting that competition with chum salmon does not have a major effect on pink salmon production.

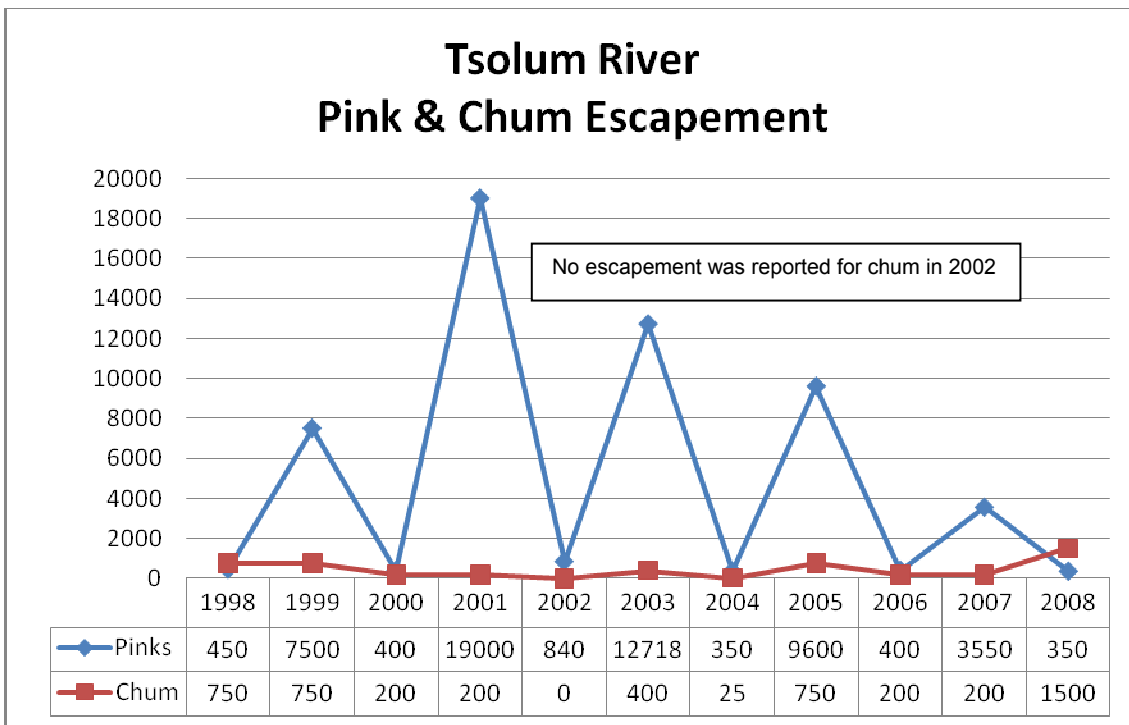


Figure 18. Pink and chum escapement in the Tsolum River 1998 – 2008.

Development of an Atlas for the Tsolum River

The key tool for restoring productivity for pink salmon in the Tsolum River is the establishment of an atlas showing reference sites. This atlas will allow researchers and volunteers to locate habitat restoration works and sampling sites and to report changes in productivity of defined river regions and reaches. The atlas can also be used to educate landowners and to assist volunteers conducting escapement studies.

Since 1999 TRRS has been using ArcView 3.1 software to produce maps that are used in planning and reporting on river restoration projects and for directing volunteers in adult enumeration projects.

