Structural hydrology and limiting summer conditions of San Juan County fish-bearing streams

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Summary

Instream flow stages and summer pool conditions (depth, temperature, dissolved oxygen, fish presence and activity) were measured in seven Orcas Island streams and one San Juan Island stream where native fish (coho, chum, cutthroat, rainbows, sticklebacks) had been observed by Wild Fish Conservancy water typing surveys in 2004-2007. Most of the fish consistently observed were coastal cutthroat (*Oncorhnchus clarki clarki*).

Results indicate that while island salmonid stocks seem relatively tolerant of high summer pool temperatures, low levels of dissolved oxygen, and exposure to mammal and bird predators in confined shallow waters, a minimum continuous stream flow of 0.1 was required for salmonid survival, and minimum flow of 0.25 cfs was necessary to maintain some degree of pool connectivity by glides. Underwater video confirmed that cutthroat were actively feeding in daytime conditions as extreme as 20^{o}C and 3 mg/L of dissolved oxygen. Video records and redd surveys also confirmed that cutthroat adults enter island streams from late August to December and spawn in March-April; and that juveniles tend to spend their first summer in isolated stream pools before emigrated in fall.

Summer stream flows are a function of the summer reservoir capacities of island watersheds. Natural water storage features such as vernal pools, bogs, and other wetlands have been drained, diverted, excavated and impounded extensively, reducing the summer flows in many streams. Changes in island weather patterns, including drier summers and more extreme precipitation events in the winter, will increase the need for summer water storage while reducing infiltration rates and the proportion of winter precipitation stored. Artificial reservoirs—ponds and modified lakes—can be harnessed to replace some of the islands' lost natural storage capacity, but can lose as much as half of the stored water to summer evaporation. Salmonid survival and recovery in San Juan County is impossible without effective protection of the islands' remaining natural reservoirs, and expansion of capacity by a combination of recreating wetlands (for example by modifying ponds) and regulating outflow from ponds and lakes.

Additional concerns, such as continued introduction of invasive fish and frogs and persistent construction of roads with inadequate culverts, are also discussed.

Priority action is recommended for the Garrison watershed (San Juan Island), and the West Beach and Bayhead watersheds on Orcas, on the basis of historical fish use, the potential for habitat improvement, and sea-accessibility. Ongoing surveys of Lopez, San Juan Island and Shaw streams may identify additional priority targets for action.

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Table of Contents

Structural hydrology and limiting summer conditions of San Juan County fish-bearing streams

Methods and Overview

The Wild Fish Conservancy has been mapping habitat structure and fish presence in San Juan County streams since 2004. Most Orcas Island streams, and some streams on San Juan Island, were completed in 2008. Additional streams and stream reaches on San Juan Island, Lopez, Shaw and Waldron continue to be surveyed.

Surveys have thus far located two streams with significant populations of coastal cutthroat (*Oncorhynchus clarki clarki*) and three streams with marginally small cutthroat populations, one of which appears to have already been extirpated by development while this study was underway. Rainbow trout or steelhead (*Oncorhynchus mykiss*) were found in three streams albeit two represented the descendants of documented planting. Juvenile Chum salmon (*Oncorhynchus keta*) and Coho salmon (*Oncorhynchus kisutch*) were seen in four streams. Only the cutthroat trout have been documented repeatedly with multiple age classes demonstrating instream reproduction.[1]

Whether these salmonid populations are "natural", as opposed to being planted or introduced, is not a legal requirement for habitat protection, but descriptions of individual streams include whatever evidence we have gleaned from the recollections of landowners and fly fishermen. Genotyping will be necessary to resolve the origins of island cutthroat and steelhead stocks reliably. Our laboratory genotyped an initial sample of 54 Garrison and Cascade cutthroat specimens using the Wenberg microsatellite marker set (Wenberg et al. 1998, and Wenberg and Bensen 2001). The two populations are genetically distinct from one another and internally relatively homogeneous.[2] Relative homogeneity of fish from Cascade Creek, Mountain Lake (the stream source), and Cascade Lake suggests that WDFW planting of cutthroat fry in the lakes has overwhelmed any native stocks. Further sampling and genotyping is recommended to identify genetically distinctive native stocks with confidence.

As a local partner in these surveys, Kwiáht has focused on two related questions: Why are Pacific salmonids and other native fish species only surviving in a small number of streams where there is seemingly adequate habitat in terms of riffles and pools, gravels and shade? What has changed, and is still changing in habitat conditions that restricts the current distribution of Pacific salmonids in San Juan County, and threatens the survival of these existing island salmonid populations?

Based upon our previous understanding of island hydrogeology, we hypothesized that summer drought conditions are the limiting factor for salmonid survival. Unless fish leave island streams by May or June, they face low to zero flows, isolation in small pools

[1] Some rainbows are reproducing in lakes where they were planted and have been observed foraging—but not necessarily spawning—farther downstream. Juvenile False Bay Creek chum observed in May 2010 are almost certainly the offspring of fish spawning in that stream, but only one generation has yet been seen.

[2] Complete unpublished genotyping data are available upon request as an Excel spreadsheet.

with gradually warming water, and possible hypoxia, as well as increased vulnerability to predators such as mink, river otters, herons, and kingfishers. If trout over-summer before migrating to sea—or if they are land-locked residents—then they must: (1) tolerate warm, hypoxic and relatively exposed conditions, and/or (2) be restricted to streams that retain a certain minimum summer stream flow that must be maintained, for trout survival, against pressures from riparian development and climate change. As described below, our results indicate both relatively high toleration of summer pool conditions, and the necessity of at least some continuous summer flow.

This is consistent with studies elsewhere in our region (e.g. Wigington et al. 2006) suggesting that intermittent streams can be productive, albeit fragile salmonid habitat.

Methods

Instream flow stages and summer pool conditions (depth, temperature, dissolved oxygen, fish presence and activity) were measured in seven Orcas Island streams and one San Juan Island stream where native fish (coho, chum, cutthroat, rainbows, sticklebacks) had been observed by Wild Fish Conservancy water typing surveys in 2004-2007.

<u>Stream flows</u>: Flow velocity was measured with a Global Water Flow-Probe held in mid-channel for 3 minutes; average flow in feet per second was recorded as computed by the instrument. Most flow measurement stations were culverts, making it possible to calculate water volume precisely from the cross-sectional area of the filled portion of the pipe. Where measurements were of necessity made in a natural stream channel, a broad, relatively flat and shallow point in the stream was chosen to minimize distortions from an irregular cross-section, or differences in velocity from the center to edges of the flow.

<u>Stream pool depths and dissolved oxygen</u>: Enameled steel staff gauges marked in whole centimeters were bolted to meter-long steel posts pounded into the substrate at the deepest point of each monitored pool. Volunteer stream monitors visited and read gauges 2-3 times per month, also measuring dissolved oxygen and water temperature at the pool surface using an EX-TECH Pro dissolved oxygen instrument, and noting flow conditions, wildlife, fish, and weather. This was organized both as a data-gathering exercise, and as a means to mobilize local citizen support for longer term monitoring and protection.

<u>Stream temperature records</u>: HOBO Water-Temp Pro loggers were strapped with cable ties to the bottom ends of staff gauges in monitored pools, and programmed to take temperature readings every 15 minutes. Staff gauges were positioned so that the HOBO instruments measured temperatures at the substrate or just above it, *i.e.*, at pool bottoms. Volunteers measured pool surface temperatures 2-3 times per month using their Ex-Tech dissolved oxygen instruments, hence for a number of summer dates there are comparable surface and bottom records.

