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Internship report submitted in partial fulfilment of the requirements
for the second year of a Master's Degree

Study of hatchery Coho salmons released into the Calamity watershed

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Géosciences Environnement   IMACOF

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Given the fact that I've been hiking through bushes and streams for months carrying a jar of salmon roe, I must say thank-you to all cougars, black bears and wolves that didn't attack me.

I finally would like to mention my family, who always encouraged me in my choices, and supported me morally, as well as financially.

Wide-public presentation

This report describes Thomas Chabanne's activities during his five-month internship from April to August 2009, in partial fulfillment of the requirements for the second year of Master Engineering of Freshwater Hydrosystems (University of Tours). This internship was completed in the Huu-ay-aht First Nation Fisheries Department on the west coast of Vancouver Island, British Columbia, Canada. First Nations are independent aboriginal communities and participate in the management of natural resources in their traditional territory. In this context, the Huu-ay-aht Fisheries Office carries out enhancement and fish habitat restoration projects to increase the number of salmon returning to spawn in their coastal rivers and creeks.

Coho (*Oncorhynchus kisutch*) is one of three salmon species that spawn in Huu-ay-aht First Nation territory streams. Spawning occurs during the fall, when spawners gather in rivers and streams with well-oxygenated coarse gravel beds. Females dig nests and deposit a few thousands eggs that are buried after males spread sperm on them. After a three months incubation, juveniles called fry emerge in early spring from the gravel and reach preferentially back eddies and log jams for rearing. When fall freshets come, fry gather in hideout zones like side channels or oxbow lakes and remain there until spring. During April or May of their second spring, Coho called fingerlings become smolts by modifying their osmotic systems and migrate toward the ocean. They remain a few weeks in estuarine zones, where they get used to the salty water environment and then enter the ocean. Some Coho fry may remain one or two more years in freshwater before migrating downstream. Coho salmon is usually mature after three years of life in the ocean, when they gather in coastal zones before migrating upstream to spawn.

During the last decades, most salmon populations collapsed within their entire distribution range. This decline is a direct consequence of human activities. In British Columbia, the logging industry greatly impacted the capacity of streams to host salmon runs because of clear-cut logging practices. During the summer, most water flows subsurface due to the input of great quantities of gravel from denuded hillsides: the riverbed is dry and no aquatic life is possible. Other impacts include the destruction of over-wintering habitats for juveniles and the modification of water temperature patterns caused by canopy removal. Overfishing, salmon aquaculture and climate change also contributed to the decline of most wild salmon populations.

One of the main annual salmon enhancement projects of the Huu-ay-aht Fisheries Department is the release of juvenile Coho salmon, in order to supplement wild reproduction. Since 1999, Coho juvenile are released in Calamity Lake, which is drained by Calamity Creek. These hydrosystems constitute a small sub-watershed of the Pachena River. Pachena is one of the most important watersheds for salmon reproduction in Huu-ay-aht traditional territory. Calamity Creek was studied in 2000 and restoration works were completed in 2001, in order to restore habitat and migration possibilities, which were damaged by bad logging practices. Hatchery Coho fry are released at two release spots within the Pachena watershed. These areas host a limited amount of wild salmon fry, minimizing competition between hatchery and wild Coho. These areas are also good habitat for Coho fry. However, no estimate or study of the efficiency of the release in Calamity Lake were ever carried out. The 5-month long project describes the behaviour and fate of hatchery Coho released in 2009 into Calamity Lake and Creek. The objectives of this study were also to identify potential competition with wild Coho fry and estimate the quality of Calamity Lake and Creek as a salmon rearing area.

Juvenile salmon production is conducted at the Huu-ay-aht hatchery at Sugsaw. Eggs and sperm are collected from wild spawners captured during the fall in Rousseau Creek, which is part of Pachena watershed. After 3 months of incubation, fry emerge and are kept in growing tanks until they reach a average size of two grams and are ready for release. Two weeks prior to release, 10 500 juvenile Cohos were adipose fin-clipped and released on May 15th in Calamity Lake. An additional 150 pelvian fin-clipped Coho were released the same day into Calamity Creek.

The fish survey consisted of a weekly minnow trapping campaign from April 26th to August 17th. A total of 24 traps were set from the creek mouth to the lake outflow and 21 traps were set in the lake in potential good rearing habitat for Coho juveniles. Fish captured were identified, counted, measured and weighted. Fish habitat assessments were conducted in Calamity Lake and Creek on June 22nd and July 2nd respectively. Parameters monitored were: depth, width between banks, pool frequency, woody debris presence, cover percentage, channel disturbances and riparian vegetation. Plankton was also sampled in Calamity Lake.

Minnow trapping in Calamity watershed indicates relatively good fauna diversity as two species of Sculpins (*Cottus spp.*), Three-spine stickleback (*Gasterosteus aculeatus*), two species of trouts (*Oncorhynchus spp.*), one crayfish type (*Pacifactacus leniusculus*), and wild

Coho fry and fingerlings were captured. Catches of trout greatly decreased in both the lake and creek after the first two weeks. This observation may be attributed to downstream migration behaviour induced by an increase in water temperature and decrease in the water level.

Despite the fact that the habitat assessment indicates a lack in holding pools, canopy closure and spawning gravel, an important number of wild fry were captured all along Calamity Creek. This observation indicates that migration is possible along Calamity Creek and that the stream represents good summer rearing habitat for Coho.

Results suggest a migration of hatchery Coho released in the lake toward the creek during the first days after release. Some of the hatchery Coho released in the lake established themselves in the creek and probably also in Pachena River since adipose fin-clipped Coho were capture all along Calamity Creek until the end of the study.

Hatchery Coho were captured during the first two weeks after release all around Calamity Lake. After this, Hatchery Coho catches greatly decreased and no Coho fry were captured from July 1st until August 17th. This observation probably indicates that all hatchery fry released in 2009 left the Lake or died. Since only one wild Coho fry was captured in the lake, Calamity Lake may be not a good summer habitat for Coho juveniles. It is not surprising that hatchery Coho released in the lake did not remain there, since the habitat assessment indicated a lack of cover and woody debris. One-year-old non-marked Coho salmon were also captured in the lake at the beginning of this study. As only one wild Coho fry was captured in the lake during the entire study, it is probable that these fish came from non-marked hatchery Coho released in spring 2008 in Calamity Lake. Perhaps a migration of the Coho fry toward the creek in the summer and back to the lake explains the results obtained in 2009.

Physical parameters of the Lake showed that the traps set in shallow areas which exhibited high water temperature, well above the maximal temperature tolerance for salmonids. In other words, the reliability of the sampling method seems limited since traps were not set in area where salmonids could live.

This survey provides a number of conclusions concerning fish habitat quality for juvenile, hatchery fry behaviour and distribution of the wild Coho population in the Calamity watershed. However, the behaviour of hatchery Coho released in Calamity Lake in 2009 can only be guessed from the results obtained. It could be interesting, for the further studies, to modify the trapping method, using rather methods such as barrier-traps, electro-shocking or seining rather than only minnow traps.

Huu-Ay-Aht Fisheries

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Abstract

On May 17th 2009, 10 500 hatchery Coho salmon fry (*Oncorhynchus kisutch)* were marked and released in Calamity Lake, British Columbia, Canada. This lake is drained by Calamity Creek which flows into Sarita River. A minnow trapping session was completed by the intern between April 24th and August 17th 2009. The objective is to estimate the efficiency of the release effectuated in order to supplement the natural reproduction impacted by forestry activities. The results of this study showed a quick migration of part of the fry released in the lake toward the creek during the first weeks. From July until the end of the survey, no Coho juveniles were captured in Calamity Lake. The fish habitat and water quality assessments of the lake showed water temperatures higher than salmonids tolerances and a lack of woody debris. This would explain the migratory behaviour of the fry toward the creek and indicates that Calamity Lake has not a good summer habitat for juvenile salmon rearing. However during the month of May, a significant number of Coho fingerlings were captured, probably originating from hatchery fry released last spring. A migration of the fish from the lake to the river in summer and the opposite in winter could explain these results. Hatchery fry and a majority of wild fry were captured in Calamity Creek until the end of the study, suggesting a good summer habitat for salmon juveniles.

Keywords: Coho salmon, hatchery fry, fin-clipping, minnow-trapping, habitat assessment

Résumé

Le 17 Mai 2009, 10 500 juvéniles de saumons Coho (*Oncorhynchus kisutch*) élevés en écloserie par la communauté aborigène Huu-ay-aht ont été marqués et relâchés dans le lac de Calamité, Colombie Britannique, Canada. Ce lac est drainé par le ruisseau de Calamité qui se jette dans la rivière Sarita. Une campagne de piégeage par pièges à vairons a été réalisée par le stagiaire entre le 24 Avril et le 17 Août 2009. L'objectif étant d'estimer l'efficacité du rempoissonnement destiné à soutenir la reproduction naturelle impactée par l'industrie forestière. Les résultats de cette étude ont montré une migration rapide d'une partie des alevins relâchés dans le lac vers le ruisseau durant les premières semaines. A partir de Juillet, aucun saumon n'a été capturé dans le lac de Calamité et ceci jusqu'à la fin de l'expérience en Août. L'étude de l'habitat et de la qualité de l'eau du lac de Calamité ont montré des températures estivales supérieures aux niveaux de tolérances des salmonidés ainsi qu'un manque d'abris. Ces observations pourraient expliquer la migration des juvéniles vers le ruisseau et indiquerait que le lac ne représente pas un bon habitat pour les juvéniles de Coho saumons. Cependant, durant le mois de Mai, un nombre significatif de tacons de Coho a été capturés dans le lac, provenant probablement de la relâche effectuée l'année précédente. Une migration du lac vers la rivière en été puis l'inverse en hiver pourrait expliquer ces résultats. Des individus d'écloserie et une majorité de juvéniles sauvages ont été capturés dans le ruisseau jusqu'à la fin de la campagne de piégeage, indiquant une bonne qualité d'habitat pour les juvéniles de saumon.

Mots clés: Saumon Coho, juvéniles d'écloserie, marquage à la nageoire, piégeage par piège à vairon, estimation qualité d'habitat.

1 Introduction

In partial fulfillment of the second year of Master Engineering of Freshwater Hydrosystems, a five-month internship was completed. This report summarizes the works carried out by the intern during summer 2009 with the Huu-ay-aht First Nation Fisheries Department on the west coast of Vancouver Island, British Columbia, Canada.

Aboriginal First Nations participates in the management of the natural resources within their traditional territory. The two main resources available in the Huu-ay-aht First Nation territory (78 000 km²) being seafood and wood. Pacific salmons are the most important commercial and traditional species of coastal aboriginal communities along Canada's west coast. Since the 1950's, Pacific salmon populations have decreased in their entire distribution range, mostly because of overfishing and bad forestry practices. Intensive logging activities along rivers significantly reduced the suitability of streams for salmon's freshwater life stages, by destruction of fry summer and overwintering habitats and by altering the spawning gravel suitability.

Since 1997, the Huu-ay-aht First Nation Fisheries Department is carries out Salmon habitat restoration projects within the Huu-ay-aht territory. These projects include the construction of side channels for rearing, spawning channels for reproduction, the placement of wood to create pools and cover. The Huu-ay-aht Fisheries Department also runs the Sugsaw hatchery, to supplement natural reproduction. Hatchery Coho fry are released every year in Calamity Lake which is connected to the Pachena River through Calamity Creek. Pachena is one of the main rivers hosting Salmon spawning within the Huu-ay-aht territory.

This study focused on the assessment of the quality of Calamity Lake as a release area for Coho fry. The main objectives of this survey were to describe the behavior of the hatchery fry after their release and the interactions between wild and hatchery fry. Habitat, spawning gravel assessments and water parameters surveys were also completed in Calamity watershed.

Several surveys carried out within the Huu-ay-aht territory by the Federal Department of Fisheries and Oceans or private environment consulting companies were also completed. These works were geomorphology, habitat and fish studies using methods such as leveling, gill net trapping and electro-fishing.

2 Firm presentation and intern activities

In 1991, the provincial government of British Columbia officially recognized the inherent rights of First Nations to aboriginal title, self-government, and pledged to negotiate just treaties.

The Huu-ay-aht First Nation is one of the aboriginal native bands of the west coast of Vancouver Island, British Columbia, Canada. Lands and resources rights were given by the Canadian government and are self-managed within the Huu-ay-aht territory (78 000 km²). The Huu-ay-aht First Nation Fisheries Department is situated in Anacla aboriginal reserve, situated about 5 km south of Bamfield, on the West coast of Vancouver Island, Canada. The Fisheries Department is working on two main sectors: shellfish production (oysters, clams…) and stream restoration, juvenile salmon production. The Huu-ay-aht fisheries Department is actually employing a full time manager and three part time employees (see hereunder Figure1).