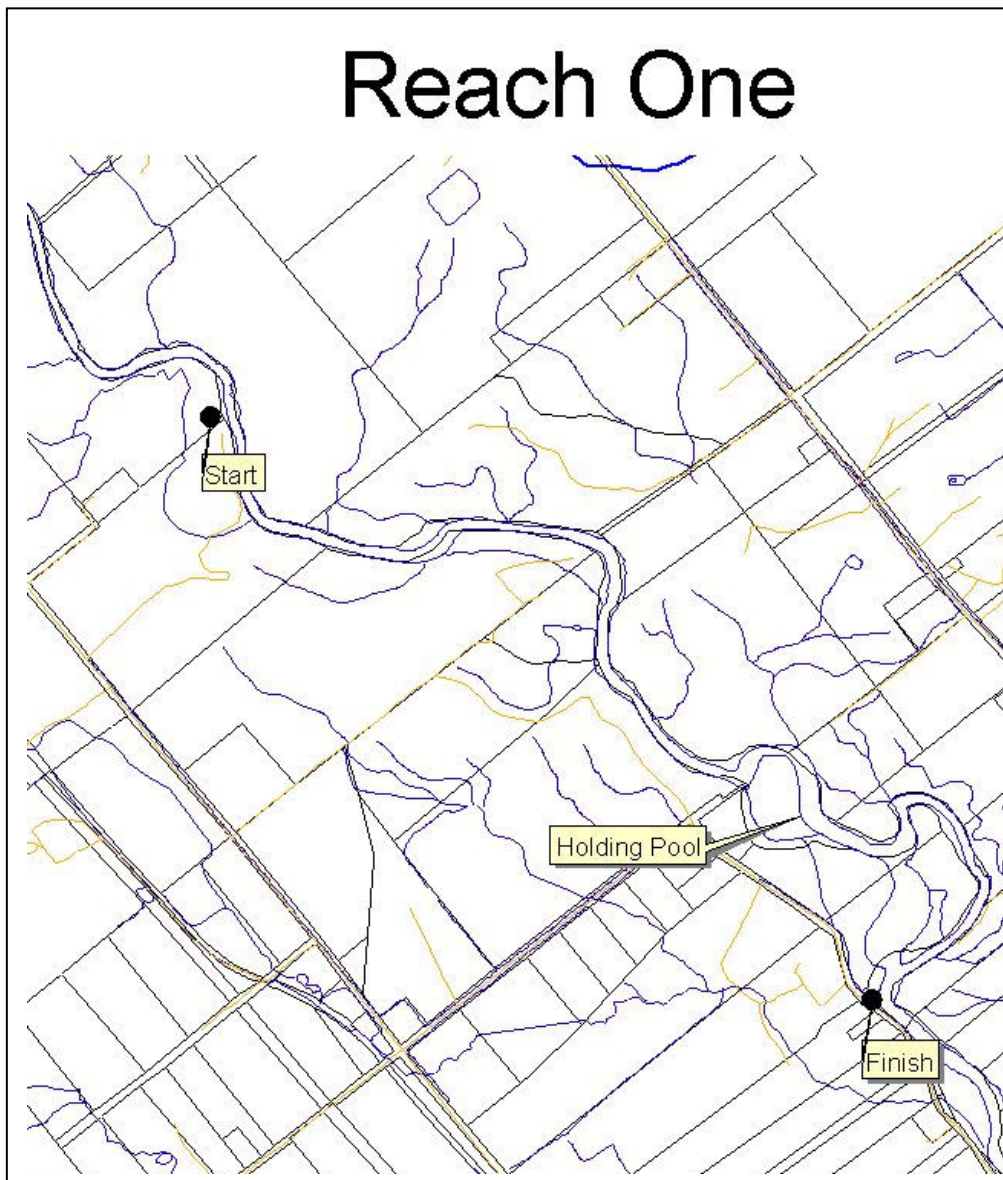


Figure 19. ArcView 3.1 map of Reach 1 in the lower Tsolum River.

Restoration projects in the watershed can be better managed if the Society uses modern imaging technology such as Google Earth to establish an atlas of the Tsolum River watershed.

The use of the term “reach” to describe the lower Tsolum River should more aptly be described as a region since instream habitat is variable throughout this area. The river needs to be defined into a series of regions. Each of these regions should be defined as a series of reaches. The Society could use this reference system to manage restoration projects and to direct volunteer activities. Each area

should identify a series of features such as bridges or tributary confluences that will become the benchmarks of the atlas. Production and restoration targets can then be developed for each region and a community of residents and volunteers can be identified for each region of the river.

Selection of the benchmarks of the atlas should begin with consultation with volunteers, watershed residents, and professionals that are familiar with the watershed. This can be done by meeting with volunteers and by using online resources and then they should be verified by groundtruthing. Each benchmark chosen should be identified as being within a region, within a reach and with descriptors that can be easily identified by volunteers. The benchmarks will be located using GPS and GIS mapping technology, so that funders and other professionals working in the watershed can determine the exact location of a project. By using bridges or other easily identified features volunteers will be able to identify and communicate their position without the need to take GPS or other technology into the field.