<u>Fish behavior</u>: An Ocean Systems DeepBlue digital underwater video camera was used to make hour-long, fixed-point observations of fish in selected pools at intervals of two to three weeks in summer and fall 2007-2008, when stream flows were lowest. From February to May 2009, stream riffles were walked to locate redds.

Summary of results

The threatened status of San Juan County streams is reflected in a summary of the flow conditions we observed in mid-July 2007. Each block in the flow column represents one-half cfs to a maximum of 2 cfs. Gray represents less than 0.1 cfs, and blank mean the stream glides were dry. Glide refers to whether there was at least one inch of water in the channel flowing between pools. Fish refers to whether salmonids were present.

Table 1: Summer flows and fish presence (July 2007)

Island	*Watershed*	*Sampling station*	*Flow*	*Glide?*	*Fish?*
Lopez	Hummel	Cross Road		No	No
	Davis Bay West	Davis Bay Road		No	No
	Davis Bay East	Davis Farm		No	No
	Jasper Cove	Blue Fjord Cabins		No	No
Orcas	Cascade	Pt Lawrence Road		**Yes**	**Yes**
	Crow Valley	Margo's Lane		No	No
	Doe Bay	Doe Bay Resort		**Yes**	**Yes**
	Skull Creek	Deer Harbor Road		No	No
	Bayhead-Victorian	Meadowbrook Lane		No	**Yes**
	West Beach	West Beach Road		No	**Yes**
San Juan	Beaverton Valley	University Road		No	No
	False Bay	Bailer Hill Road		No	No
	Westcott Bay	Westcott Drive		No	No

Midsummer stream flows of 0.1 cfs or greater were a necessary, but not sufficient condition of salmonid presence. Pool conditions vary within streams; key factors such as temperature and dissolved oxygen may reflect pool depths, riparian vegetation, substrate characteristics and biological oxygen demand (BOD) from decaying organic materials, as much as the availability of stream flow. Tables 2 and 3 summarize conditions in several stream pools we monitored in summer 2007 and summer 2008.

In two streams—Doe Bay and West Beach—we observed cutthroat in a deep pool but not a shallower and better oxygenated pool less than 20 meters away. Temperature is not the issue: the shallower pool in each pair was not significantly warmer. Food supply is a possible explanation, but we believe that a more plausible explanation is refuge from predators. Cutthroat appear to retreat to the deepest pools available as summer flows fall, even if this means that they risk hypoxia. We note that only sticklebacks were seen in the shallow pools monitored on Crow Valley Creek—and they disappeared when oxygen fell below 30 percent in September 2007. Sticklebacks also disappeared from the dug pond on the West Beach system when oxygen levels fell below 30 percent in 2008.

Note too the survival of cutthroat in a dug pond in the Garrison system at very high (surface) temperatures. We filmed these fish resting on the bottom during the day, and only rising in the evening to feast on floating insects.

Table 2: Pool conditions and fish use (July-September 2007)

Stream	Site	Pool conditions			
		Highest °C	Lowest DO%	Lowest depth	Fish use
Cascade	Olga tank	15.5	94.3	36	Cutthroat
	Footbridge	14.9	88.6	30	Cutthroat
Crow Valley	Big pool	15.6	23.4	49	Sticklebacks
	Stream pool	15.5	43.2	23	Sticklebacks
	Long pool	13.5	29.7	25	Sticklebacks
Doe Bay	Plunge pool	14.1	38.5	51	Cutthroat
	Stream pool	14.1	50.5	12	None
Garrison	Alpaca pond	23.9	65.8	160	Cutthroat
West Beach	Stream pool	15.5	76.5	24	None
	Plunge pool	15.7	62.8	54	Cutthroat

Depths recorded in centimeters

Table 3: Pool conditions and fish use (June-October 2008)

Stream	Site	Pool conditions			
		Highest °C	Lowest DO%	Lowest depth	Fish use
Cascade	Olga tank	16.1	75.4	28	Cutthroat
	Footbridge	16.1	72.2	25	Cutthroat
Doe Bay	Stream pool	18.0	70.6	41	None
	Plunge pool	16.2	69.5	44	Cutthroat
Garrison	States Inn	17.1	64.3	26	Cutthroat
	Troutbeck	16.0	66.0	17	Cutthroat
West Beach	Plunge pool	19.0	52.5	56	Cutthroat
	Pottery pond	19.0	11.6	62	Sticklebacks

Depths recorded in centimeters

A mitigating condition in Cascade Creek was relatively high summer flows (never below 0.25 cfs) that maintained glides. This presumably afforded salmonids opportunity to evade predators that they would have lacked in isolated pools. In 2008, Cascade pools were even lower, but still sustained juvenile cutthroat.

Temperature fluctuations were measured hourly in pools in five streams where we found cutthroat or sticklebacks (Appendix II). Diurnal and seasonal variation was greater at Cascade, Crow Valley and West Beach than at either Garrison or Doe Bay, but with no obvious consequences for fish survival. Average summer temperatures were well within the reported comfort range for cutthroat in 2008-2009, but it should be borne in mind that summer weather can vary considerably from year to year. An unusually warm summer—or the removal of shading vegetation—could easily raise stream pool temperatures from a comfortable 14-16^{o}C to a potentially dangerous 20^{o}C or greater.

We originally predicted that salmonids in isolated pools would all behave like the cutthroat in the dug pond at Garrison in 2007: resting close to the bottom, at least during daytime, and only rarely actively foraging or interacting. Our video monitoring of pools (Appendix I) found cutthroat active most of the time, however, not only feeding both at the surface but on the bottom, but engaging in aggressive behavior with each other and, in the case of West Beach, other fish (sticklebacks and pumpkinseeds) in the same pools.[3] This suggests that island cutthroat populations are relatively well adapted to the extremes of temperature and oxygen that we observed: 19^{o}C (and possibly greater at the bottom of the dug pond on the Garrison system) and 38.5 percent dissolved oxygen (at least briefly in the Doe Bay system). However, there are clearly limits. No fish survived less than 30 percent dissolved oxygen, equivalent to roughly 3 mg/L, and no pool continued to harbor fish if summer flows ceased altogether.

Video records also suggest migration times when unimpeded passage is critical. Mixed aggregations of adult and juvenile cutthroat were filmed in the estuary of Cascade Creek on August 31 and in the plunge pool beneath the first waterfalls on November 20. Redds were observed the following April. In the Garrison system, a mix of juvenile and adult cutthroat were filmed at States Inn in March and November 2008; redds were seen in April that year as well. Adults appear to enter these streams from August to November and spawn in March and April. Some but not all juveniles migrate out in fall as adult fish are arriving. Those that remain abandon their summer pools and range more widely. The trigger is presumably the onset of fall precipitation, which gradually increases flows and re-connects pools and glides.

This cutthroat life cycle necessitates that 0+ age fish remain in the stream for their first summer. Summer pool conditions therefore determine the survival of each cutthroat generation. Pool conditions depend on stream flows, which in turn are a function of the limited summer water storage in wetlands and lakes.

[3] Aggressive behavior included tail following and sudden lunges.

General observations

Summer water storage is the principal natural limitation on salmonid survival and reproduction in San Juan County. Natural water storage features such as wetlands (bogs, marshes, vernal pools, wet deciduous woodlands) and lakes are necessary for maintaining summer stream flows that irrigate, cool and oxygenate the stream pools where salmonids retreat in the dry months. Diverting, impounding, or degrading natural reservoirs reduces summer flows and forces pool conditions beyond levels that salmonids can tolerate.