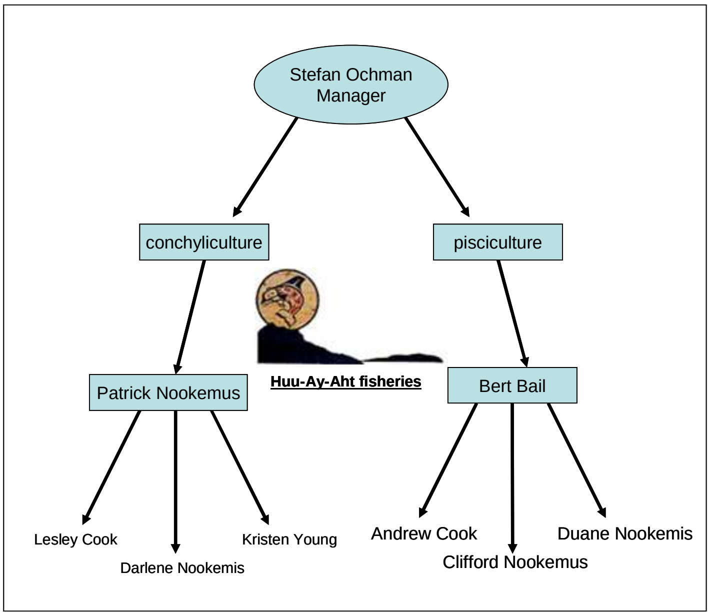

Figure 1: Huu-Ay-Aht First Nation Fisheries Department operating chart (source Clarke, 2006)

The goal of the stream restoration is to protect, restore and manage the freshwater fisheries resources of the traditional Huu-ay-aht territory. Pacific salmon populations which spawn in coastal streams are the main restoration target of the Huu-ay-aht Fisheries Department. As this service has a non commercial goal, funding is provided by Federal and Provincial grants, the Pacific Salmon foundation and the Huu-ay-aht First Nation.

During the last decade, the Huu-ay-aht fisheries Department carried out numerous restoration projects such as construction of side and spawning channels and large woody debris structures. The Fisheries Department also owns a small hatchery where 25 000 Pacific salmon juveniles are produced every year and released in spring. During the past 9 years, a total of 1 700 000 juveniles Chum salmon (*Oncorhynchus keta*), 130 000 Coho salmons (*O. kisutch*) and 13 000 Chinook salmon (*O. tshawytscha*) were released (Ochman, 2009).

The main project the intern worked on was a survey on hatchery Coho salmon fry released in Calamity Lake, which is part of the Pachena watershed (see Figure 2 hereunder, detailed map available in Annexe 1). The intern also took part in several other activities as surveys with consultant firms, experiments on fry in Nitinat federal hatchery and hatchery works (fry feeding, marking, releasing). Laboratory works such as plankton identification or scalimetric studies were also carried out by the intern at the Bamfield Marine Science Center.

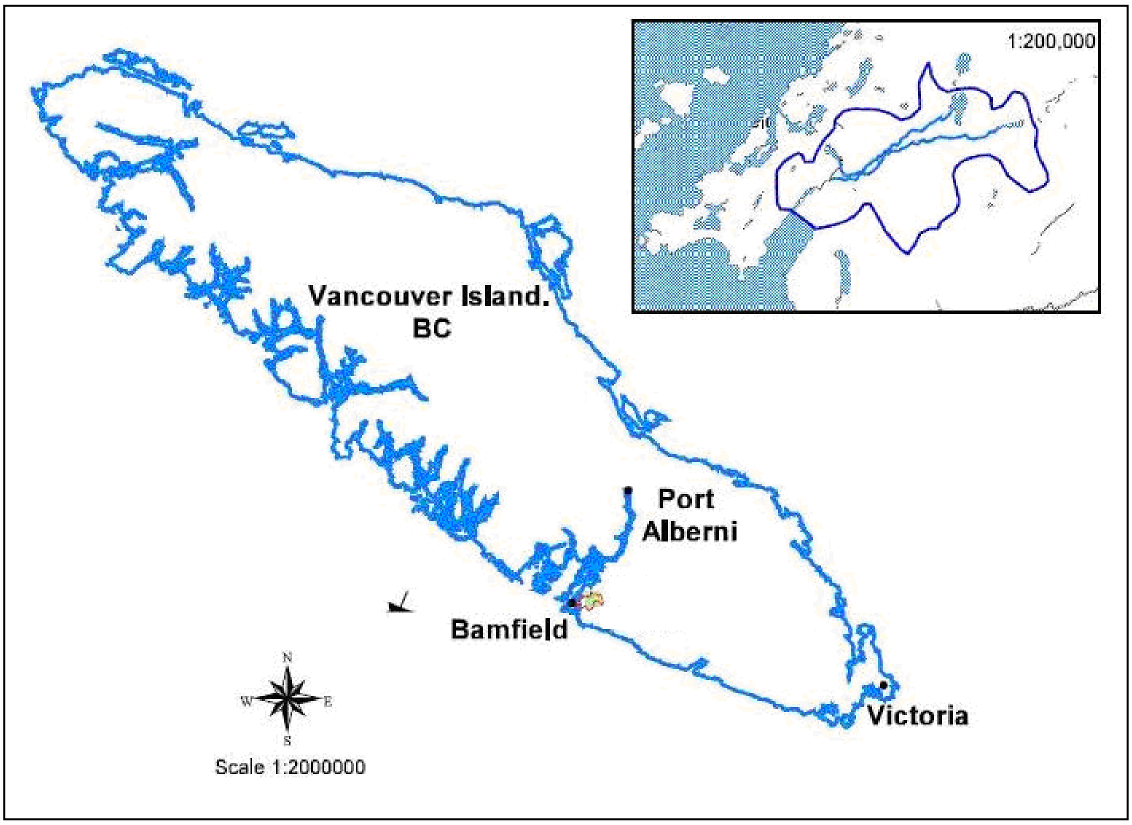

Figure 2: Pachena watershed localization on Vancouver Island, BC, Canada (source Ochman, 1998)

3 Introductive section: the Coho salmon, life cycle and threats

3.1 The Coho salmon

3.1.1 Distribution area

The distribution area of the Coho salmon (*Oncorhynchus kisutch*) extends from Japan to Kamchatka in western Pacific and from California to Alaska in eastern Pacific through clusters in the Bering sea. The highest densities are found between southern Alaska and the large Columbia River, Washington State, United States (see Figure 3 hereunder).

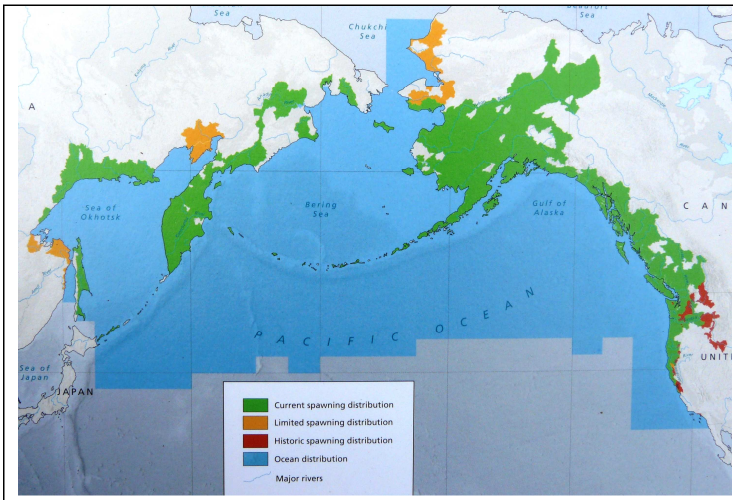

Figure 3: Coho distribution (source Augerot, 2005)

3.1.2 Coho salmon life cycle

The Coho salmon life cycle is constituted by several stages: egg, alevin, fry, smolt, adult and genitor (see hereunder Figure 4). As this project concerns the fry-to-smolt stage, this part of the life cycle will be particularly detailed.

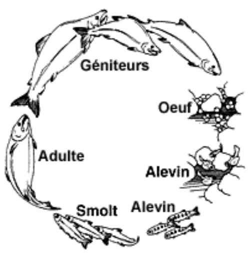

Figure 4: Pacific salmon life history (Source Groot and Margolis, 1991)

3.1.3 First life cycle stages: from egg, through alevin, to fry

Between November and January, Coho salmon eggs are deposited by females in well oxygenated stream and river beds. The length of time required for eggs to incubate in the gravel is largely dependent on temperature and can vary from 100 days at 5°C to 40 days at 10°C. (Taft, 1954).

The time from hatching, through yolk absorption, to fry emergence depends also mostly on temperature, 20 to 40 days is the more typical time observed along the canadian coast. After hatching, alevins stay into the gravel bed without feeding until the yolk is totally absorbed. Then fry emerge at a 30-40 mm size between the end of the winter and mid spring (Mc Phail and Lindsey, 1970).

The survival to emergence depends on stream and streambed conditions. For example, a high winter flood disturbing deep gravel beds can destroy every single egg along a river. As well as a rare, but possible dry spring that will create low water levels and flows, conditions that can be lethal for eggs. Under average conditions, 15 to 30 % of the eggs will survive to emergence, but under very harsh conditions, no eggs will survive (Neave, 1949; Crone and Bond, 1976).

3.1.4 Early fresh water life: from fry to smoltification

3.1.4.1 Juvenile colour

Once fry emerge, their pigmentation is modified to ensure an optimal protection against predators (see hereunder Figure 5). Young Coho salmon have silver or gold coloured bodies, orange fins and large vertically oval blobs of dark brown pigment along the lateral line (Scott and Crossman, 1973).

Figure 5: Coho salmon fry photo (source perso.)

3.1.4.2 Feeding

Fry start active feeding mostly in the water column but also on insects falling on the water surface. In British Columbia, juvenile Coho salmon food appeared to be constituted by 80% dipterans larvae and adults. The 20% remaining being constituted by other insect orders, terrestrial macroinvertebrates or smaller salmonid juveniles (Mason, 1974). Chapman (1965) found that less than 11% of the lake-dwelling coho population had zooplankton in their stomach, observations realised on two lakes in British Columbia. At the yearling stage, Coho may become predatory, supplementing their insect diet with fry of their own or other species (Mundie, 1969).

3.1.4.3 Habitat utilization

Coho salmon juveniles can be found feeding in riffles as well as in pools, but their morphology is more adapted to low velocity currents. Coho salmon juveniles are not usually competing with other salmonids like trout juvenile that are staying in high velocity zones. In the other hand, habitat competition in lakes between juvenile salmon and trout seems to be more important (Armstrong and Argue, 1977). The best habitats are the ones that provide food as well as predator protection. Coho progress through a serie of preferred habitats: back eddies, log jams, undercuts, open bank area and fast water (Lister and Genoe, 1970).

Just after emergence, Coho salmon fry are staying in groups called schools, as they become older, they move to open areas along open shoreline and high velocity areas. Coho juveniles show a territorial behaviour few weeks after emergence; once territories are established, Coho fry can remain in the same zone during relatively long periods. As bigger individuals occupy best habitats, weaker juveniles remain in areas where predation is more important and food less available, a natural selection occurs (Mason and Chapman, 1965).

The habitat availability limits the abundance and survival of Coho salmon fry in a stream. Indeed, territory surface varies with juvenile size, Allen (1969) proved that a 0,34m² territory is necessary for a 49 mm juvenile and a 3,7 to 5,5m² for a 110 mm juvenile. This territory notion implies a fry migratory behaviour from the initial hatching zone during the first weeks of life. Migration along the stream of several kilometers can be effectuated by fry in order to find enough available habitats. As autumnal floods arrives, Coho salmon juvenile habitat changes. Fry are gathering in deep pools or side channels, preferentially in those holding large woody debris (Allen, 1969).

Most of the Coho salmon fry communities are found in streams, but Haslet and Farner (1942) found that some populations in Oregon where rearing along lake shores and using them as a summer habitat as well as a winter habitat (see hereunder Figure 5).

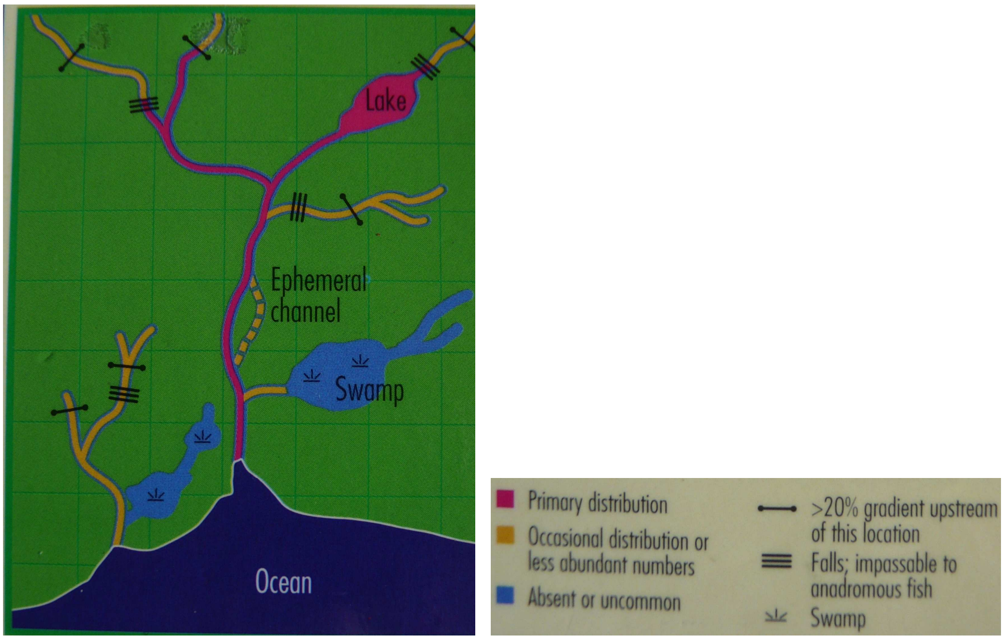

Figure 5: Coho salmon fry habitat utilization (source Pollard and al, 1997)

3.1.4.4 Smoltification process

After a first or second winter spent in freshwater, the smoltification process takes place. However, some populations remain three, four years in freshwater; this phenomenon occurs more often as growth rates are low. This process implies intern modification: changes take place in different endocrine tissues such as pituitary and thyroid cells (Stefansson and Ekström, 2000). Water and ion regulatory mechanisms are affected such that smolts have an increased resistance to higher salt concentrations.