The advantage to establishing the atlas is that by agreeing on a standard series of benchmarks along the river the Society can begin to develop a new level of fluency and understanding of how river processes and productivity change over time.

Present online technology allows atlas images to be labelled and transmitted without the need of expensive ArcView software or GIS training. For example, volunteers returning from a session of salmon spotting could upload their data directly onto the maps and over time we would have a geo reference of how spawning frequency and the location of spawning and rearing habitat is changing in the river.

This project will develop a level of territorial knowledge and fluency that we have never seen before. Once we are all working with the same benchmarks and the same map series we will be able to share and build on our knowledge of our river that will help us build productivity region by region, reach by reach, and species by species for all seasons.

The following Google Earth image shows the same region of the lower Tsolum River as was shown in Figure 19, however the area is shown with greater detail.



Figure 20. Google Earth image of the lower Tsolum watershed.

By working with mapping technicians from Project Watershed, the Society can produce an atlas that will also contribute to community knowledge of the watershed. This atlas will be the cornerstone for a complete stock and habitat recovery plan for the watershed.

Recommendations

The following actions are recommended in order to establish strong even and odd year runs of pink salmon in the Tsolum River.

1. TRRS and the Ministry of Environment must continue water quality sampling to verify the effectiveness of the mine site cover.
2. Once copper concentrations are proven to have stabilized below levels defined in the *Ambient Water Quality Objectives for the Tsolum River Basin*, upper watershed habitat enhancement projects and estuary net pen programs can be initiated.
3. Develop specific objectives for restoration goals, as have been developed for copper, to clarify recovery targets and measures of success for pink salmon sustainability.
4. Develop a GIS atlas for the Tsolum River that can be used to coordinate restoration efforts along the watershed. The atlas will aid in the development of productivity targets for all regions of the watershed and assist the Society in following changes in the watershed over time. This atlas should be easily updated, and accessible to volunteers without the need for ArcView software.
5. The Courtenay River Estuary is a vital extension of the Tsolum River and has a strong effect on pink salmon productivity. Tsolum River Restoration Society (TRRS) should establish a marine survival committee that participates with the Estuary Working Group to better understand research catches and ocean conditions.
6. Develop a restoration plan for pink salmon in coordination with Puntledge Hatchery. Enhancement programs must be regulated by the availability of rearing habitat in the Courtenay River Estuary.
7. Recognize the Tsolum River even year stock as endangered and develop a long-term production plan that includes using net pens to increase early marine survival. Returns of even year pink salmon should be protected from recreational fisheries until even year runs increase to 10,000 fish as seen in 1974 – 1975.
8. Remove the barrier fence structure located in the lower Tsolum River watershed GIS UTM: (U10 E 0355043 N 5507820). This fence inhibits migration of salmon upstream at low water. Fish held behind this barrier at low tide are threatened by predation and may be stressed by high water temperatures. Spawning habitat immediately above and below the fence is laden with silt, which may deter pink salmon from spawning.

9. Strengthen volunteers “on the river” presence during times of adult and fry migration. Develop an information plan that identifies deficiencies of productivity and habitat enhancement opportunities for each river region.
10. Identify reaches of high flow sensitivity and work with upland owners to reduce conditions that lead to extreme high water flows.
11. Work with streamside landowners to understand their needs and to share our knowledge about the needs of the river. August and September are the times of lowest flow; nothing should be done to decrease flow or water quality during this critical time.
12. Even year returns of pink salmon have been declining in the Puntledge as well as the Tsolum River. Consult with the K’omoks First Nation to determine the effect of food fish harvesting on low even year pink returns.
13. Study the effect of predation on pink salmon survival. Seals, crayfish and trout populations have increased while pink salmon returns have been declining.
14. The Tsolum River Restoration Society should work with its funders and partners to complete at least one project each year that will bring forward knowledge about the watershed.