Island soils are post-glacial: young, thin, and clay-rich with poor infiltration. The deepest and most porous island soils are "mucks" (mainly decomposed vascular plants) and "peat" (incompletely decomposed vascular plants such as sedges or sphagnum moss) that accumulated for millennia in depressional wetlands. Apart from a few natural lakes filling glacial potholes such as Hummel and Killebrew, island streams rely upon wetlands and wetland soils for summer storage capacity.

Our study of 19th century maps and recent soil surveys suggests that as much as 50 percent of the islands' total area comprised shallow seasonal wetlands 150 years ago. Most large island wetlands are "vernal pools" that fill in winter, with up to several feet of standing water, then slowly drain and evaporate in summer. Typically these features hold water because they are relatively shallow and bottom into watertight glacial clays. Their soils range from Coast Salish peoples planted camas and other staple foods in shallow wetlands, and when settlers brought European farming practices to the islands in the 19th Century, they too found the best soils and growing conditions in vernal pools.

Incompletely decomposed plant material—peat, broadly speaking—absorbs water literally like a sponge, in fibrous vascular structures. Sphagnum peat can absorb as much as ten times its volume: a saturated sphagnum peat is 90 percent water. Some peats float on water, furthermore, providing a cap that minimizes evaporation. Floating peat can be seen at Summit Lake on Mount Constitution, and is also found in the Deer Harbor (Fish Trap Creek) watershed, among others. All peats drain slowly into any available natural or artificial outflow channel; their capacity depends on depth and integrity. Removing the peat to create an open artificial reservoir simply accelerates evaporation, so that up to half of the stored water is lost each summer rather than flowing downstream.

Unlike Coast Salish peoples, 19th Century settlers wanted drier fields for summer row crops, hay and livestock, so they drained wetlands, often by excavating large ponds down to the clay. Peat bogs were excavated, and sometimes mined or burned. Beavers, which had continually created shallow short-lived ponds in wetlands by diking them with brush and mud—leaky dikes that actually contributed to stream flows—were trapped out, leaving deeper, less vegetated, and generally less leaky artificial ponds for reservoirs. On the whole, digging ponds reduced net water storage capacity due to increased evaporation –and took much of the storage capacity "off line" by stopping leaks and seeps. Ponds did not increase water retention in the islands, but the contrary.

Lacking snow pack to hold winter precipitation until summer, the islands depend mainly on wetlands—in particular wetlands with thick peat deposits—to ensure summer stream flows naturally. Unfortunately, the islands' wetlands continue to be compromised by development notwithstanding the laws aimed to protect them. Arguably a major issue is the lack of a biologically meaningful standard for prioritizing wetlands for protection. A natural bog that drains into a stream with freshwater fish is far less expendable than an accumulation of water above an improperly culverted roadbed; however, we encountered evidence, speaking with landowners in the course of our field studies, of variances given for the destruction of critical bogs and enforcement actions over unintended wetlands that resulted from poor infrastructure engineering. Credible consistent enforcement is needed, to help stabilize what remains of the islands' natural surface water storage capacity.

When storage capacity declines, summer stream flows not only decrease, but also may cease altogether in mid- to late summer. A growing number of island streams stop flowing for weeks to months each year. And as storage capacity continues to decline, the length of time that streams are dry increases. When flows cease in summer, fish become isolated in small pools that slowly grow warmer and less oxygenated until flows resume.

The present study found salmonids in isolated pools where there is at least some flow—as little as 0.1 cfs—throughout the summer. No fish survived in pools that had no flow for any period of time. The only significant populations of salmonids we observed, in the Cascade and Garrison streams, enjoyed at least 0.25 cfs throughout the dry season. This should not be taken to be a benchmark for healthy salmonid populations, but rather as an absolute minimum for their survival. Summer flow of 0.25 cfs is required in all the streams we studied to maintain at least some summer glides between pools—connectivity of pools and foraging habitat. Higher summer flows would be better.

Climate change will continue to affect the ability of island watersheds to maintain summer stream flows. In the rain shadow of the Olympic Mountains and the Vancouver Island Coast Range, the San Juan Islands tend to be relatively dry, with annual rainfall on the south end of Lopez and San Juan Island averaging as little as 14 inches. Rain shadow effects are strongest to the south and weakest to the north of San Juan County. The north end of Lopez enjoys nearly twice the annual rainfall of the south end. Eastsound tends to be nearly three times as wet as southern Lopez. Elevation also matters: the highest peaks and ridges in the islands—which also happen to be northerly—are the wettest parts of the county, and sources of the county's largest streams. But throughout the archipelago there has been a trend towards milder winters, more extreme winter precipitation events (more rainfall per minute), and drier summers. This results in a larger proportion of winter rain running off rather than infiltrating in soils and aquifers; at the same time that it increases the need for reservoirs to maintain summer stream flows.

Declining winter infiltration and summer precipitation have probably been factors in the loss of summer stream flows and salmonid populations in San Juan County over the past 75 years—particularly in the driest southerly parts of the county—and this trend will continue. Human activity has also played a growing role in degrading island streams and diminishing salmon habitat. Early British and American settlers drained wetlands, leveled stream channels and planted reed canary grass, excavated the peat from bogs, and built dikes in salt marshes and estuaries to enlarge their pastures and produce "salt hay". The combined effect of climate change and degrading our natural water retention features has helped create the pattern of seasonal stream flow seen today.

In 2007, a large reach of the Garrison stream between the States Inn and Blazing Tree Road was dry from August 3 to October 20. Many other streams on Orcas and San

Juan Island did not begin flowing until October, and their glides did not fill enough to re-connect stream pools even later the season. In the following table, "first flush" refers to a measurable flow greater than 0.1 cfs. Fish use refers to conditions in summer 2007 in the same reach as the sampling station or above it.

Table 4: Dates of first fall flush and glide restoration (2007)

Island	*Watershed*	*Sampling station*	*Fish use*	*First flush*	*First glide*
Orcas	Bayhead-Victorian	Meadowbrook Lane	Cutthroat	November 5	December 5
	Crow Valley	Margo's Lane	Stickleback	November 13	November 20
	Doe Bay	Doe Bay Resort	Cutthroat	November 13	November 28
	Fish Trap Creek	Cormorant Bay Road	None	January 27	March 10
	Pickett Springs	Johnston's Pond	None	November 13	January 18
	Skull Creek	Deer Harbor Road	None	November 20	December 27
	West Beach	West Beach Road	Cutthroat	October 8	October 8
San Juan	Garrison	Blazing Tree Road	Cutthroat	November 21	November 28

Several streams remained functionally disconnected for four to eight months after midsummer, including most (or all) of the window for the return of adult cutthroat in the autumn. Late streams had no salmonids (like Pickett) or only resident salmonids (Doe Bay). Hydrographs of late streams (Appendix III) illustrate the effects of ponds that must fill completely before they can spill over into the channel downstream. Upstream ponds also result in abrupt cessation of stream flows in early summer, potentially stranding fish in de-watered glides.

Historical processes of water storage loss and stream dismemberment may explain the loss of some island salmonid populations that were fished recreationally as recently as the 1970s, and the marginal status of others, such as West Beach and Doe Bay cutthroat.

While it may sometimes be feasible and desirable to restore natural water storage features—for example, by partly filling, widening, and re-vegetating ponds so that they function more like natural vernal pools or beaver ponds—there is also a potential role for using existing artificial reservoirs as resources for maintaining summer stream flows. As described in this report, regulated summer discharges of water from existing dug ponds can enhance habitat conditions in some island streams. The choice between taking water from a pond, and restoring the wetland that preceded it, is not simply a matter of cost, but also one of results. Rebuilding wetlands creates off-channel habitat for fish, amphibians, bats and birds. Ponds are more likely to attract nuisance species such as bullfrogs, geese, and (if ponds are stocked with fish) otters and to require aeration and periodic dredging to control algae and bacterial sludge.