As they approach migratory smolt age, the lateral marks become less evident, the overall colour of the fish is more silvery and fins colours fade from orange to pale yellow (see hereunder Figure 6). Downstream migrations occur during May or June and is influenced by factors such as fish size, flow conditions, water temperature or day length (Shapovalov and Taft 1954). Once they have reached the estuary, Coho smolts stay in coastal zones during few weeks, adapting progressively to a new salty environment by vertical up and down movements from fresh to salty water layers.

Figure 6: Coho salmon smolt captured in Calamity creek in April 2009 (source perso.)

3.1.4.5 Juvenile growth

In average food availability and temperature, Coho juvenile grow from about 30-40 mm after emergence to 60-70 mm after the first summer, to 80-95 mm around March the next year and reach 100-130 mm in late spring before downstream migration toward the ocean (Rounsefell and kelez, 1940). Growth is highly limited during winter because of low food production and feeding possibilities.

3.1.4.6 Fry-to-smolt survival

During their life history stage in freshwater, two main factors are influencing Coho salmon fry survival: water discharge and temperature. Low summer flows reduce potential hideout areas, fish can be blocked in small ponds where predation is highly increased. High winter and autumn floods can be very hostile to fish 45-70 mm. That is why protective habitats such as pools, side channels or log jams are important to limit flood impacts on juveniles (Smoker, 1953 and Neave, 1946-1947). Studies in British Columbia have shown that fry-to-smolt survival average rate was 1 to 2 % in a pristine coastal stream, with highest mortality recorded during the first summer (Neave and Wickett, 1953).

3.1.5 Ocean life

After few weeks spent in the estuarial zones, young Coho salmons go to the ocean. Some of them will remain within the coastal areas, others will migrate up to ten thousand kilometers into the Pacific Ocean (Clemens, 1930). Coho captured at sea are silver-coloured on their sides and ventral, dorsal surface is dark metallic blue.

Coho salmon grow very rapidly after they reach the marine environment, feeding on adult fish like anchovy, flatfish or sardines. Average growth was estimated from 1.2-1.5 mm per day, reaching a size averaging 600 mm and 3.0-3.5 kg as they mature, oldest individuals can reach 10 kg (Hartt, 1980).

Smolt-to-Adult survival depends highly on ocean food availability and human harvesting activities. During the last 15 years, smolt-to-adult survival was estimated from 5.4 to 15.5 % in British Columbia stocks (Morrison and Stevenson, 2008).

The natural predators of the pacific salmon are mostly large marine mammals (sea lions, orcas, dolphins, seals…) or fish like tunas.

3.1.6 Upstream migrations and Reproduction

The majority of Coho salmons mature in their third year of life, having spent about sixteen months growing in the ocean. Coho spawners migrate toward their birth coastal zone where they gather during summer. In British Columbia, Coho salmon start migrating upstream in September or November until January, this migration occurs generally when there is a large increase in flow combined with a high tide (Briggs, 1953). Most Coho stocks actively migrate during daylight hours rather than at night, holding in pools and downstream from barriers (Brett and MacKinnon, 1954).

As spawning time approaches, the back, head and ventral surface of males turn bruish green; the sides develop broad red streak. The upper jaw forms an elongated hooked snout, their teeth become greatly enlarged and the dorsal area is projected slightly upward (see hereunder Figure 7). Females are not as brightly coloured but appear more brassy green and the jaw elongation is much lesser extreme than that observed in the males (Hartt, 1973).

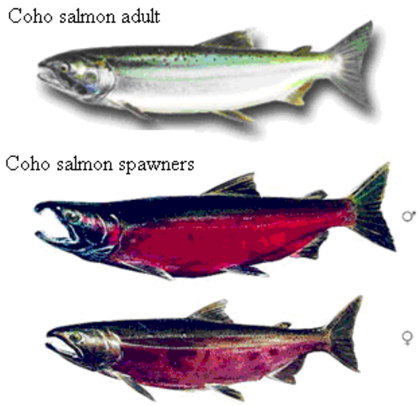

Figure 7: Coho salmon morphological changes during spawning periods (Source DFO, 2003)

When salmons reach the spawning grounds, the female selects a nest site that she will defend against other females. Coho salmons mostly select small streams where the flow is about 5.0-7.0 m^3/min and depth do not exceed 1 m.

Substrate is generally constituted by coarse gravel up to 15 cm diameter. The female begins digging the nest by rolling onto either side on the gravel and by body and tail flexing.

Once the nest is completed, the female and the dominant male swim closely alongside and deposit both eggs and sperm simultaneously. Up to seven thousands eggs of 4,5-6 mm diameter can be deposited in every nest by the same female. Once the spawning act is completed, female buries gingerly the eggs by up and down tail movements (Rounsefell and Kelez, 1940).

After spawning, salmons quickly die from both external and internal deterioration (cardiovascular system, liver, stomach degeneration or fungus infections…). Salmon carcasses represent the majority of the winter diet of a lot of animals like bears, otters or birds. Salmon bodies represent also a precious resource in nutrient (Phosphore and Nitrogen) for the aquatic life and are necessary to ensure future juvenile feeding, especially in oligotrophic systems (Bilby, 1996).

3.2 Threats in British Columbia

Salmon species on the west coast of Canada have experienced dramatic declines in abundance during the past several decades as a result of human-induced and natural factors. A large part of Coho stocks are still under moderate or high risk of extinction (see hereunder Figure 8).

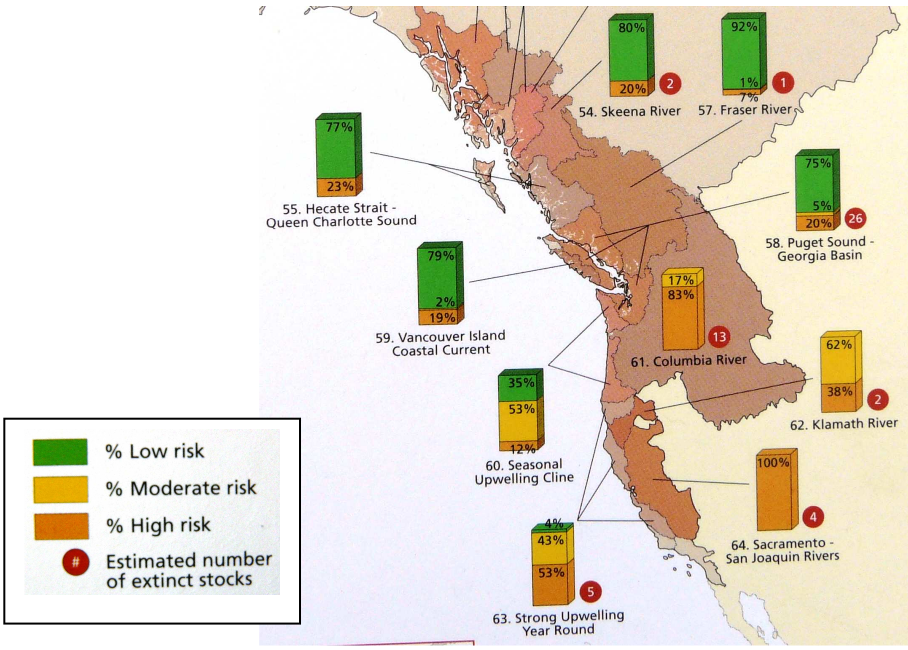

Figure 8: Coho risk of extinction along the Canadian southern west coast (source Augerot, 2005)

3.2.1 Forestry activities

Salmon have specific needs for spawning, growing, feeding and hiding areas during their freshwater life stages. Logging activities have numerous consequences on the Pacific salmon ecosystems and populations. In British Columbia, the forestry sector is considered as responsible for 50 to 70% of the salmon fisheries collapse during the last 50 years (Slaney and Zaldokas, 1997).

In Canada, the most used logging method is clearcut, all trees are cut off in once within the exploited area, which can be hundreds of hectares. This method disturbs particularly streams capacity to hold salmon populations, the consequences of clearcuts on streams and salmonids are described in Table 1 hereunder.

Table 1: Consequences of logging activities on Salmon (source Reiser and Bjornn, 1979)

Logging activities/ clear cut	Stream environmental factors	Habitat quality of Salmonids	Growth and survival of Salmonids
Forestry activities along streams in the riparian zone	Solar rays increase	- Water temperature increase - Luminosity levels increase - Autotrophic production increase	- Growth rate modification - Disease risks increase - Trophic patterns modification
	Large woody debris quantity decrease	- Reduction of potential habitats and hideouts - Flow modification reduction	- Predation vulnerability increase - Winter floods vulnerability
	Logging left over gather	- Oxygen demand increase - Fine organic particles increase - Dam creations	- Reproduction success reduction - Nutrient production increase
	Bank erosion	- Vegetation covering reduction - Potential habitat reduction - Stream bed width increase - Water depth decrease - Fine organic and mineral increase causing spawning and feeding gravel clogging	- Reproduction success reduction - Predation vulnerability increase
	Destruction of wetlands, side channels and oxbow lakes	- Destruction of high/low water hideout zone for juvenile salmon	- Reduction of salmon juveniles growth and survival
Forestry activities on slopes and logging roads	Stream flow modification	- Water retention/release within rainforest reduction causing high flow picks and summer critical low level	- Augmentation of eggs disturbance and embryos mortality during floods - Reproduction disturbance caused by low water levels
	Surface erosion increase	- Fine and coarse particles increase causing sediment clogging	- Eggs survival reduction
	Nutrient flow increase	- Nutrient concentration increase	- Modification of the trophic functioning: oxygen level modification

Several restrictions have been imposed to the logging sectors, in the aim to limit the impact of these activities on streams and rivers. For example, a 20 meters wide stripe has to be kept along every stream bank or lake shore within the exploited area. This stripe is supposed to preserve the aquatic ecosystem from erosion and deterioration. In fact, this restriction can only protect partially the streams from logging activities, even though this kind of policy represents an improvement.

The forestry sector is actually a powerful key stakeholder in the salmon fisheries management that is hard to restrict. That's why restoration projects have been carried out during the last decades in salmon streams in order to limit the forestry impact on salmon habitats and ensure sustainable wild salmon populations in British Columbia.

3.2.2 Overfishing

Salmon are fished traditionally for thousands of years by the native population along the west coast of Canada. But since colonization during the early 50's, industrial fishing roughly impacted the wild salmon populations in Northern Pacific. During the last century, unconsidered harvesting participated in a large salmon populations collapsing: along the British Columbia-Washington coasts, some Coho salmon populations were harvested at rates of 70 to 80 percent in the later part of the 20th century (Pacific Salmon Comission, 2008). During the last 30 years, Coho salmon also became a famous sport fishing target along Vancouver Island, and is harvested by short line troll gear during summer when salmons gather before spawning.

Recently, authority established harvesting periods and quotas to ensure a sustainable salmon fishing, but the wild salmon population remains fragile, especially in countries like Japan or Russia where the rules are not always followed (Pacific Salmon Comission, 2008).

3.2.3 Climatic changes

According to the predictions of the Intergovernmental Panel on Climate Change (based on the year 1994 CO^2 emissions), if nothing changes the atmospheric accumulation of greenhouse gases will be twice what their were in preindustrial time by the end of the 21st century. Extend and timing of this phenomenon on climates during the 21st century are not precisely known; but few projections are already considered as sure. For example, in British Columbia late winter, accelerated snowmelt, higher streams levels are expected, on the other hand, summers should be dryer with lower stream levels and higher temperatures. The consequences on salmon migration, reproduction, incubation, juveniles' growth and survival are not actually well estimated but will be obviously negatives (Levy, 2002).

3.2.4 Fish farming

The Salmon farming industry has quickly and widely developed during the last 25 years along the Vancouver Island coasts, mostly because of the decrease of wild stocks (Allendorf, 2005). This intensive method involves the use of large floating open net-cages located usually in sheltered bays. Important amounts of nutrients and antibiotics are used in order to ensure a rapid growth of hatchery salmons. Atlantic salmons (*Salmo salar*) are also often produced because of their high growth capacity and resistance.

Hence, in high intensive fish farming areas, marine biodiversity and salmon especially are highly impacted by eutrophication (dead zone creation), diseases, parasites (sea lice) and interspecies competition with escaped Atlantic salmons(Ford and Meier, 2008)

Several "fish farming impacts reduction" programs are today occurring in British Columbia. Those programs are focusing on decreasing and treating the amounts of nutrients and chemical compounds used in fish farming. However, modern salmon farming still represents a serious threat to wild salmons on Vancouver Island.

4 Study area presentation

4.1 Physical features

Calamity Creek watershed is situated on the West Coast of Vancouver Island at about 4 km south of Bamfield, BC, Canada (48°49'N and 125°05'W). Calamity Creek is a first order stream which drains Calamity Lake (15 m elevation) and flows south about 550 m before reaching the southern portion of the Pachena River at a 4 meters elevation. This sub-watershed is one of the smallest of the Pachena river watershed and represents a surface of 2.25 km² (Morgan and Ochman, 2001).

Calamity Lake has two main non-permanent tributaries situated on its North-Western part, the main characteristics are described in the following table (see hereunder Table 2).