References

- Barry, K. L., Grout, J. A., Levings, C. D., Nidle, B. H., and Piercey, G. E. 2000. Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound, British Columbia. *Can. J. Fish. Aquat. Sci.* 57: 2032-2043.
- Cairns, M. A., Ebersole, J. L., Baker, J. P., Wigington, Jr., P. J., Lavigne, H. R., and Davis, S. M. 2005. Influence of summer stream temperatures on Black Spot infestation of juvenile coho salmon in the Oregon Coast Range. *Tran. Am. Fish. Soc.* 134: 1471-1479.
- Deniseger, J. and L. W. Pommen. 1995. Ambient water quality objectives for the Tsolum River basin. Overview report B.C. Ministry of Environment. Environmental Protection Division. 9 p. Available from <http://www.elp.gov.bc.ca/wat/wq/objectives/tsolum/tsolum.html> [accessed December 10 2009].
- Department of Fisheries and Oceans 2007 Quinsam Hatchery Fish Culture Operations Manual Unpublished Staff Report Sections A1-6
- Farrell, A. P. 2002. Cardiorespiratory performance in salmonids during exercise at high temperature: insights into cardiovascular design limitations in fishes. *Comp. Biochem. Physiol. Part A*, 132: 797-810.
- Fisheries & Oceans Canada. NuSEDS V2.0 Regional Adult Salmon Escapement Database. Tsolum River Pinks 1953-2005. Retrieved November 15, 2009. www.heb.pac.dfo-mpo.gc.ca/maps/maps-data_e.htm [accessed December 10, 2010]
- Fisheries Research Board 1951. Progress Report Pacific Coast Station Drought Brings Death to Salmon 88:72
- Galbraith, M. 1992. Mt. Washington Mine Reclamation Project Proceedings of the 16th Annual British Columbia Mine Reclamation Symposium in Smithers, BC, 1992. 176 p.
- Gooding, David 2009. Tsolum River Biophysical Inventory, a report for the Tsolum River Restoration Society (unpublished).
- Hamilton, S. L., Bravender, B. A., Munro, B., Stephens, S., and Dziekan, T. 2002. Results of beach, mini purse, purse, gee trap and pole seine surveys at the Courtenay River estuary and Baynes Sound, Courtenay, B.C. 2001. *Can. Data Rep. Fish. Aquat. Sci.* 1089: 141 p.

- Jenkins, J.A., Bravender, B.A., Beggs, C., Munro, B., and Miller, D. 2006. The distribution and abundance of juvenile salmonids and other species in the Courtenay River estuary and Baynes Sound, 2000. Can. Tech. Rep. Fish. Aquat. Sci. 2659: xiv + 77 p.
- Jensen, J. O. T., McLean, W. E., Damon, W., and Sweeten, T. 2004. Puntledge River high temperature study: influence of high water temperatures on adult pink salmon mortality, maturation and gamete viability. Can. Tech. Rep. Fish. Aquat. Sci. 2523: 50 p.
- Levings, C. D., Barry, K. L., Grout, J. A., Piercey, G. E., Marsden, A. D., Coombs, A.P, and Mossop, B. 2004. Effects of acid mine drainage on the estuarine food web, Britannia Beach, Howe Sound, British Columbia, Canada. *Hydrobiologia* 525: 185-202.
- Minard, Jack, 2009. Executive Director Tsolum River Restoration Society Personal Communication.
- Morris, S, Leaney, A. J., Bell, L. M., and Thompson, J. M. 1979. The Courtenay River estuary: Status of environmental knowledge to 1978. Report of the estuary working group. Fisheries and Environment Canada Special Estuary Series 8: 355 p.
- Riddell, A., and Bryden, G. 1996. Courtenay River water allocation plan. B.C. Ministry of Environment, Lands and Parks, Regional Water Management, Vancouver Island Region, Nanaimo, B.C. 80 p.
- Sweeten T. 2010. Department of Fisheries & Oceans Temperature Records for Puntledge and Tsolum Rivers Unpublished Data. Accessed January 2010
- Windom, H., Wallace, G., Smith, R., Dudek, N., Maeda, M., Dulmage, R., and Storti, F. 1983. Behavior of copper in southeastern United States estuaries. *Mar. Chem.* 12: 183-193

Appendices:

Appendix 1. Headquarters Creek Pink Salmon Releases and Returns (*DFO Quinsam Hatchery Manual 2007)