In addition to reducing the water storage capacity of island watersheds, draining and excavating wetlands continues to create barriers to fish passage. Most of the islands' streams alternate between steep and relatively level reaches. In more level terrain, stream channels tend to meander, wander and fragment producing side channels; winter flooding maintains extensive shallow seasonal wetlands shouldering the channel. Excavating deep ponds directly in the channel drains the wetlands but disconnects the stream. Even in the absence of dam or weir—a physical barrier to fish passage—ponds experience warming, eutrophication, and hypoxia in summer, which can make them inhospitable to fish and as effective a barrier as a physical obstruction.

Natural barriers to fish passage also abound in the islands. Bedrock ledges create waterfalls with steep drop-offs. Where streams cut through glacial clays, there are often steep slippery chutes. In some island streams, a barrier is located at the sea's edge and all freshwater fish are necessarily residents, for example at Doe Bay. Other streams, such as Cascade, are divided into distinct reaches by a series of natural barriers, including a small sea-accessible reach—with salmonid populations in each reach, some anadromous or sea-run, and others resident.

Land-locked salmonids can result from fish planting by landowners, sportsmen or state agencies, of course, but they may also be relics of natural sea-run populations that gradually became landlocked by post-glacial rebound and changes in relative sea levels in the islands. Relative post-glacial sea level change on the Turtleback, as witnessed by the fossil mud flat (complete with entombed soft shell clams) at the headwaters of Fish Trap Creek, has been +382 feet. Cascade Lake was a bay when salmon returned to the islands in the wake of retreating glaciers. Cutthroat, steelhead, and other salmonids presumably colonized many island streams when they were sea-accessible; and some of those that can switch relatively easily to land-locked life histories—notably the "trout"—have survived.

Indeed, *downstream* fish passage and gene flow have continued, without upstream fish passage or gene flow. One-way connectivity of island salmonids with their Salish Sea metapopulations is interesting from an evolutionary viewpoint, and may contribute to regional salmonid genetic diversity and resilience (*see* Schindler et al. 2010). Genetic analysis of the origins of San Juan County's freshwater salmonid populations, and their current relationships with each other and with mainland stocks, were beyond the scope of the present study; but would be relevant to the recently reopened USFWS review of coastal cutthroat for listing under the Endangered Species Act.

Resident island salmonid populations can be sustained, and potentially contribute to regional salmonid survival, even if they continue to reproduce above one-way natural barriers. Nor is it certain that removing or overcoming the natural barriers, for example by use of fish ladders, will enable isolated populations to expand; opening these streams to upstream migration may simply provide an opportunity for other stocks to colonize the streams. Expanding and improving habitat within streams—more spawning riffles, better summer flows and summer pool conditions, and more consistent connectivity of pools—should be considered before contemplating restoration of sea accessibility through natural barriers.

Most of the natural and artificial barriers we observed in fish-bearing streams are located on private property and can be addressed as a part of cooperative programs with landowners—such as the evolving restoration process in the Garrison watershed launched by the Wild Fish Conservancy in 2009. County government also has an important role to play with respect to the design and maintenance of its infrastructure, mainly roads. In the course of this study, we found inappropriate or failed road culverts on every fish-bearing and potentially fish-bearing stream. Unimpeded stream flow and fish passage should be a criterion in all future road design, construction and maintenance by the county.

Table 5: Summary of road crossing issues

Watershed	*Fish use*	*Culvert locations*	*Issues*
Bayhead	Cutthroat	Killebrew Lake Road	Perched/failing culverts (3)
		Meadowbrook Lane	Perched culvert
Cascade Creek	Cutthroat	Point Lawrence Road	Undersized culvert
Crow Valley	Potential	Deer Harbor Road	Undersized span
Doe Bay	Cutthroat	Point Lawrence Road (3)	Perched/failing culverts (3)
Fish Trap Creek	Potential	Channel Road	Undersized span
		Cormorant Bay Road	Undersized failed culvert
Pickett Springs	Potential	Point Lawrence Road	Perched box culvert
Skull Creek	Rainbow*	Deer Harbor Road	Perched undersized culvert
West Beach	Steelhead	West Beach Road	Perched failing culvert
Garrison	Cutthroat	West Valley Road	Undersized failing culvert

*Planted but naturalized and likely partly sea-run (steelhead)

The field surveys conducted for the present study noted visible potential sources of contaminants such as effluent pipes, dumped trash, residential density, and production activities. Actual measurement of toxics in water, sediments or fish was not included, but any contamination would most likely be associated with homes and gardens. Thus far the principal toxic threats to aquatic wildlife identified in San Juan County are the pyrethroid pesticides found in home and garden products; anionic and non-ionic surfactants found in cleaning products as well as adjuvants in herbicides, pesticides, fertilizers, motor oils and fuels, paints and other garden, motor vehicle and boating products; metals such as copper and zinc used in marine anti-fouling treatments; and polycyclic aromatic hydrocarbons or PAHs found in creosote, asphalt, tar, motor oils and incompletely burnt fuels (Barsh et al. 2008; 2009; and forthcoming). A focal study of these toxics in the False Bay (San Juan) Creek aquatic food web is underway and results will be published by December 2010.

Existing countywide data suggest that all outdoors use of products containing the pyrethroid pesticides or surfactants should be reduced. A simple way to begin is to spot-apply all pesticides and herbicides, rather than area spraying. Spot application minimizes collateral damage to non-target species such as beneficial soil arthropods and pollinators, and largely eliminates the adsorption of chemicals to soil, and their transport to wetlands, streams and bays in runoff water. As the WSU Extension program stresses, moreover, it is essential to learn to recognize pests and weeds, remove them manually if possible, and use chemicals sparingly and selectively only when they are really needed. Pyrethroids and surfactant-rich herbicides are also used commercially by pest control operators, some builders and landscapers in the county, and these practices should be reviewed and where possible, made more compatible with the "short run to the sea" hydrology of the islands.

Roads and marinas are also significant sources of the existing toxic threats to fish in San Juan County streams and nearshore habitats. Many roads lack sufficient ditches or swales to prevent water from running off directly to nearby wetlands and bays. Indeed in Lopez village, roadside ditches have increasingly been tight lined to the bay and channel. Bioremediation features, such as constructed wetlands, are few. The Friday Harbor and Eastsound storm sewer systems exit directly into marine habitats without treatment. In a county where roads are perched along the seashore or cut across wetlands on causeways, more attention should be given to managing toxics in road runoff.

One other important issue cross-cutting our assessment of local habitat conditions for salmonids is competition from invasive non-native fish species. Our surveys located more non-native fish stocks than native ones. Most commonly seen were large and small mouth bass, pumpkinseeds, and bluegills—all "warm water" fish native to the Southeast. Bass are voracious predators of fish eggs and larvae, incompatible with salmonids. They were observed in Killebrew Lake, Hummel Lake (with bluegills), and Sportsman's Lake. Brook trout, an Atlantic salmon, are abundant in the Cascade watershed, introduced only within the past decade. They too are voracious consumers of eggs and larval fish, posing a serious threat to native salmonids. Fathead minnows have been introduced extensively in private ponds. American bullfrogs, an Atlantic species, have been introduced for food and (misguidedly) aesthetics repeatedly; they are incompatible with native fish, and most other amphibians and turtles as well.