Table 2: Calamity Lake physical parameters (source Morgan and Ochman, 2001)

Elevation	46 m
Surface area	125000 m²
Area above 6 m contour	103000 m²
Volume	366000 m^3
Mean depth	2.9 m
Maximal depth	14 m
Perimeter main shore	1800 m
Perimeter Islands	130 m
Bench mark height above water level	2.75 m

Climate conditions of the studied area are based on fourteen similar Atmospheric Environment Service stations on Vancouver Island. The mean annual temperature in low elevation stations is about 8°C. Most precipitation occurs during winter (between October and February) with an average of 308 mm per month. Rainfall is much reduced in the summer averaging 30 to 60 mm from May to September (Atmospheric Environment Service, 1994).

The Calamity Creek watershed was heavily logged between 1960 and 1970 and the implementation of the Forest Practice Code in 1995. Most of the shores and banks of Calamity Lake and Creek were extensively logged, from the riparian zone until the ridges forming the watershed boundaries (see hereunder Figure 9). Excessive amounts of woody debris within the streambed and riparian canopy destruction are noted as the direct result of the clear cutting practices (Krajewsky, 2000).

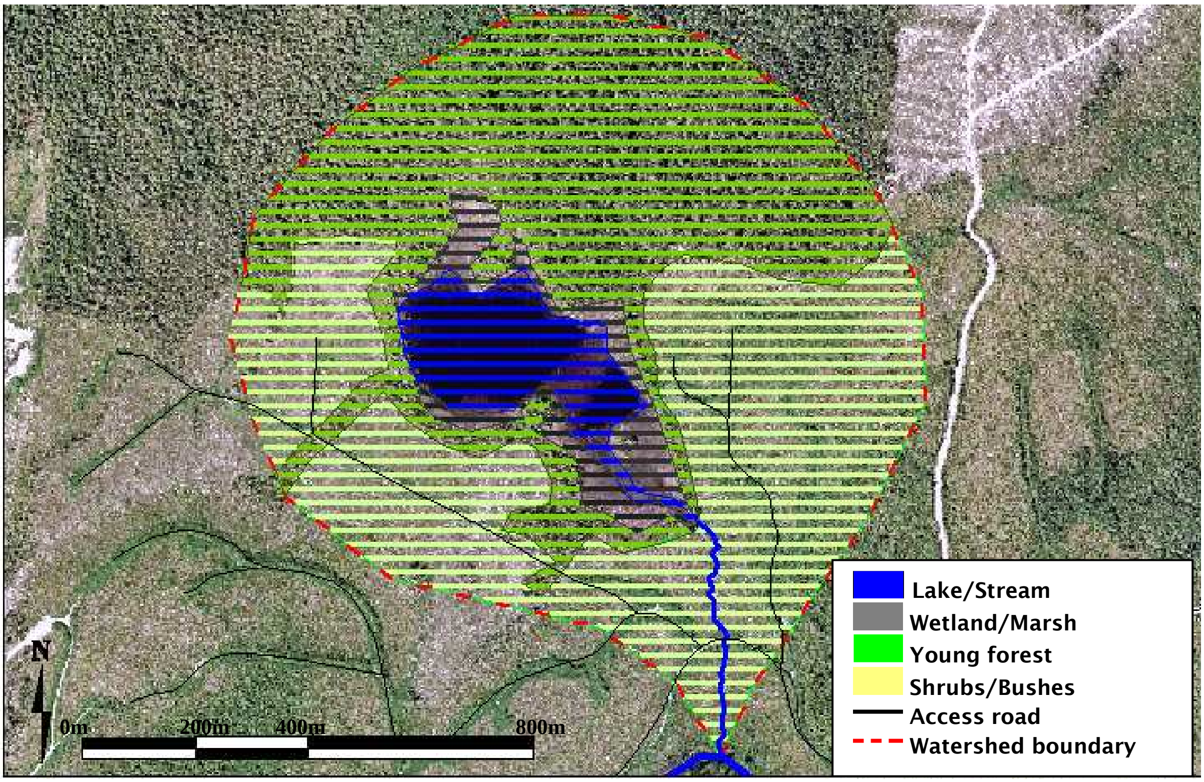

Figure 9: Map of logged areas within Calamity watershed (source perso.)

4.2 Restoration works completed

4.2.1 Habitat assessment and stream restoration

In the Watershed Restoration Program context, the Huu-hay-aht fisheries Department carried out studies on Calamity watershed and produced a “Level 1 fish habitat assessment” and a “Level 2 fish habitat restoration prescriptions” respectively in 2000 and 2001. The level 2 identified two large woody debris wedged into the river banks, and several logjams along Calamity Creek which were representing “definitive barriers to fish migration” that has to be removed. These reports were rapidly followed by instream restoration works carried out in Calamity Creek in September 2001, small logjams where removed and notches were cut into large logs (see hereunder Figure 10).

Figure 10: Notches dug in barriers at 494 and 502 m (source perso.)

4.2.2 Juvenile Coho release

In the aim to support the natural reproduction, juvenile Coho salmons from hatchery are released every year in different watersheds by the Huu-ay-aht fisheries Department. When a sufficient staff is available, juveniles are fin-clipped in order to estimate the proportion of spawners that are from hatchery origin (see hereunder Table 3).

Table 3: Juvenile production at Sugsaw hatchery and releases (Ochman, 2009)

Year of Release	Production			Release areas	
	Pachena coho	**Fin-clip**	**Sugsaw coho**	**Calamity lake**	**Pachena**
1999	5 800			5 800	
2000					
2001	8 500	8 500		8 500	
2002	9 200	9 200		9 200	
2003					
2004	14 800	10 000	14 200	14 000	
2005					
2006	2 300	2 300			2300
2007					
2008	24 000			10 000	14 000
2009	26 000	10 500		10 500	15 500
Total	90 600	30 000	14 200	45 500	38 500

Fry release sites are important to ensure maximal survival: the site has to be favorable for juvenile growth during their entire freshwater life and should include optimum winter and summer habitat in quantity as well as in quality. Release sites were chosen in areas where the wild juvenile Coho salmon are not present or in low numbers, to limit intra-specific competition. The quantity of juveniles released is also a major parameter influencing the success, as it is crucial not to overload the ecosystem and ensure habitat and food for the released fry. The density of fish usually used for the estimates is 1 fry/m².

The population of wild Coho salmon in Calamity Lake is probably limited, given the fact that access for spawners to the lake trough Calamity creek is relatively uneasy (low flow rate and no deep pools).

5 Hatchery juvenile Coho behavior and fate assessment in Calamity watershed

5.1 Methods and materials

A total of 10 500 Coho fry were fin-clipped marked and released in Calamity Lake on May 15th 2009. In addition, 150 Coho fry right pelvian clipped were released the same day in Calamity Creek. The main objective of this survey was to estimate the quality of Calamity Lake as a releasing area for hatchery juvenile Coho salmons. To study these hatchery fry released in Calamity Lake and Creek, studies were carried out on physical features, fishes and plankton population of the lake and stream.

5.1.1 Physical parameter measurement

5.1.1.1 Oxygen and Temperature

Oxygen and Temperature were recorded 8 times in both Calamity Creek and Lake between April 26th and August 17th, using an electronic oxygen sampler (type OxyGuard). Oxygen and temperature were recorded under the logging road crossing the stream at about 280 meters upstream of Pachena River (see Figure 14 p 25). In the lake, these two parameters were recorded along the water column every meter from the surface to the bottom at the deepest point (see Figure 14 p 25).

5.1.1.2 Turbidity

Turbidity was recorded during each minnow trapping session at the deepest point (see Figure 14 p 25) using a Secchi disc.

5.1.1.3 Morphological features: habitat and spawning gravel assessment

- A habitat assessment was conducted in Calamity Creek, on July 2nd 2009. The method used was the same as the one used for the level 1 fish habitat assessment completed in 2000 and 2001. The stream was divided in 30-m sections, and a total for the entire creek was calculated. Within each section, physical attributes were recorded or estimated according to methodologies and procedures in Watershed Restoration Technical Circular n°8 (Ochman and Morgan, 2001). These physical attributes concerned pools, bed material, woody debris, cover, off channel habitat, channel disturbance, riparian vegetation and barriers. Results obtained in 2009 were compared with those obtained in 2000 by Krajewsky.

The habitat diagnosis was based on 8 parameters, a rating of poor, fair or good was given for each section and each parameter:

– Percentage pool=total pool area/total wetted area. Poor<40%, Fair 40-55%, Good>55%
– Pool frequency=reach length/ mean bankfull width/ total number of pools. Poor>4, Fair<=4, Good<2
– Number of LWD debris per channel width. Poor<1, Fair<=2, Good>2
– Percent wood cover for pools. Poor<5%, Fair 6-20%, Good>20%
– Value is sub-dominant substrate C=cobble, G=gravel, S=sand (as gravel was dominant substrate). Rating is based on sand abundance. No sand=Good, limited sand=Fair, extensive amount of sand=Poor
– Off channel habitat with good access. Presence=Good, absence=Poor
– Amount of spawning gravel. None=Poor, isolated pockets=Fair, extensive amounts=Good
– Maximum depth of holding pools. Depth<1m=Poor, >1m=Good

▪ A habitat and spawning gravel estimation was carried out in Calamity Lake, on June 22nd 2009. Habitat quality was estimated visually: dominant substrate, riparian vegetation, percentage of cover. This assessment was completed only visually from a boat, so only the zones with depth inferior to 2 m were sampled. Oxygen and temperature were recorded into potential spawning gravel areas, using a electronic Oxyguard sampler.

5.1.2 Fish population survey

5.1.2.1 Juvenile Coho salmon production method in hatchery

The Huu-ay-aht First Nation hatchery is situated along Sugsaw creek estuary in Grapler Inlet. During the annual Coho salmon run which usually occurs from November to January on the Pachena River, adults are captured using a seine net in Rousseau Creek. The number of adults captured depends of the spawners abundance, female sizes and needs (in fall 2008, 80 females were spawned).

After their capture, fish are killed; eggs and sperm are taken out and brought to Sugsaw hatchery as quickly as possible. Fecundation is effectuated by mixing sperm and eggs during few minutes, afterwards, eggs are washed and placed in incubation drawers until hatch. The length of time required for eggs to incubate is largely dependent on water temperature but usually takes 80 days at 5°C at Sugsaw hatchery.

After hatching and yolk sac absorption, fry are transferred in a 1000 liters round tank, where they will grow till the release date, during the month of May. Juveniles are fed daily with fry fish food (BioVista Starter by Bio-Oregon) at a rate of 1.6 percent of their weight per day.

The egg-to-fry survival rate at Sugsaw hatchery is estimated from 90 to 95 % versus 15 to 27 % in natural conditions (see *Chapter 3.1.3 First life cycle stages: from egg, through alevin, to fry* p 9).

5.1.2.2 Juvenile marking: fin clipping

In the aim to identify hatchery from wild fry, Sugsaw hatchery juveniles were marked. Marking consisted in an adipose fin clip (see hereunder Figure 11). This fin being an evolution relic that is useless in salmonids life cycle. To be efficient, clipping was realised with surgery scissors and the adipose totally cut off to avoid fins to grow back. Fishes were desensitized using a MS 222 solution. As Fin clipping is easier on bigger fish, this operation was realised the week prior to release.

Figure 11: Coho salmon juvenile prior and after fin clipping (source perso.)

Fin clipping in 2009 was completed between April 25th and May 10th, when about 13 000 Chum and 10 500 Coho fry were adipose marked by a 4 person crew. In addition, 150 Coho juveniles were marked by right pelvic fin clipping and released in Calamity Creek.

5.1.2.3 Fish transportation and release

- Juvenile Coho salmons were transported in a 100L tote with an air stone and oxygen bottle and placed on the back of a pick-up truck (see hereunder Figure 12).


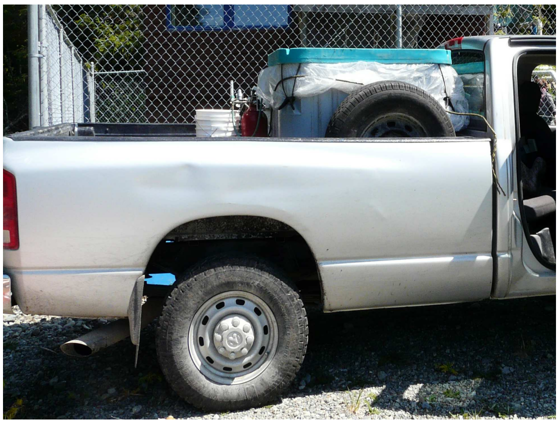

Figure 12: oxygenated tank and truck used for juvenile transportation (source perso.)

- Coho fry were carried from the truck to the releasing area in 10 liters buckets in less than 5 minutes to avoid mortality given the fact that water was not oxygenated in the buckets (see hereunder Figure 13).


Figure 13: Coho juveniles releases in Calamity Lake and Creek (source perso.)

- A total of 10 500 juveniles with adipose fin clipped were released on May 15th 2009 in Calamity lake in a unique releasing spot (see hereunder Figure 14) in order to limit transportation time.
- The same day, 150 right pelvic fin clipped juveniles were released under the logging road bridge in Calamity Creek situated about 260 m from Pachena River (see hereunder Figure 14).