Headquarters Creek Pink Salmon Enhancement				Odd Year Releases/Returns Quinsam Donor Stock				
Year	# Released	# Returned in Year	# Returned	Return/ Effort	Fry Release with		Fry Release with	
					100% Wild	% Enhanced	50% Wild	% Enhanced
		1999	7,500		5,062,500	9.0%	2,531,250	16.5%
1999	500,000	2001	19,000	3.80%	12,825,000	7.2%	6,412,500	13.5%
2001	1,000,000	2003	12,718	1.27%	8,584,650	10.4%	4,292,325	18.9%
2003	1,000,000	2005	9,600	0.96%	6,480,000	13.4%	3,240,000	23.6%
2005	1,000,000	2007	3,550	0.36%	2,396,250	29.4%	1,198,125	45.5%
2007	1,000,000	2009	50,000	5.00%				
Total Releases	4,500,000			Total Returns	94,868		Average Return/Effort	2.108%

Headquarters Creek Pink Salmon Enhancement				Even Year Releases/Returns Quinsam Donor Stock				
Year	# Released	# Returned in Year	# Returned	Return/ Effort	Fry Release with		Fry Release with	
					# Eggs	% Release	50% Wild	% Enhanced
		2000	400		270,000	79%	135,000	88.1%
2000	1,000,000	2002	840	0.08%	567,000	64%	283,500	77.9%
2002	1,000,000	2004	350	0.04%	236,250	81%	118,125	89.4%
2004	1,000,000	2006	400	0.04%	270,000	79%	135,000	88.1%
2006	1,000,000	2008	350	0.04%	236,250	81%	118,125	89.4%
2008	1,000,000	2010	N/A	NA				
Total Releases	4,000,000			Total Returns	1,940		Average Return/Effort	0.0485%

Appendix 2. Water Temperatures Recorded at Headquarters Creek Hatchery 1997 – 2005 (Sweeten 2010 Unpublished)

Water Temperature Headquarters Creek Hatchery Intake												
1997												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.66	2.83	3.74	7.55	12.41	14.82	17.22	18.72	15.77	10.26	7.16	4.76
Max Mean	2.30	4.30	5.40	9.28	15.14	17.06	19.24	20.19	18.02	13.16	9.34	6.49
Min Mean	0.48	1.54	2.20	5.08	8.18	12.90	14.75	16.71	13.12	8.53	5.43	3.70
N	31.00	28.00	31.00	27.00	31.00	30.00	31.00	31.00	30.00	31.00	30.00	31.00
Max	2.67	5.44	6.25	10.28	16.95	18.63	20.99	21.86	18.96	13.50	9.47	6.74
Min	-0.80	0.20	0.87	4.14	7.54	12.21	14.15	15.79	12.54	7.86	4.96	3.48
1998												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.40	4.10	5.40	8.25	13.07	15.88	18.45	18.69	17.05	11.92	8.09	4.20
Max Mean	4.13	4.46	6.82	12.41	15.26	18.51	22.46	20.55	20.86	14.92	9.85	5.92
Min Mean	-0.83	3.65	3.49	5.99	10.73	14.04	14.69	17.05	14.12	9.36	6.28	1.14
N	31.00	28.00	31.00	30.00	31.00	30.00	31.00	31.00	30.00	23.00	30.00	31.00
Max	4.63	4.63	7.54	14.80	17.28	21.51	24.51	22.26	21.93	15.16	10.05	6.19
Min	-0.96	3.32	2.67	4.78	9.15	12.21	13.98	15.63	12.99	8.97	5.87	0.85
1999												
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	3.63	3.02	3.90	7.16	10.43	14.11	16.71	17.61	15.59	10.35	7.01	4.87
Max Mean	4.42	3.50	5.25	10.13	13.81	16.57	18.77	19.67	17.30	13.01	8.24	6.19
Min Mean	2.46	2.47	2.22	4.87	8.25	11.64	13.91	14.54	12.78	7.37	5.55	3.14
N	31.00	28.00	31.00	30.00	31.00	30.00	31.00	31.00	30.00	31.00	30.00	31.00
Max	4.63	4.00	5.71	11.58	14.84	17.85	21.26	22.26	18.17	13.28	8.34	6.33