Plantings of hatchery salmonids have also been widespread over the years. Most serious and, we believe, inappropriate has been the recent heavy planting of cutthroat fry in Mountain Lake, the source Cascade Creek, which appears to have overwhelmed native coastal cutthroat genetically. Rainbows have been planted widely by private landowners for example in the Lakedale Lakes (San Juan Island). Triploid rainbows planted by State agencies in Egg Lake and Hummel Lake cannot reproduce but do compete with other fish for prey. Local sportsmen have introduced Coho fry in island streams for two or three generations, although anecdotal evidence suggests that most were unsustainable. Schools continue to release Chinook and other salmon fry into island streams, but these efforts are also unsustainable, as far as we have been able to determine.

Stocking—in particular the introduction of non-native fish such as bass and Brook trout, and non-native amphibians—should not be permitted in any watershed with native salmonids, or where salmonid restoration is contemplated. In view of the potential harm to other native fish (sticklebacks or freshwater sculpins), locally scarce amphibians (Red-legged frogs, Northwestern salamanders, Long-toed salamanders, Western toads) and any remaining Western pond turtles, introduction of any fish or amphibian should be avoided, at least until a thorough assessment has been made of the watershed to determine whether any native species are present that may be affected.

Recommended actions

Priority action is recommended for the Garrison watershed (San Juan Island), and the West Beach and Bayhead watersheds on Orcas, on the basis of historical fish use, the potential for habitat improvement, and sea-accessibility. Ongoing surveys of Lopez, San Juan Island and Shaw streams may identify additional priority targets for action. Criteria for our selection of priority watersheds were applied as follows:

- Garrison sustains the largest salmonid population we have yet identified in the islands that is not clearly the result of recent introductions. Sufficient summer flows in the upper reaches of the watershed can be extended downstream by a combination of removing barriers, recreating a lost part of the stream channel, and providing supplemental water from an artificial lake that already drains to the stream. Landowners are favorably inclined towards restoration.
- West Beach sustains the relic of an historical recreational cutthroat fishery and steelhead have also been identified in its seaward reach. Failure to act quickly will probably result in the loss of these stocks as stream conditions continue to deteriorate. Replacing a county road culvert; improving summer water flows and fish passage through a single in-line pond; and augmenting summer flows by re-vegetating the source area and improving its water retention capacity are relatively inexpensive, and will re-connect thousands of feet of shaded gravel. Introduced fish (Pumpkinseeds) are present but not a serious threat. Many, if not all landowners are amendable to restoration.
- Bayhead-Victorian sustained a small native sea-run cutthroat escapement until 2007 when flows were reduced by upstream impoundments. Prompt action is not a guarantee of restoring this run but would (at a minimum) provide access to nearly two thousand feet of shaded gravels by coastal cutthroat, Coho, and or Chum. Removing a low concrete weir and replacing two perched culverts would restore fish passage, and regulated summer discharges from a privately owned pond would restore adequate summer pool conditions. Landowners of the lowest reach of the stream have been interested in restoration.

Considerations according lower priority to other watersheds include invasive fish, significant natural barriers to fish passage, and challenges to augmenting flows. Cascade is included in this list in part because the most serious issue we identified—an undersized road culvert—is already being addressed by the county. Importance of the fish to genetic diversity and sustainability of salmonids has also been considered.

- Cascade Creek hosts the largest extant cutthroat population in the islands, but with the Washington Water Trust's recent acquisition of water rights for fish, continued protection of the headwaters by Moran State Park, and protection of most of the stream corridor by private landowners, habitat conditions are relatively secure at this time. The one significant artificial barrier—a culvert under Point Lawrence Road—is already scheduled for replacement by a span. The only major remaining barriers are waterfalls; the lowest waterfall could be overcome by a fish ladder or "stepping stones". Countervailing factors are a growing invasive Brook trout population; and State cutthroat fry planting in the headwaters, which reduces the value of these fish for genetic diversity.

- Doe Bay has a small, potentially unique land-locked cutthroat stock, isolated above a coastal waterfall. Restoring upstream fish passage over this barrier is neither feasible nor necessarily desirable. Stream conditions between the two points where the stream crosses Point Lawrence Road—the upper and lower plunge pools described in this report—can be enhanced by replacing perched road culverts with bottomless culverts. Greater summer flows would enhance conditions appreciably, but we did not locate a promising source.
- Pickett Springs does not appear to have had sustained salmonid use since the 1950s. Three ponds dissect the seaward thousand feet of stream channel, and summer flows are restricted by additional ponds above Point Lawrence Road and near the source on Mount Pickett A spawning channel could be built by excavating the seaward 200 feet of the stream, which is shallow, choked with reed canary grass, and periodically blocked by sediments and driftwood after winter storms. Considerable construction would be required to create passage farther upstream, and recreate a suitable channel above the high-tide mark. It is plausible that salmonids would utilize a spawning channel if built; summer flows will be a limiting factor.
- Skull Creek hosts rainbow trout that escape downstream from a stocked pond on the upstream side of Deer Harbor Road; they functionally become sea-run steelhead if they can overcome a modest waterfall at the sea's edge. Channel habitats between the sea and Deer Harbor Road are suitable, but flows can be erratic and inadequate. The sources are the stocked pond, and a second larger pond above it that actually diverts water from the Deer Harbor watershed. As a result winter flows have increased sharply while summer flows are nil. The two ponds would need to be regulated to restore habitability of the stream.

Monitoring

Data collected for the present report can provide only a snapshot of conditions in San Juan County fish-bearing streams. Much more can be learned, by using this study as a baseline for long-term monitoring, much of which could be carried out by volunteers—like the volunteers that gathered data for this report. Some key parameters and methods for monitoring fish-bearing streams include:

- The date that stream flow ceases (or glides disappear) in summer, and the date that flow resumes in autumn. The total number of dry days is directly related to pool conditions such as temperature and dissolved oxygen, and is a function of climate as well as human activities that divert flow from stream channels.
- Flow (if any), temperature, and dissolved oxygen in stream pools bearing fish, during the islands' driest period—typically June through September. Weekly or biweekly data collection would be desirable. Small flows can be measured easily with a bucket and stopwatch. An electronic instrument such as the YSI ODO is costly but durable, reliable and precise for temperature and oxygen.

- Redds can be counted by walking stream riffles every second or third week—for cutthroat in the islands, between mid-February and early May.
- A representative sample of salmonids in each stream (minimum ten) should be brought to hand by hand-seine, hand-net or electrofishing as appropriate every three to five years for fin clips and genotyping. Genotyping will identify any changes in the composition of stocks and exchange of genes with other stocks, and is the least intrusive method for estimating the size of a salmonid stock.

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Bayhead – Victorian Valley – Mount Woolard

Orcas Island

Sources

The stream that meets salt water at Bayhead Marina, Orcas, rises from three main sources: (1) a string of wetlands to the north of Bayhead along Victorian Valley Road; (2) a string of wetlands to the northeast of Bayhead and east of LaPorte Road; and (3) several dug ponds (former wetlands) in the open fields on the south side of Killebrew Lake Road. The LaPorte wetlands capture some runoff from the southwest slopes of Mount Woolard, and appear from topography to have long been the largest of the stream's sources. In this report we refer to the Victorian wetlands and channel as the west branch, and the LaPorte wetlands and channel as the east branch of the Bayhead system

Most of the Victorian and LaPorte source wetlands today are former pastures with numerous dug ponds impounding downstream flows. Reed canary grass dominates these wetlands, but the west channel where it runs along LaPorte Road, and much of the stream below the confluence of its west and east branches, flows through cedar-shaded ravines.