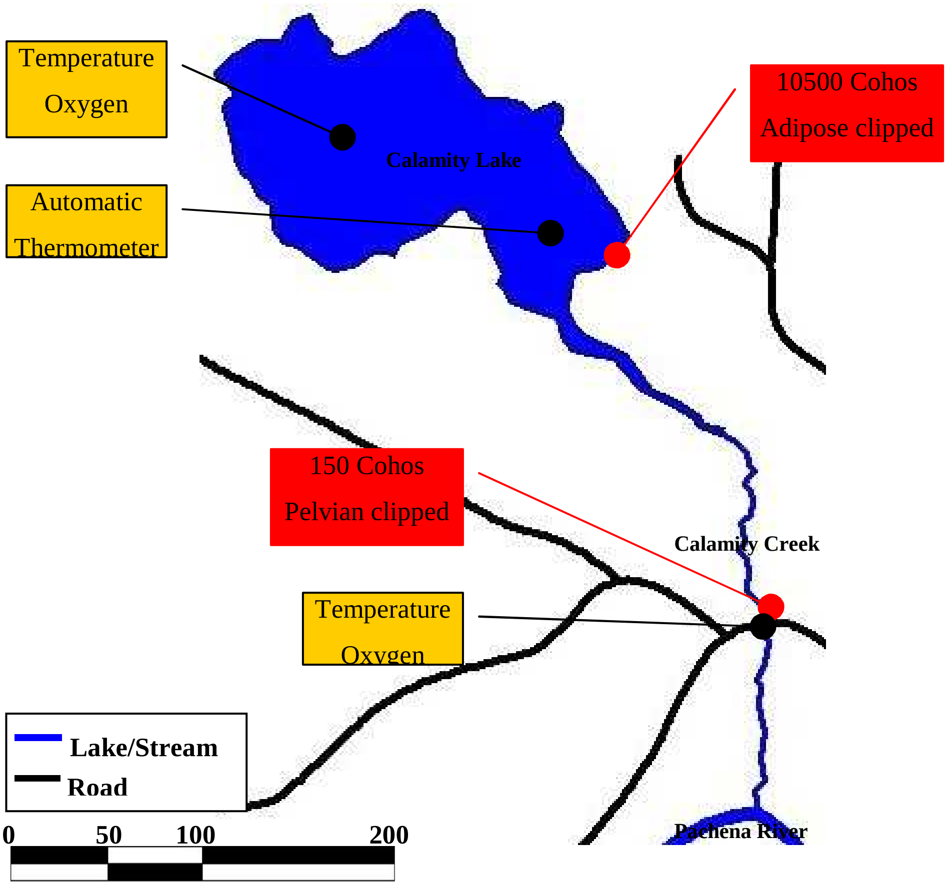

Figure 14: Releasing and physical parameters points localization in Calamity (source perso.)

5.1.2.4 Fish trapping method

- The released Coho juveniles were followed in Calamity Lake and Creek using minnow traps (see hereunder Figure 15), placed along the creek banks and lake shores. In order to follow the movement of hatchery juvenile Coho, a total of 46 minnow traps were set during a 24 hours period, 8 times between April 26th and August 17th. To attract the fish into the minnow trap, Chum salmon roes were used as bait.

Figure 15: minnow trap and fish sampling (source perso.)

The mesh constituting the trap is 4 mm, with opening averaging 2 cm, so the length of the fishes that can be captured varies from about 5 to 15 cm.

- A total of 24 traps (see hereunder Figure 16) were placed in Calamity Creek in potential good fry habitat zones such as pools, side channels, logjams or rootwads (Rounsenfell and Kelez, 1940). In Calamity Creek as well as in most of coastal streams on Vancouver Island, Sculpins (*Cottus spp.*) are present in so high densities that big individuals get in the traps first, scaring away salmonids or eating them once they get in the trap (Clarke, 2006). Hence, sculpins were systematically killed during trapping sessions in Calamity Creek.

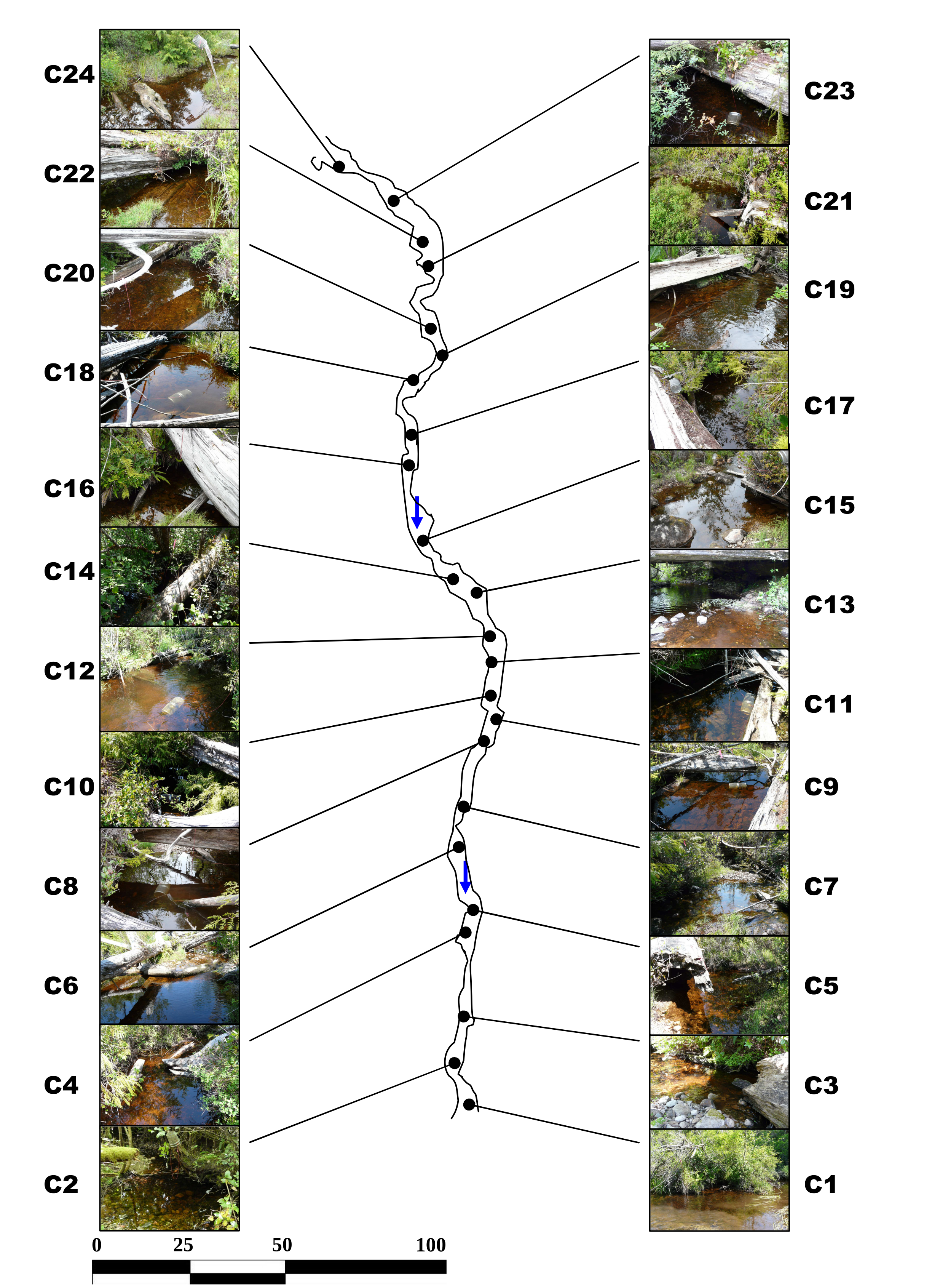

Figure 16: Minnow trap localizations along Calamity Creek (source perso.)

- Twenty one traps were placed in Calamity Lake, every 50 to 100 meters along the shores (up to 1m50 deep) in potential good habitat zones like woody debris, aquatic plants or tributaries inflow (see hereunder Figure 17). Even though juvenile salmon is expected to stay in shallow zones (Mason, 1974), two traps (number 7 and 16) were positioned in deeper zones, respectively at a depth of 10 and 6 meters. On June 20th 2009, 3 traps were added at point 7 (2, 4 and 6 meters deep) and 2 were added at point 16 (2 and 4 meters deep).

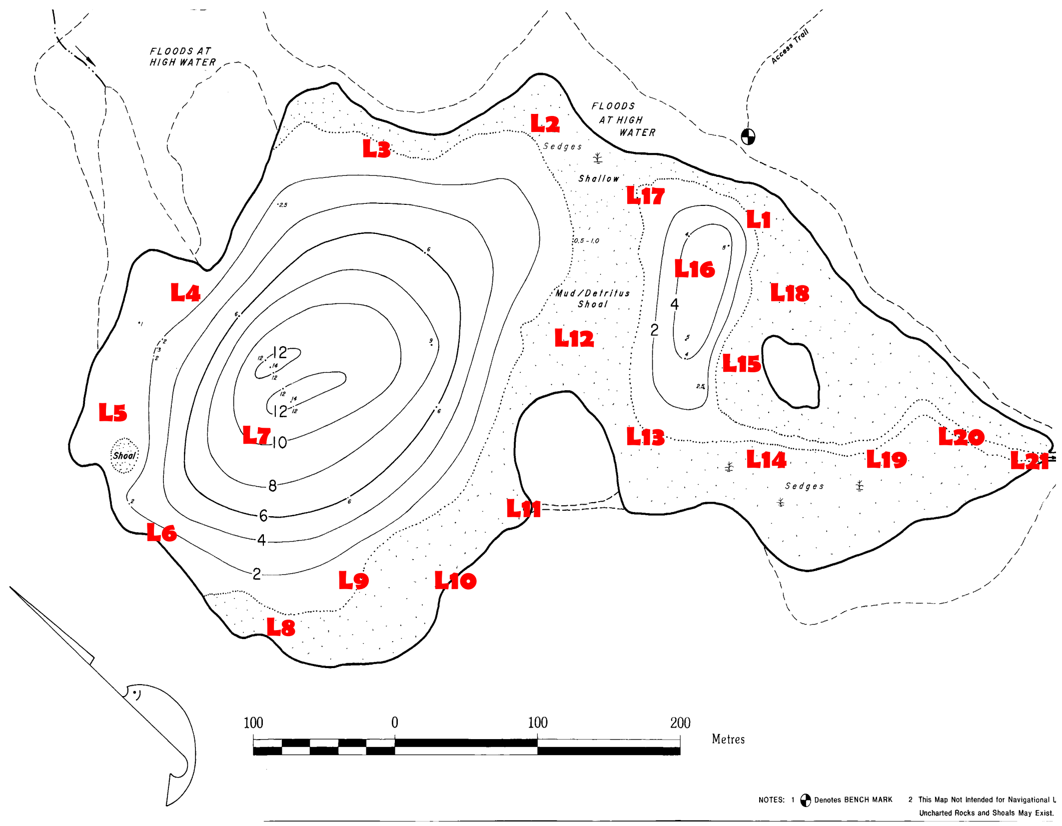

Figure 17: Minnow trap localizations in Calamity Lake (Source Morgan and Ochman, 2001; modif. perso.)

5.1.2.5 Collected data on fish and trapping points

- After 24 hours trapping, traps were pulled up and every Fish or Crustacean was identified. Salmonids were anesthetized using a MS 222 solution, measured using a centimetric ruler, and only salmons were weighted using a PESOLA weight (max 30x0.25 g). A few scales were sampled on 10% of the non-marked captured Coho using a sharpened knife on the side behind the dorsal fin in order to complete a scalimetric study.

- The scalimetric study was carried out using a binocular microscope (zoom x40) at the Bamfield Marine Science Center. Scales were cleaned in alcohol and placed on a glass slide. Growth of a salmonid is “readable” on its scales: during the winter growth rate is low and the lines are tight.

But during the rest of the year, spaces between the lines are wide as fish growth increases. Age of the fish can be estimated by counting the series of tight lines which is the number of “winters” a fish is old (see hereunder Figure 18).

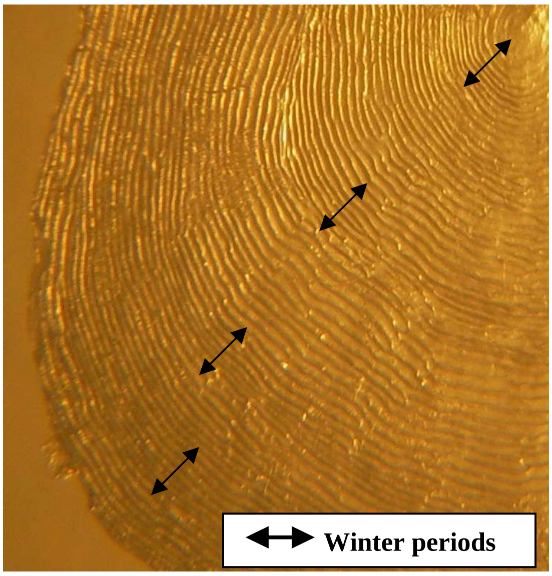

Figure 18: Salmonid scale sight through a binocular X40 (source perso.)

- On every trapping zones, substrate, depth, cover percentage, flow velocity and periphyton cover were visually recorded in Calamity Creek. Only depth, cover type and substrate were recorded in the lake.

5.1.3 Plankton population survey

The plankton communities were studied using a plankton net (153 microns mesh diameter) that was towed behind a row boat at a 1 m depth during 100m. A qualitative 50 ml sample was taken out from the collecting bottle and stabilized with about 10 ml of alcohol. Only zooplankton was identified at the Bamfield Marine Station laboratory to Family. Two samples were collected on June 22nd and July 20th.