Water Temperature Headquarters Creek Hatchery Intake

2000

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.66	3.47	5.24	8.96	11.15	14.92	16.75	16.93	15.78	10.55	6.33	3.67
Max Mean	3.97	4.59	7.34	10.48	13.33	18.59	18.67	19.05	17.50	12.81	9.08	6.58
Min Mean	1.74	2.38	3.97	7.96	8.58	12.37	14.65	15.04	13.92	8.56	4.34	0.15
N	31	29	31	30	31	30	31	31	30	31	30	31
Max	4.16	4.94	8.65	12.18	15.42	20.86	21.51	21.51	18.11	13.41	9.25	6.64
Min	0.69	1.80	3.38	6.64	7.57	11.72	13.56	13.41	12.95	7.88	4.01	-0.07

2001

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	3.88	3.16	5.28	7.98	11.60	13.93	16.12	17.39	15.56	10.44	7.43	3.99
Max Mean	4.67	4.49	6.38	9.98	14.89	16.24	18.01	19.95	17.09	13.04	9.16	4.95
Min Mean	3.16	1.97	3.43	6.11	9.05	11.95	14.61	14.62	13.28	7.44	4.28	2.66
N	31	28	31	30	31	30	31	31	30	31	30	31
Max	4.80	4.80	7.12	11.45	16.72	18.64	20.76	20.92	18.16	13.88	9.39	5.20
Min	2.92	1.51	2.61	5.27	7.90	10.17	13.58	13.88	12.65	6.92	3.16	2.21

2002

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	3.59	3.65	3.77	7.64	12.17	15.69	17.74	18.83	15.52	10.79	7.25	5.73
Max Mean	5.06	4.39	6.30	10.17	13.39	17.86	19.96	20.60	18.88	13.73	8.92	7.02
Min Mean	1.23	2.70	1.19	6.25	10.35	12.31	15.04	15.05	12.90	5.30	4.20	3.48
N	31	28	31	28	26	30	31	31	30	31	30	31
Max	5.36	4.89	7.69	13.42	14.66	20.76	22.93	21.75	19.29	14.03	8.96	7.28
Min	0.78	2.37	0.13	5.04	8.46	11.41	13.73	14.04	12.34	4.65	3.57	2.79

Water Temperature Headquarters Creek Hatchery Intake

2003

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	4.72	4.42	5.41	7.77	11.72	15.78	17.27	18.14	16.04	11.68	5.15	4.50
Max Mean	5.65	5.41	7.06	11.44	14.64	18.48	20.00	20.35	19.88	15.53	6.75	5.26
Min Mean	3.51	3.41	2.03	5.77	9.02	13.48	14.96	16.62	13.73	6.43	2.90	2.22
N	28	28	31	30	31	30	31	31	30	31	30	31
Max	5.89	6.04	8.04	13.27	15.59	20.69	21.68	21.19	20.37	16.38	7.12	5.58
Min	3.26	2.47	1.04	4.95	8.20	12.18	13.42	15.28	12.97	5.89	2.15	1.68

2004

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.91	4.09	6.12	9.68	13.41	16.25	17.65	20.27	15.42	11.70	7.90	5.48
Max Mean	4.44	5.29	7.42	12.67	14.93	19.55	19.33	22.37	18.26	14.07	9.62	6.53
Min Mean	0.09	3.07	4.69	6.49	11.71	13.23	15.41	16.81	13.38	8.52	5.47	4.01
N	31	29	31	30	31	30	31	31	30	31	30	31
Max	4.65	5.58	8.20	14.81	17.17	21.36	20.21	23.41	18.97	14.98	9.70	6.76
Min	-0.06	2.63	4.03	5.42	9.88	12.03	14.66	15.77	12.33	7.86	5.05	3.65

2005

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	2.97	3.74	6.57	9.29	13.70	15.58	17.27	18.57	15.49	10.98	6.93	4.07
Max Mean	5.60	5.87	7.54	14.41	17.10	17.94	18.96	20.50	17.64	12.84	9.41	6.34
Min Mean	0.00	2.57	5.14	6.63	11.08	13.83	15.72	16.67	13.49	8.91	3.12	1.47
N	31	28	31	30	31	22	31	31	30	31	30	31
Max	5.83	6.14	8.47	16.39	18.64	19.61	21.07	21.57	18.48	13.43	9.70	6.45
Min	0.00	1.59	4.59	6.14	10.79	13.12	14.20	14.35	12.65	8.47	2.85	0.95