One large native alder-sedge wetland survives on the west side of LaPorte Road—clearly visible on Map I.2. There is no culvert under the county road, however, so flows from this wetland run south along the west side of LaPorte Road, thence west along road drainage ditches on the north side of Killebrew Lake Road, to dug residential ponds north of the Bayhead Marina driveway, never entering the Bayhead stream.

Barriers

There is a shallow plunge pool at the downstream end of a corrugated steel culvert under Meadow Brook Lane (A on Map I.2). The culvert is perched 8-10 inches above the pool even with high winter-spring stream flows, and holds barely an inch of water except at peak winter flows. There is a deteriorating low weir composed of cobbles and concrete on the downstream side of the plunge pool, forming another potential barrier to upstream movement for all but 2-3 weeks of peak winter flow. A 157-mm cutthroat was brought to hand in this plunge pool, and a 170-mm cutthroat was brought to hand in the stream some 150 feet below this plunge pool in 2004.

A second culvert barrier to fish passage is located 1500 feet farther upstream from the first, under Willow Creek Lane (B on Map I.2)

Fish presence

Two adult cutthroat trout were brought to hand below the first barrier (A on Map I.2) in June 2004. Between the first and second barriers (A and B on Map I.2) the survey team found three-spine sticklebacks and fathead minnows but no salmonids. No fish were observed or brought to hand above the second barrier.

Despite frequent visits to the Meadow Brook Lane plunge pool and stream below during winter and spring 2008-2009, no fish were observed. This was presumably due to the impoundment and consequent reduction in winter stream flow described below under Diversions.

Diversions

At least two small domestic water diversions were observed in the stream channel above the intersections of LaPorte and Killebrew Lake Roads. Their impact on instream flow is probably negligible on account of a downstream impoundment: a pond, just above the junction of the east and west branches of the stream. As noted above, the county road diverts wetland outflow from the stream to residential ponds near Bayhead Marina.

During the course of this study, an instream pond just above Killebrew Road was enlarged, impounding significantly more flow from the west branch of the stream than we previously had observed. No fish were seen downstream afterwards by our research team or by the owner of the lowest reach of the stream. The impoundment and consequent loss of stream flow was duly reported to county officials but no action was taken.

Hydrographs (Figure I.1) show that in the rainy season following the enlargement of this pond, the west branch contributed very little to stream flows below the confluence of the west and east branches of this stream. The influence of other dug ponds on stream flow is evident in the brief steep peak of the downstream (Meadow Brook) hydrograph in winter: flood-like peak season overflows, followed by near-zero spring and summer flow conditions. Barely a trickle is visible at the Meadow Brook plunge pool (A on Map I.2) for 8-9 months of the year.

Stream flows are also impeded by a small dug pond and failed county road culvert at D on Map I.2. Much of the area around this culvert is inundated in mid-winter.

Land use

Most of the Bayhead stream flows through unmanaged deep woody ravines, but is surrounded by scattered homes and fields.

Toxic sources

This watershed is rural-residential with some subsistence and market gardening. The principal potential sources of contamination are county roads, private driveways and motor vehicles, homes, gardens, and on-site septic systems. Dumping of household trash into the LaPorte Road segment of the stream appears to have been ongoing for decades—large quantities of glass, batteries, and machine parts among other items were observed in this reach wherever the top of the ravine met the county road.

Pool conditions

In 2007, there was no appreciable flow by August 22, and no glide downstream to the sea from the plunge pool at Meadow Brook Lane. The pool remained relatively well oxygenated (85.3 percent at 13.9^{o}C), but we observed neither fish nor invertebrates in the pool. On September 6, oxygen had fallen to 71.8 percent at 12.6^{o}C, and the pool was very turbid with a large submerged mat of algae. No fish were seen, but a few Gammarid amphipods were noted. There was still a trickle of water through the culvert.

The Meadow Brook plunge pool is shallow (less than 2 feet), warm and anoxic in spring and summer as soon as rains cease and upstream ponds no longer overflow. Pond enlargement at C on Map I.2 in 2007 has exacerbated this condition. In spring 2008 algal growth turned the plunge pool opaque green, and this continued until the autumn rains.

<u>Discussion</u>

Bayhead is (for the islands) a mid-sized watershed with more than enough shaded stream riffles and pools, and sufficient water to support native coastal cutthroat runs. But more than 90 percent of the stream habitat is inaccessible at present, and residential pond building has reached the point that winter flood conditions, and low to negligible summer flows, are no longer hospitable to salmonids.

Bayhead supported spawning-size cutthroat trout in 2004, but no longer does, due (it appears) to pond construction in the west branch. This is a significant loss that should be addressed by remedial measures to restore pre-2007 stream flows such as lowering the pond dam or regulating summer pond outflows at C on Map I.2; installing a culvert under LaPorte Road to restore inputs from the alder-sedge wetland to the main stream channel; and replacing the culvert under Killebrew Lake Road to ensure that the area around D on Map I.2 all drains into the main stream channel.

We also recommend replacing the perched, over-length culvert under Meadow Brook Lane with a shorter, bottomless one, and replacing the concrete-and-cobble weir at the lower end of the plunge pool (A on Map I.2) with boulders and large woody debris to foster a natural, self-sustaining pool without impeding fish passage.

Sea-run cutthroat trout from Bayhead in 2004: a run lost in 2007 due impoundment of flows by ponds.