5.2 Results

5.2.1 Physical parameters

5.2.1.1 Oxygen, Temperature, Secchi depth

Table 4: Water physical parameters in Calamity Creek

Dates	Temperature (℃)	[Oxygen] % sat	[Oxygen] ppm
26/04/2009	10	101	9.2
17/05/2009	16.2	95	8.7
23/05/2009	18.6	92	8.3
31/05/2009	19.4	94	8.4
05/06/2009	20		
20/06/2009	19.6		
01/07/2009	19.4		
10/07/2009	18		
17/08/2009	20	92	8.2

Oxygen was not monitored between May 6th and July 10th because of an oxygen-meter malfunction (see above Table 4). Water temperature greatly increased from April 26th to May 23rd then remained between 18 and 20°C until the end of the sampling on August 17th. Oxygen levels gradually decreased from 101 to 92% of saturation during the entire sampling period.

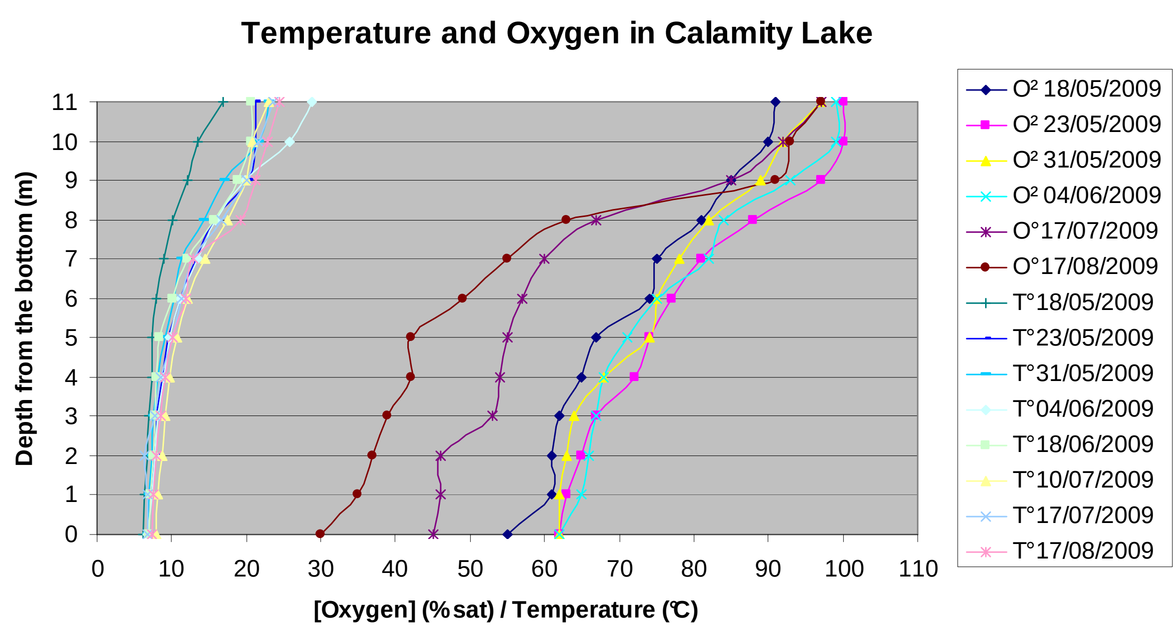

Figure 19: Water physical parameters in Calamity Lake

The water parameters results showed that an increasing stratification occurred in Calamity Lake in summer 2009 (see above Figure 19). The difference between surface and bottom temperature seems to increase, rising from 6°C on May 18th to 12°C on August 17th.

An important decrease in Oxygen concentration occurred between June 4th, July 17th and August 17th in the lower part of the water column. The thermocline zone is situated between depths of 2 and 5 meters.

Table 5: Secchi depth recorded in Calamity Lake

Dates	18/05/2009	23/05/2009	31/05/2009	04/06/2009	18/06/2009	10/07/2009	17/07/2009	18/08/2009
Secchi depth	1.6	2.5	1.8	1.6	1.7	1.5	1.15	1.20

5.2.1.2 Habitat and spawning gravel assessment in Calamity Creek

Table 6: Abstract results of Calamity Creek habitat assessment

Total sectionS	Total section length (m)	Habitat type		Habitat category		Gradient (%)		Mean water depth (m)		Mean bank depth (m)		Bankfull width (m)		Wetted width (m)		Maximum depth (m)		Pool type		Pool length (m)		Pool area (m²)		Good holding Pool		Dominant substrate		Sub-dominant substrate		Spawning gravel amount		Spawning gravel type		Compaction	
																Pools only										Bed material									
		01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09
19	30	M	M	1	1	0.9	0.9	0.11	0.08	0.47	0.65	4.3	4.1	2.7	2.1	0.36	0.32	U	U	3.4	3.0	79.8	81.2	N	N	G	G	C/S	C/S	L	L	AR	AR	M	M

Total sections	Total section length (m)	Total LWD Tally		10-20 cm		20-50 cm		>50 cm		Total functional LWD		Cover type 1		%		Cover type 2		%		Total cover %		Type		Acces		Length (m)		Channel Disturbances		Type		Structure		Canopy closure		Barriers	
		Functional LWD																				Off channel habitat								Riparian Vegetation							
		01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09	01	09
19	550	143	245	45	89	57	65	27	31	129	178	WD	WD	14.7	23.3	OV	OV	5.9	8.5	20.7	28.7	SL SC WL	SL SC WL	G	G	41.1	50.4	MC FP EB	MC FP LR	SH	SH	SHR	SHR	1	1	2X	(2X C)

Section represents the sequential number of 30-m long sections from the Pachena River.
Section location denotes the distance in meters, upstream from the Pachena River.
Habitat types are : Scour pool (P), dammed pool (DP), riffle (R), glide (G), mixed unit (M), cascade (C), other (0)
Pool type: Scour (S), Dammed (D), Unknown (U)
Good holding pool (Y) if the maximum depth X overhead cover >or=30%. Overhead cover is the sum of LWD, boulder, cutbank and overhanging vegetation.
Substrate categories are: sand, silt or organic material (S), gravel (G), cobble (C), boulder (B), bedrock (R).
Spawning gravel amount: no suitable gravel (N), little suitable gravel (L), extensive areas of spawning gravel (H).
Spawning gravel type: suitable for anadromous salmon (A), suitable for resident trout and char (R), suitable for both salmon and trout (AR), not suitable (N).
Compaction: Loose and clean substrates fines (fines<25%) receiving a rating of high (H), compact and embedded substrate (fines>50%), a medium ranking (M) refers to embedded, loose gravel (25%<fines<50%).
Total Large Woody Debris (LWD) tally includes both functional and non functional wood.
Total Functional LWD are only those LWD that influence channel geomorphology by causing scour and impoundment.
Cover type: woody debris (WD), boulders (B), undercut banks (C), deep pool (DP), overhanging vegetation (OV), instream vegetation (IV).
Off-channel habitat codes are: side channel (SC), slough (SL), pond (PD), wetland (WL), other (O).
Off-channel access codes are: no access (N), high flow only (P), most flow (G).
Channel disturbance indicator codes are: scour (SC), unvegetated bar (DW), sediment wedge (WG), midlle-channel bars (MB), extensive riffle zone (LR), low pool frequency (FP), multiple channels (MC), eroding banks (EB), backchannels (BC), LMD parallel to bank (PD); LWD jams (SH), avulsion (AV), >50% silt content (E), other (O).
Riparian vegetation type: unvegetated (N), grasslands (G), shrubby vegetation (SH), deciduous forest (D), coniferous forest (C), mixed (M);
Structure refers to structural stage: initial colonization (INIT), shrub/herb stage (SHR), pole-sapling stage (PS), young forest (YF), mature forest (MF).
Canopy closure: none (0), 1-20% (1), 21-40% (2), 41-70% (3), 71-90%(4), >90% (5).
Potential barrier codes are: none (N), log jam (X), falls>2m (F), culvert (CV), bridge (BR), beaver dam (BD) land slide or bank failure (LS), cascade or chute (C), dry bed (D), other (O).

Habitat assessment results in detailed version are available in Appendix 3.

Table 7 : Calamity Creek habitat diagnosis summary

	%Pools		Pool frequency		LWD pieces/width		% Wood		Subdominant Substrate		Off-channel Habitat		Gravel Quantity		Holding Pools	
Section	2001	2009	2001	2009	2001	2009	2001	2009	2001	2009	2001	2009	2001	2009	2001	2009
1	Poor	Poor			Fair	Fair			Fair	Fair	Poor	Poor	Poor	Poor		
2	Poor	Poor			Fair	Fair			Good	Good	Poor	Poor	Poor	Poor		
3	Poor	Poor			Good	Good	Fair	Fair	Good	Good	Good	Good	Poor	Poor	Poor	Poor
4	Poor	Poor			Good	Good	Fair	Fair	Fair	Fair	Poor	Poor	Poor	Poor	Poor	Poor
5	Poor	Poor			Poor	Poor	Fair	Fair	Fair	Fair	Poor	Poor	Poor	Poor	Poor	Poor
6	Poor	Poor			Fair	Good			Good	Good	Poor	Poor	Fair	Fair		
7	Poor	Poor			Poor	Poor	Poor	Poor	Fair	Fair	Poor	Poor	Poor	Poor	Poor	Poor
8	Poor	Poor			Good	Good			Fair	Fair	Poor	Poor	Fair	Fair		
9	Poor	Poor			Poor	Poor			Good	Good	Good	Good	Poor	Poor		
10	Poor	Poor			Poor	Poor	Fair	Fair	Good	Good	Poor	Poor	Fair	Fair	Poor	Poor
11	Poor	Poor			Good	Good			Good	Good	Good	Good	Poor	Poor		
12	Poor	Poor			Poor	Poor		Fair	Good	Good	Poor	Poor	Fair	Fair		Poor
13	Poor	Poor			Fair	Good			Good	Good	Poor	Poor	Poor	Poor		
14	Poor	Poor			Good	Good			Good	Good	Poor	Poor	Fair	Fair		
15	Poor	Poor			Fair	Fair		Fair	Good	Good	Poor	Poor	Poor	Poor		Poor
16	Poor	Poor			Fair	Fair			Good	Good	Poor	Poor	Fair	Fair		
17	Poor	Poor			Fair	Good			Fair	Fair	Poor	Poor	Fair	Fair		
18	Poor	Poor			Good	Good			Fair	Fair	Poor	Poor	Poor	Poor		
19	Poor	Poor			Poor	Poor	Poor	Poor	Fair	Fair	Poor	Poor	Poor	Poor	Poor	Poor
Total	**Poor**	**Poor**	**Poor**	**Poor**	**Good**	**Good**	**Fair**	**Fair**	**Good**	**Good**	**Good**	**Good**	**Poor**	**Poor**	**Poor**	**Poor**

Percentage pool=total pool area/total wetted area. Poor<40%, Fair 40-55%, Good>55%
Pool frequency=reach length/ mean bankfull width/ total number of pools. Poor>4, Fair<=4, Good<2
Number of LWD debris per channel width: Poor<1, Fair<=2, Good>2
Percent wood cover for pools: Poor<5%, Fair 6-20%, Good>20%
Value is sub-dominant substrate C=cobble, G=gravel, S=sand (as gravel was dominant substrate). Rating is based on sand abundance. No sand=Good, limited sand=Fair, extensive amount of sand=Poor
Off channel habitat with good access : Presence=Good, absence=Poor
Amount of spawning gravel : None=Poor, isolated pockets=Fair, extensive amounts=Good
Maximum depth of holding pools : Depth<1m=Poor, >1m=Good

5.2.1.3 Habitat and spawning gravel assessment in Calamity Lake

Observations on June 22nd in Calamity Lake showed that there is almost no covers provided by woody debris as only 12 functional large woody debris were found around the lake. However, most of the shallow parts of the lake were covered by macrophytes. Aquatic plant communities were distributed by depth: *Nuphar spp.* from 20 to 120 cm, *Callitriche spp.* from 10 to 50 cm and wetland grass until 10 cm. The substrate was mostly constituted by organic material, except for some isolated clusters. The vegetation growing along the shore was mature forest as a 10 m strip had not been logged along the lake. Although, there is no overhanging vegetation (indeed no cover) due to the presence of a wet grassland (1 to 4 m wide) between the lake shore and the riparian forest. Calamity Lake water level dropped about 8 cm from June to August.

Three zones with potential substrate gravel suitable for salmon spawning were identified on the north-western shallow part of the lake on June 22nd and represented a total surface of 50m². The substrate was constituted of clusters of coarse gravel (2 to 5 centimeter diameter) included in a relatively clear sandy matrix. As this survey was done from a boat by visual observation only areas with a maximal depth of 2 m were studied. No significant difference in Temperature and Oxygen was recorded between the gravel zone and muddy zones and was 22°C and 88% O² on the bottom June.

5.2.2 Fish trapping

5.2.2.1 All species catches

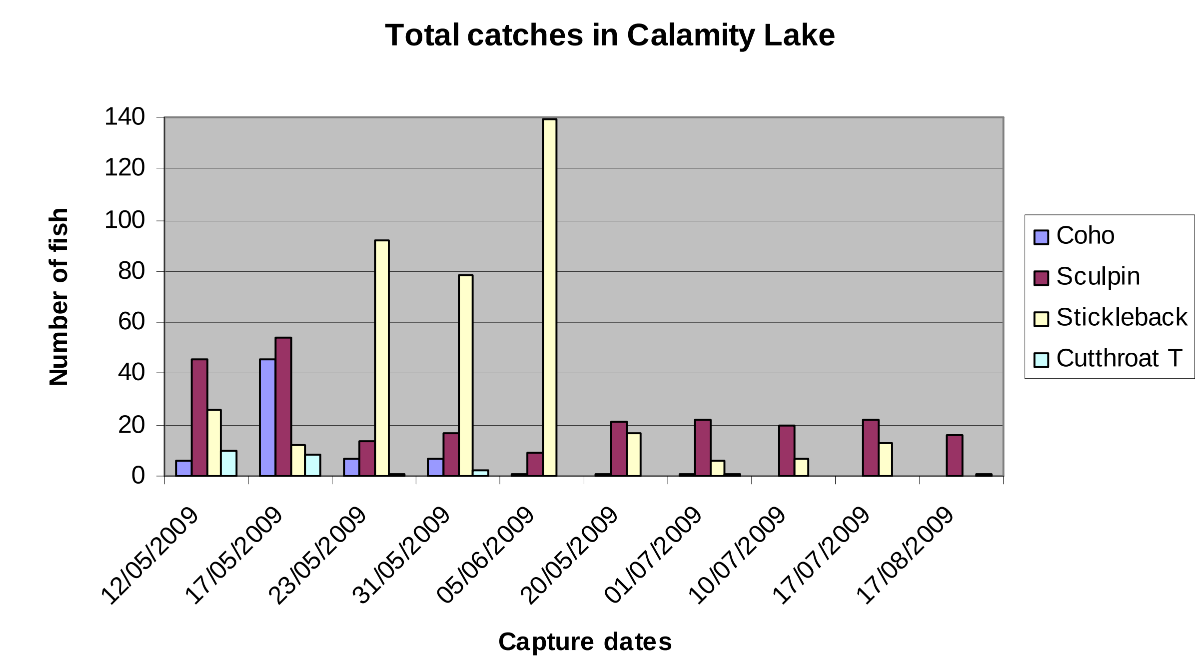

Figure 21: Number of fish captured in Calamity Lake

Results concerning Coho salmons catches will be detailed in the following section.

Three-spined sticklebacks (*Gasterosteus aculeatus*) and Prickly (*Cottus asper)* or Coastrange Sculpins (*Cottus alieuticus*) represent, during the entire trapping campaign, the most captured species in the lake (see above Figure 21). A total of 225 sculpins and 390 sticklebacks were captured, representing respectively 31% and 55% of the total catches. Numbers of sculpins and cutthroat trout (*Oncorhynchus clarki*) captured were respectively about 50 and 10 individuals on May 12th and 17th. These numbers dropped to about 15-20 Sculpins and none-1 trout from May 23rd and remained that low during the rest of the trapping campaign on August 17th.

An important increase in stickleback catches was observed on May 23rd, 31st and June 5th when 80% of the total number of stickleback was captured. A total of 7 crayfish (*Pacifastacus leniusculus*) were captured.

In the traps added on June 20th at 2, 4 m on trapping point L16 and 2, 4 and 6 m on trapping L7, two cutthroat trout and were captured on July 1st in trap L16, respectively at 4 and 2 meters.

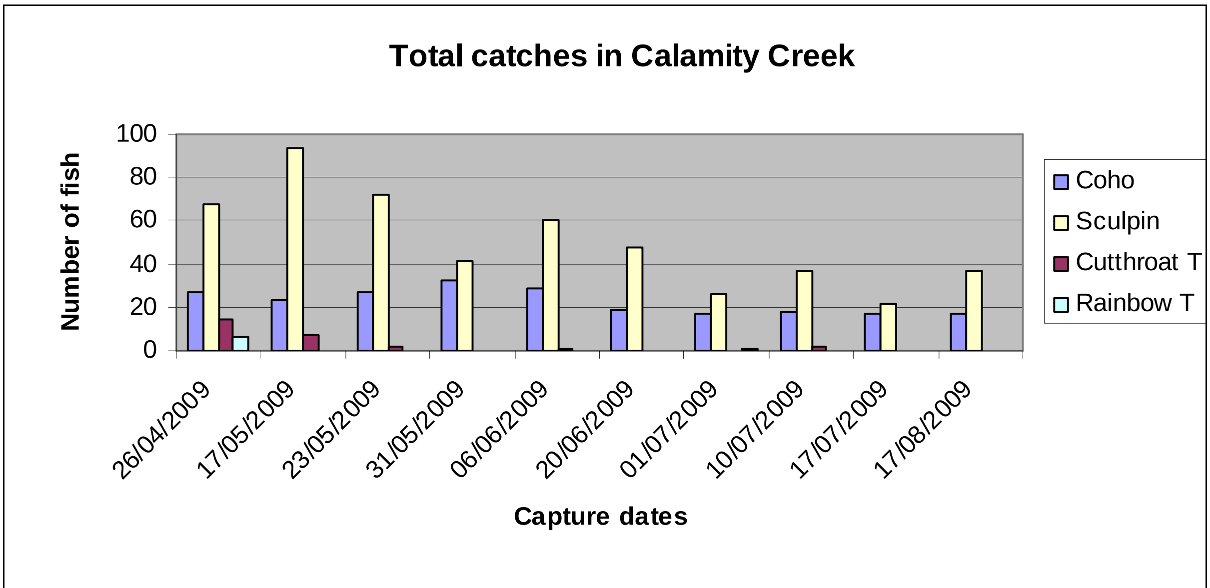

Figure 20: Number of fish captured in Calamity Creek

Results concerning Coho salmons catches will be detailed in the following section.

The majority of the fish captured from April 26th and August 17th were sculpins with 468 fish and Coho salmons (*Oncorhynchus kisutch*) with 226 fish, representing 66% and 29% respectively of the total catches (see above Figure 20). Two species of trout were captured: a total of 26 Cutthroat (*Oncorhynchus clarki*) and 7 Rainbow (*Oncorhynchus mykiss*). A total of 43 crayfish (*Pacifastacus leniusculus*) were captured.

5.2.2.2 Coho salmon catches

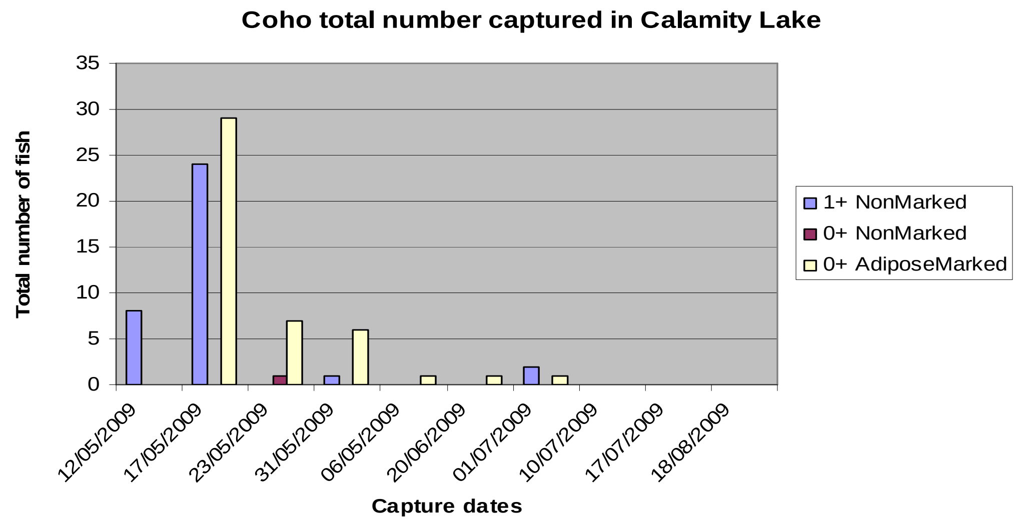

Figure 22: Total number of Coho salmon captured in Calamity Lake per date

Distinction between first-spring (0+) Cohos called fry and one-year-old (1+) Coho called fingerlings is based on results detailed in chapter *5.2.2.3 Coho growth and age distribution* p 36. A total of 35 fingerlings, 45 adipose-clipped fry of Coho salmon were captured in Calamity Lake during the entire sampling. Most of the Coho catches occurred on May 12th and 17th, then, the number of non-marked one-year-old fingerling Coho and adipose-clipped fry greatly decreased and remained insignificant until the end of the experiment (see above Figure 22). Only one wild fry was captured on May 31st in trap L14. Prior release date on May 15th 2009, only one-year-old Coho salmons were captured.

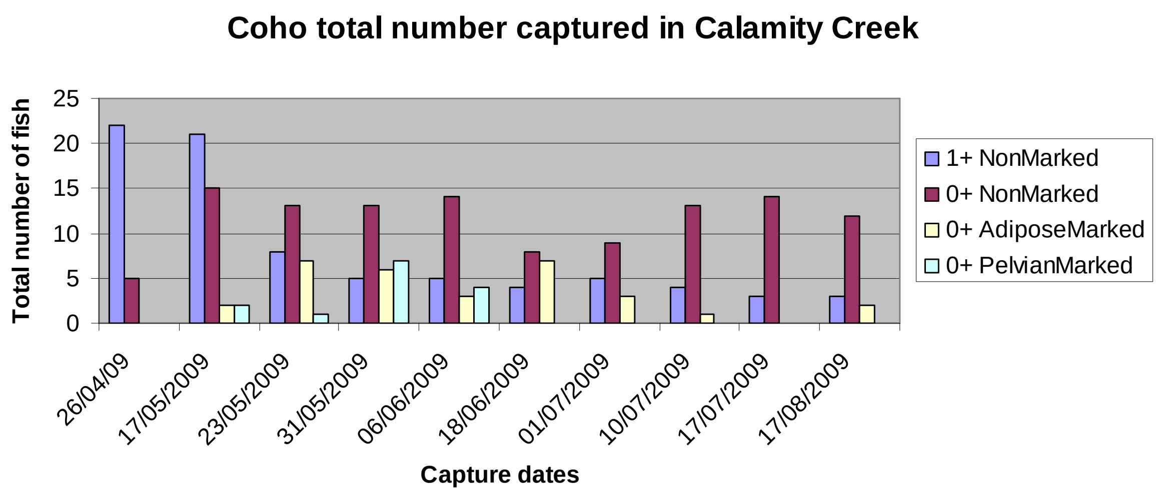

Figure 23: Total number of Coho salmon captured in Calamity Creek per date

A total of 80 non-marked fingerlings, 116 non-marked fry, 31 adipose-clipped fry and 14 pelvian-clipped fry of Coho salmon were captured in Calamity Creek during the entire trapping campaign. During the first two trapping dates, most of the individuals were one-year-old Coho salmons but these numbers greatly decreased and remained low during the rest of the survey (see above Figure 23). From May 23rd to August 17th, most of the Coho salmon captured were wild fry. Pelvian fin-clipped hatchery fry released on May 15th were captured from May 17th to July 17th in Calamity Creek from traps C7 to C 15.

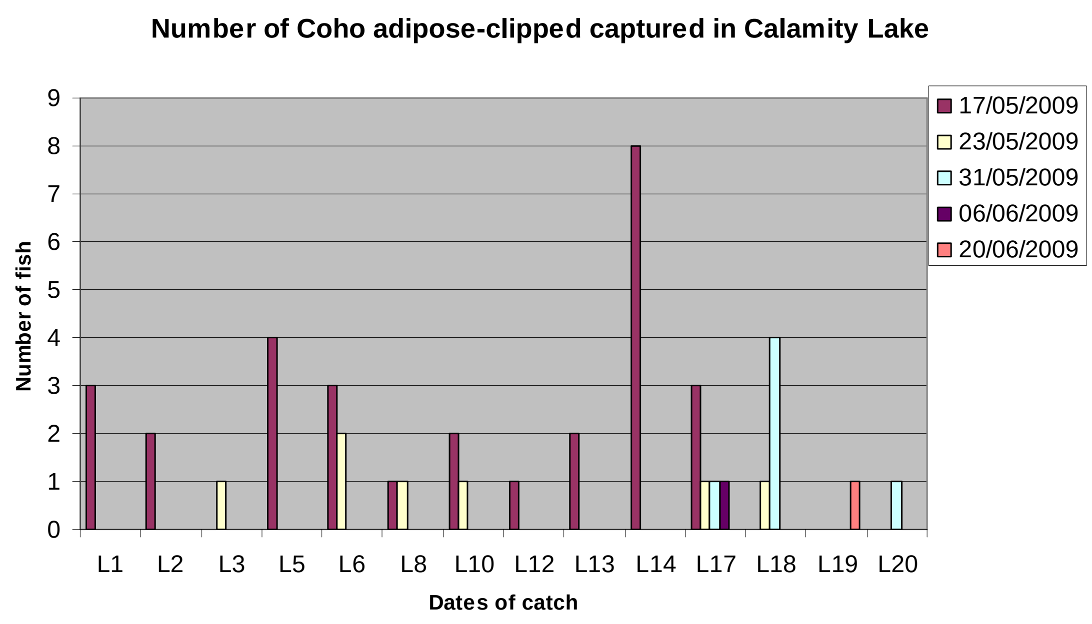

Figure 24: Adipose marked Coho captured in Calamity Lake per trap
Only traps where fish were captured are represented on Figure 24 and 25.

Most of the adipose-clipped Coho fry captured in the Lake (72% of the total captured) were trapped during the first sampling, two days after the release date on May 17th (see above Figure 24). At this date significant number of marked Coho were captured in traps L5, L6 and L8, situated at about 400m (following a strait line) from the release zone. From June 20th, no Coho juveniles were captured in the Lake.