Appendix I – Summary of video observations

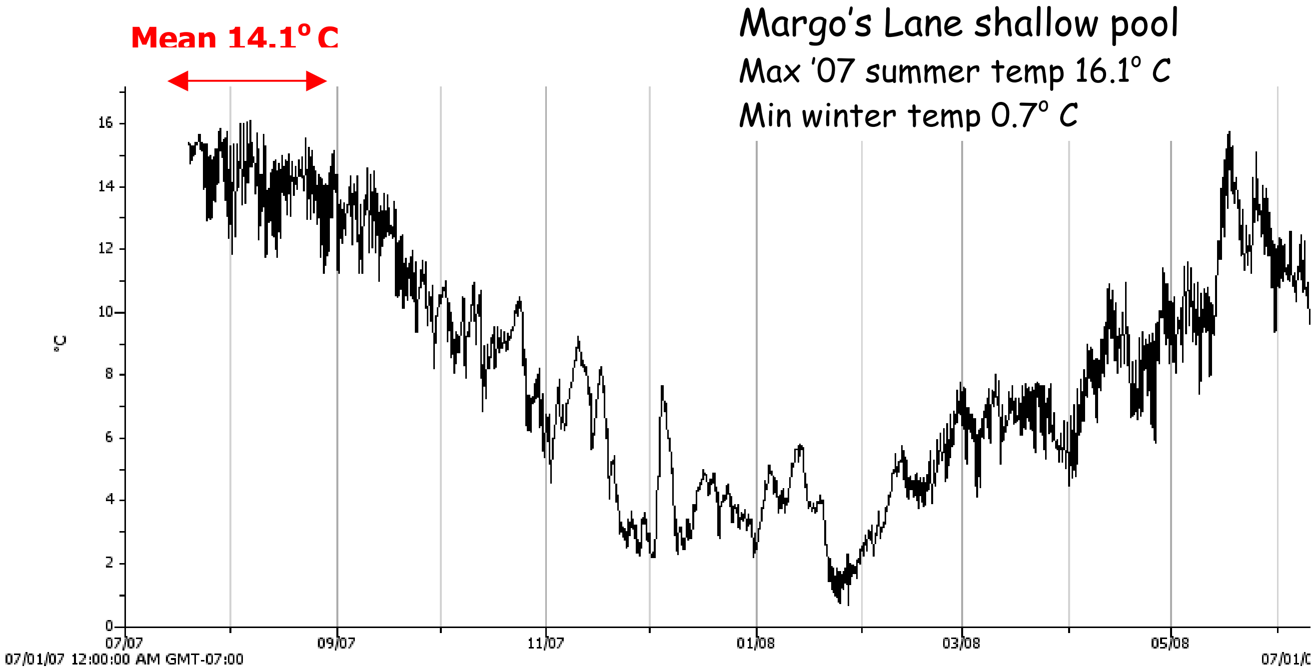
Stream – site		Date	Cutthroat			Other fish	Activity
			Number	Minutes	Ages		
West Beach	Plunge pool	3-Aug-07	3	6	0+		Benthic feeding
Doe Bay	Plunge pool	9-Aug-07					
West Beach	Plunge pool	9-Aug-07	3	13	0+	1S	Surface feeding
Doe Bay	Plunge pool	16-Aug-07	2	6	2+		Surface feeding
West Beach	Plunge pool	16-Aug-07	2	10	0+	2S 2P	Benthic feeding
Garrison	Alpaca pond	17-Aug-07	3	3	1+2+		Patrolling
Doe Bay	Plunge pool	22-Aug-07	2		2+		Surface feeding
Crow Valley	Long pool	24-Aug-07				4S	Benthic feeding
Crow Valley	Large pool	24-Aug-07				26S	Benthic feeding
West Beach	Plunge pool	24-Aug-07	2	23	0+	1S	Benthic feeding, patrolling
Cascade	Estuary	31-Aug-07	12	90	0+2+	20Sm	Surface feeding
Cascade	Olga tank	31-Aug-07	5	31	0+		Surface feeding, agonistic
Cascade	Footbridge	31-Aug-07	3	17	0+1+		Benthic feeding, agonistic
West Beach	Plunge pool	6-Sep-07	3	47	0+1+	4S 4P	Benthic feeding, agonistic
Doe Bay	Plunge pool	11-Sep-07	1	11	2+		Resting, surface feeding
Cascade	Lowest pool	11-Sep-07					
Cascade	Olga tank	11-Sep-07					
West Beach	Plunge pool	14-Sep-07	2	26	0+	1S 1P	Patrolling, feeding, resting
West Beach	Pottery pond	14-Sep-07				3S 1P	Benthic feeding, resting
Garrison	Alpaca pond	26-Sep-07	1	2	2+		Benthic feeding, resting
West Beach	Plunge pool	28-Sep-07	2	3	0+	3S 2P	Benthic feeding, patrolling
Doe Bay	Plunge pool	28-Sep-07					Surface feeding
West Beach	Plunge pool	12-Oct-07	2	3	0+	1S 1P	Patrolling, Benthic feeding
Doe Bay	Plunge pool	24-Oct-07	1	3	2+		Patrolling
West Beach	Long pool	1-Nov-07	3	8	0+	3S	Benthic feeding, resting
Doe Bay	Plunge pool	5-Nov-07					
West Beach	Plunge pool	13-Nov-07	2	14	0+		Benthic feeding, resting
West Beach	Plunge pool	16-Nov-07	2	24	0+	3S 5P	Benthic feeding, patrolling
Cascade	Plunge pool	20-Nov-07	13	45	0+2+		Surface feeding, agonistic
Garrison	Inn riffles	18-Dec-07	3	14	0+		Surface feeding
West Beach	Plunge pool	26-Feb-08					
Cascade	Plunge pool	26-Feb-08	1		2+		
Garrison	Inn riffles	11-Mar-08	8	8	0+2+		Patrolling
Garrison	Driveway pool	18-Nov-08	4	19	0+1+2+		Patrolling

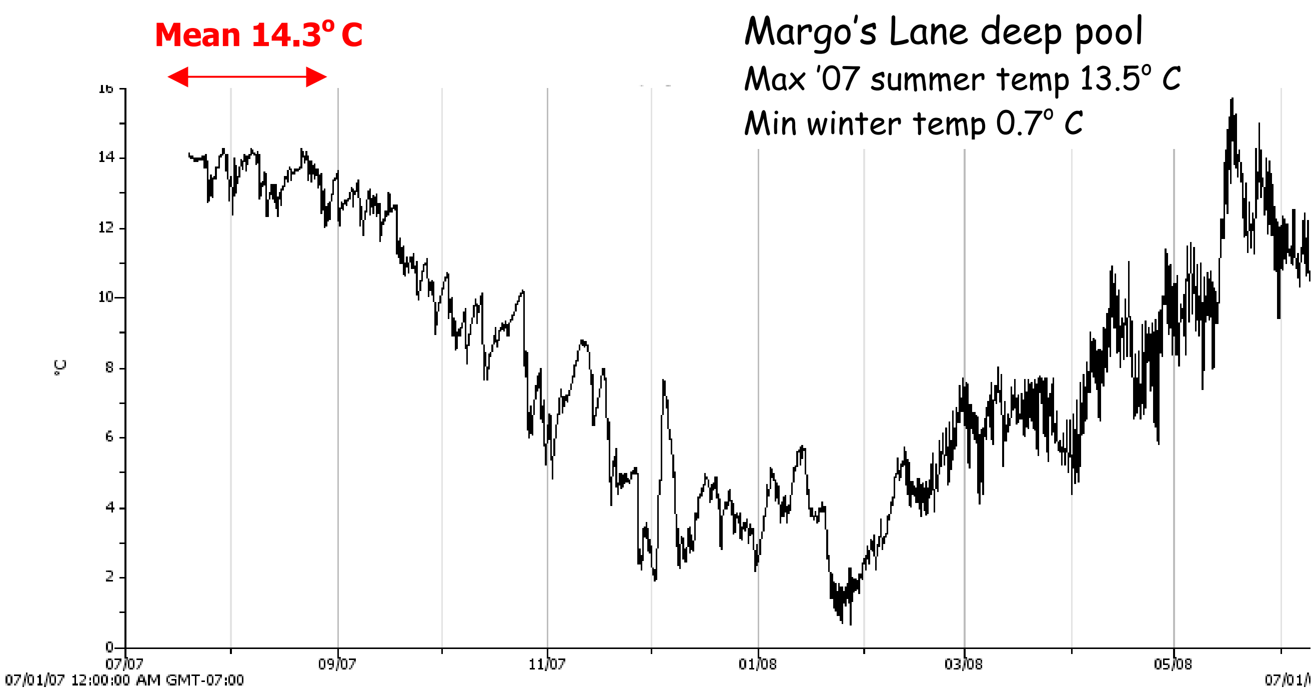
Number of cutthroat is minimum number of fish. Other fish = S(tickleback), Sm(elt), P(umpkinseed)

Appendix II.2

Crow Valley Pool Temperatures

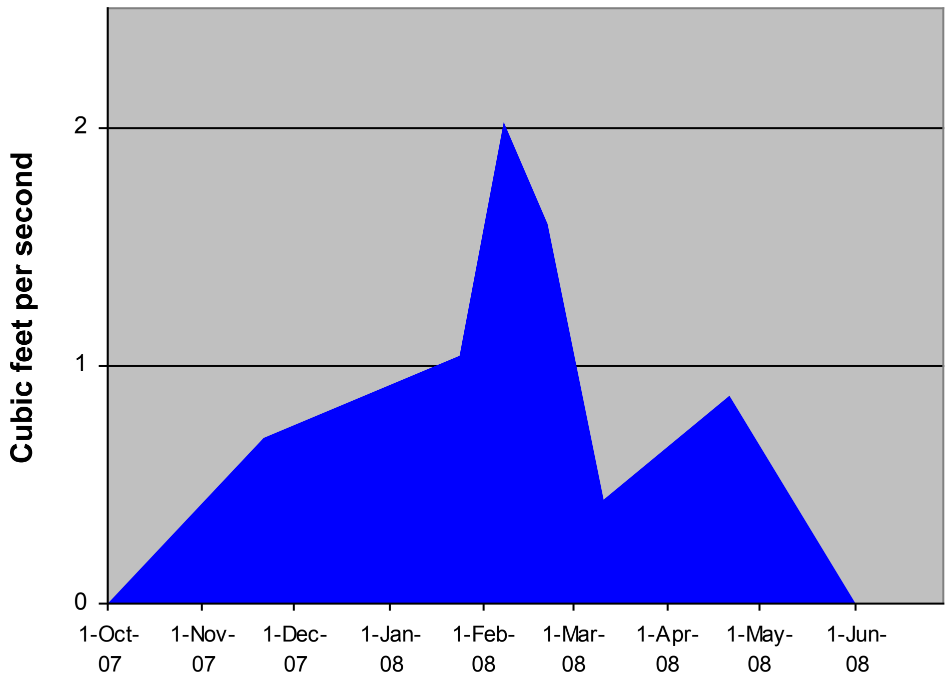
Summer 2007 – Spring 2008



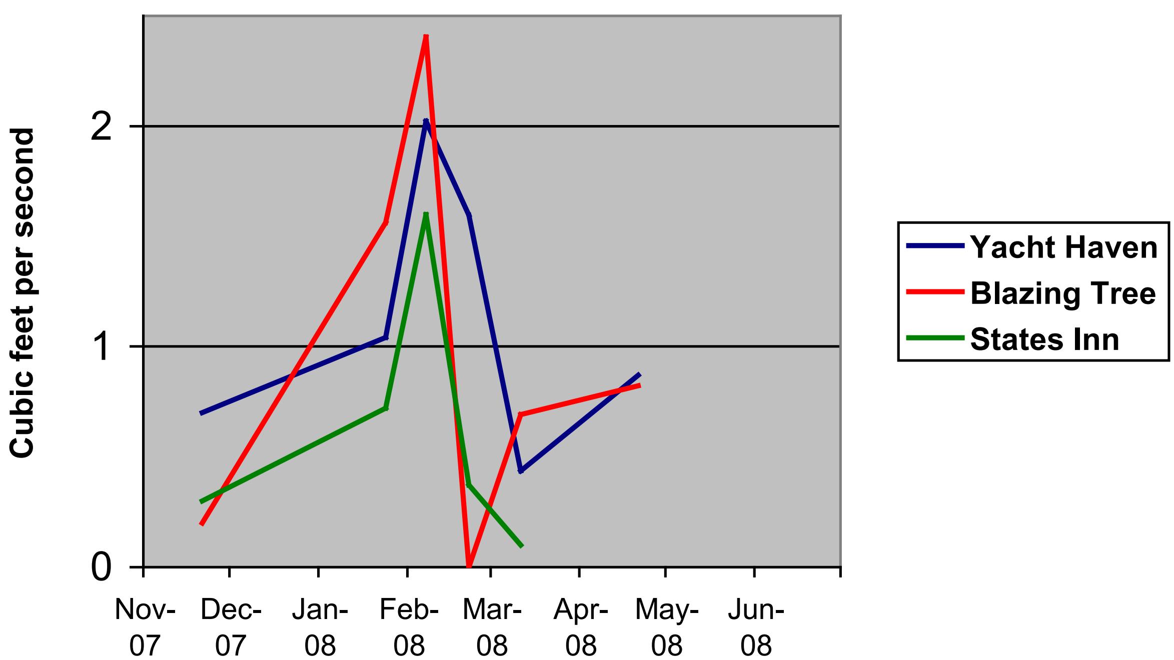


Appendix III.1

Hydrograph of Garrison Creek
Measured at Yacht Haven Road, winter 2007-2008



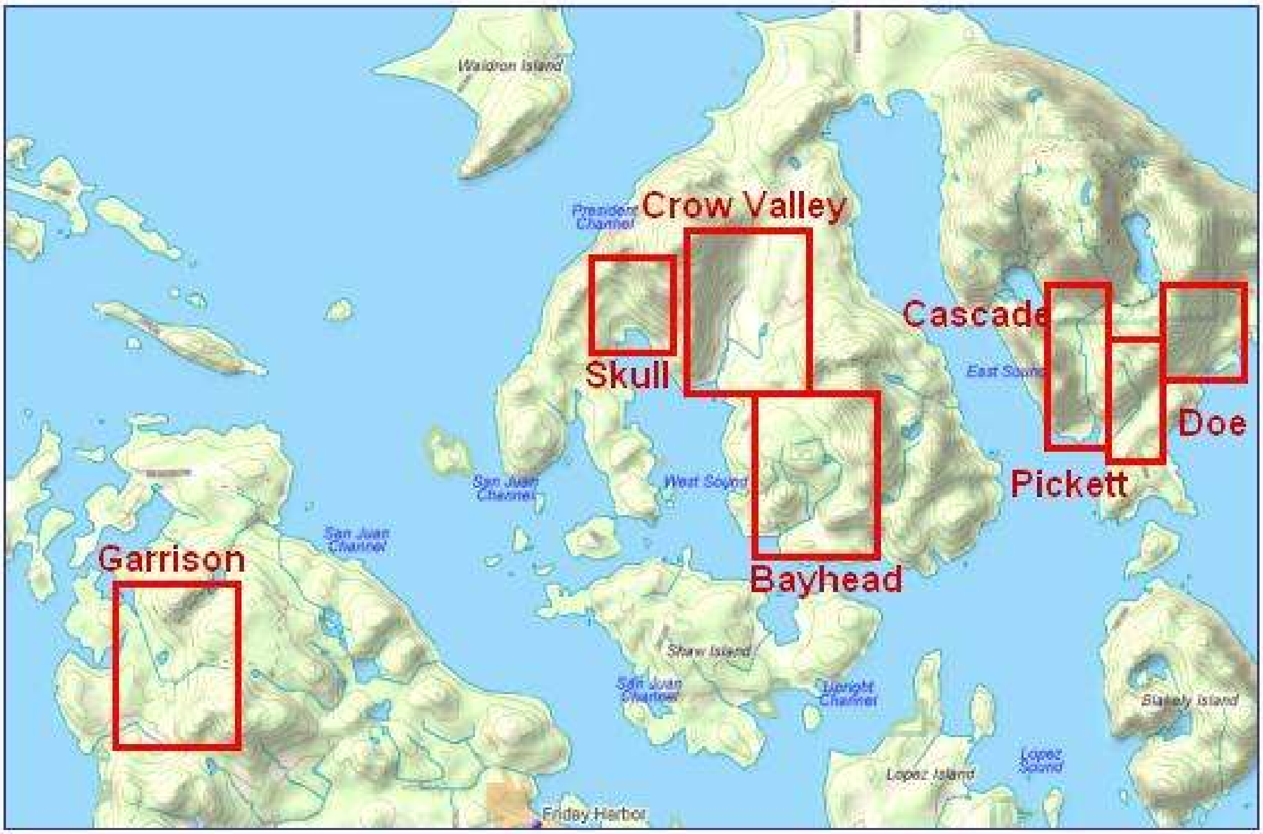
Garrison Creek Flow Stages
Winter 2007-2008



Appendix IV.1

Structural diagrams

Locations of target watersheds



Appendix IV.2

Bayhead-Victorian, Orcas

Structural diagram