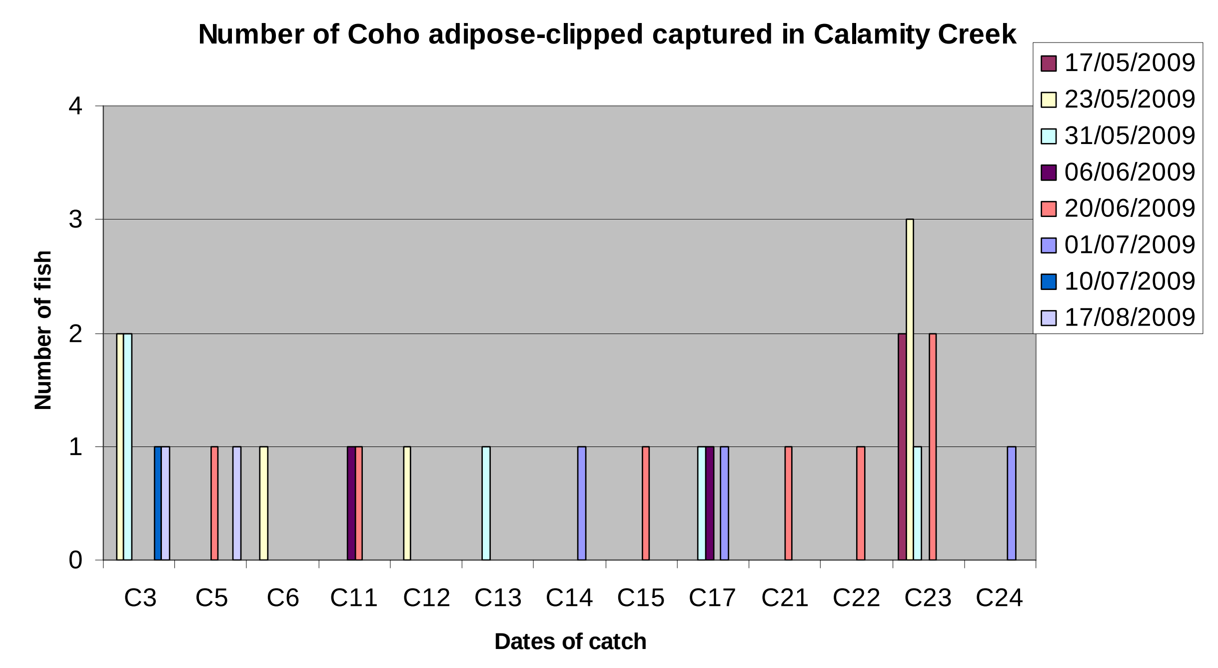

Figure 25: Adipose marked Coho captured in Calamity Creek per trap

During the whole trapping campaign, a total of 31 adipose marked Coho released in the lake were captured in the creek (see above Figure 25). Two days after the release date on May 15th 2009, two adipose-marked Coho released in the lake were captured in trap C23 situated 20 m downstream of the lake outflow. And about 8 days after they were released in Calamity Lake, adipose clipped Coho were captured along Calamity Creek (up to trap C3 situated 460 m downstream of the lake). Adipose-clipped Coho were captured in the creek until the last sampling on August 17th.

5.2.2.3 Coho growth and age distribution

Only Growth rates of non-clipped and adipose-clipped Coho captured in Calamity Creek were studied because the number of Pelvic-clipped and salmons captured in the lake was to low to allow any significant study (total of 14 fish captured).

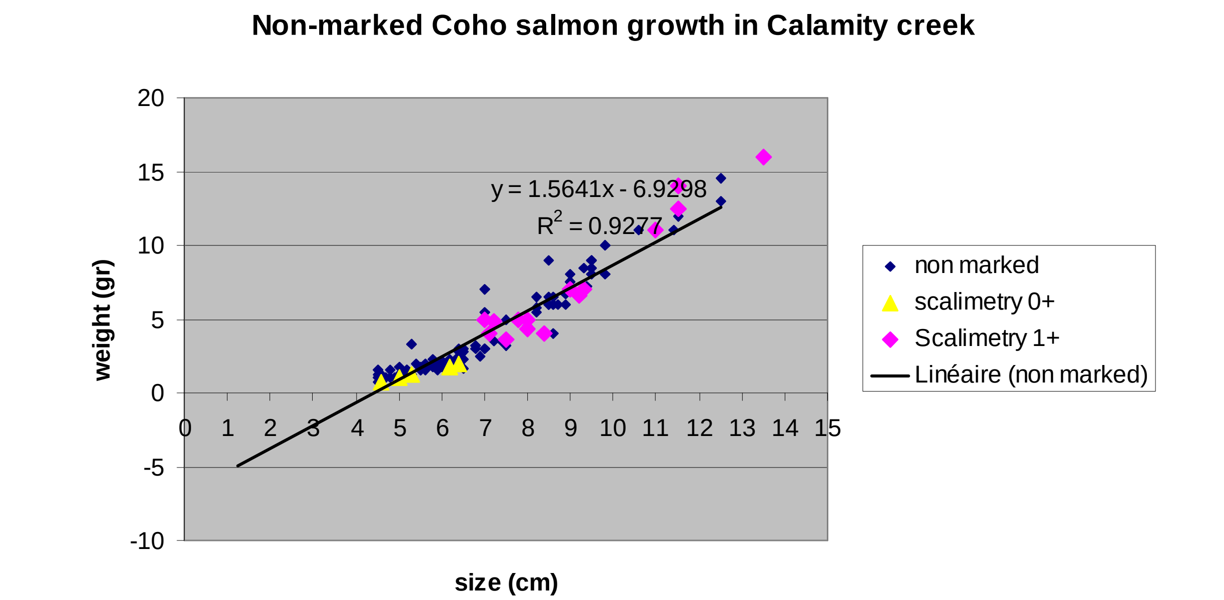

Figure 26: Non-marked Coho growth rates and scalimetric study results

The smallest fish captured was 4.5 cm and the biggest 14.9 cm which is the range expected when using minnow trapping. The scalimetric study showed that only first-spring (called 0+) and one-year-old (called 1+) were captured (see above Figure 26). First-spring wild Coho fry captured from April 26th to August 17th had a size from of 4.2 to 8 cm and weighted from 0.75 to 4 gr at the end of the sampling period. One-year-old Coho fingerlings had a size from 7 to 13.5 cm and weighted from 4 to 16 gr at the end of the sampling period.

Table 8: Size of hatchery and wild fry captured in Calamity Creek per date

		17/05/2009	23/05/09	31/05/09	06/06/2009	20/06/2009
Wild	MAX	6.5	6.5	6.5	6.5	6.4
	MIN	4.5	4.6	4.5	4.5	4.5
	MOY	5.5	5.6	5.5	5.2	5.8
Hatchery	MAX	5.5	5.5	6.6	7.2	7.7
	MIN	4.7	4.7	5.3	5.2	5.0
	MOY	5.1	5.1	6.2	6.1	6.6
		01/07/2009	**06/07/2009**	**17/07/2009**	**17/08/2009**	
Wild	MAX	8.5	8.9	8.2	8.0	
	MIN	4.7	4.5	5.0	5.5	
	MOY	5.7	6.6	6.4	6.6	
Hatchery	MAX	7.0	6.5		6.4	
	MIN	5.4	6.5		6.0	
	MOY	6.3	6.5		6.2	

5.2.2.4 Coho catches per trap efficiency and trapping points parameters

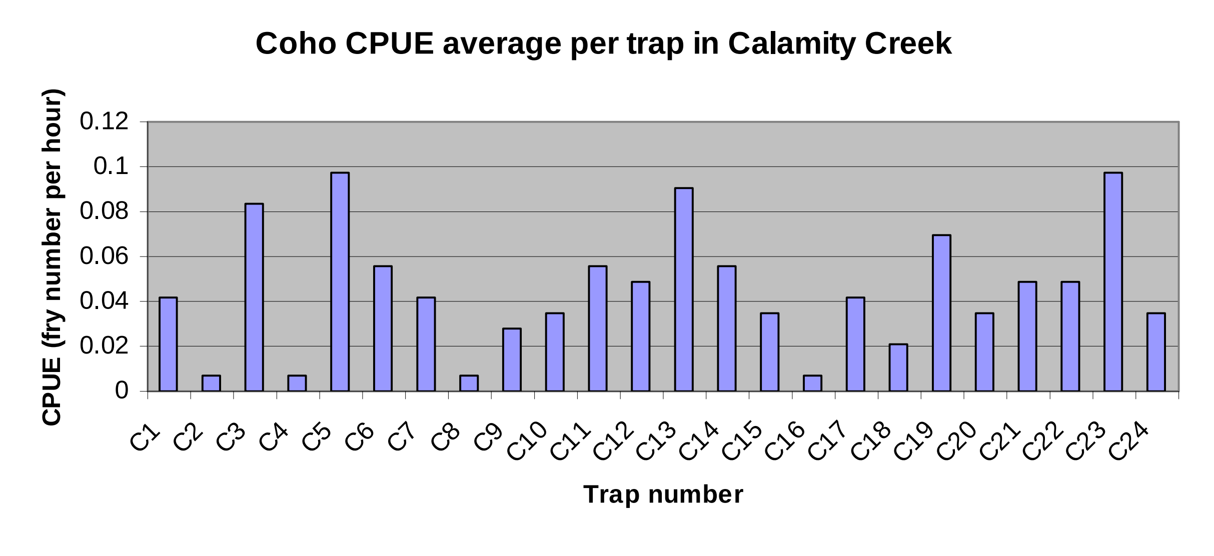

Figure 27: Average Catches Per Unit Effort per trap in Calamity Creek

Statistical results were obtained by comparing the average catches per unit effort (see above Figure 27) of each trap with each physical parameter recorded: depth, flow velocity, substrate type, cover percentage and periphyton cover.

An ANOVA test was carried out on each parameter. Description of parameters recorded per trap is available in Appendix 2.

Table 9: Anova test results on trapping points parameters

Parameter	ANOVA result
Depth	P=0.345, α=0.05
Velocity	P=0.454, α =0.05
Substrate type	P=0.082, α =0.05
Cover percentage	P=0.935, α =0.05
Periphyton cover	P=0.023, α =0.05

According to this ANOVA test, only periphyton cover has a significant influence on the number of Coho salmon captured (see above Table 8). A Tuckey test showed that traps C2, C4, C8 and C16 were significantly different than the others because of a low CPUE.

5.2.3 Plankton population survey

The zooplankton survey was only qualitative, two orders of zooplankton were identified in the samples collected: Cladocera (*Bosmia spp* and *Holopdium spp*) and Rotifera (*Keratella spp and Kellicotta spp*). A limited number of *Hydracaria spp.* was also found in the samples taken out.

5.3 Discussion

5.3.1 Physical parameters

5.3.1.1 Oxygen, Temperature

- **Calamity Creek**

The water temperature quickly increased during the month of May as temperatures recorded doubled during this period. Until the end of the monitoring period on August 17th, the temperature remained between 18 and 20°C. It can be assumed that these levels of oxygen are hardly well-suited for salmonid species. Indeed, as written by Barnhart (1986), a productive trout stream should have summer temperatures in the range of 10 to 15°C and an upper limit of 20°C.

However, the oxygen concentration remained in the acceptable range for salmonid with a minimum concentration recorded of 92% saturation and 8.3 mg/L. Levels recommended for salmonids are at least 80% of saturation, with temporary levels no lower that 5.0 mg/l, according to Reiser and Bjornn (1979).

High temperatures recorded in Calamity can be explained by a lack of canopy closure. The fact that the lake flowing into the creek is shallow also contributes in keeping water temperatures high.

- **Calamity Lake**

Oxygen concentration remains important (90-100% saturation) in the top two meters of the water column. These high concentrations can be explained by gaseous shifts at the water-air interface or by photosynthetic oxygen production in the trophogenic zone. It can be assumed that the oxygen concentration drops as the photosynthetic activity decreases and decomposition phenomena occur near the bottom. The important decrease in oxygen observed in July 17th and August 17th could be a consequence of dead plankton sinking in the lower water column. The lower part of the water column was not suitable for salmon rearing in July and August since growth, food conversion and swimming performances of Coho juvenile are affected for concentrations lower than 60% sat according to Bjornn and Reiser (1991).

Water temperature reached 18°C at noon within the first two meters from May 31st, to August 18th and a maximum of 28.8°C was recorded on July 4th. Stein and al. (1972) found that the growth rate of Coho fry was high in the 9 to 13° C temperature range, but slowed considerably at temperatures near 18° C.

In July and August 2009 salmonids will likely be positioned below 2 m depth, where the water is cooler but above 3 m where the oxygen start to decrease. This assumption is corroborated by the fact that on July 1st, the only fish captured were two Cutthroat trout in the middle of the lake at 2 and 4 meters.

Water temperature was recorded at the deepest point in the middle of the lake, but it can be assumed that the water is even warmer in the shallow parts of the lake. So fry would not be positioned along the shore but rather in deeper areas. This assumption would suggests that Calamity Lake is not an ideal rearing zone for Coho juvenile during the summer as Mundie (1969) found that cover and food for fry are most likely available in shallow parts of lakes.

5.3.1.2 Habitat and spawning gravel

- **Calamity Creek**

The method chosen in 2000 and used in 2009, based on 30 m sections seems not to be adapted to Calamity Creek. Stream bank wetted width varies from 1 to 4 m in most of the sections. Consequently, it is hard to provide a correct estimation of the stream dimensions within the 30 m scale chosen. It would have been more reliable that section sizes were chosen one by one according to the field observations. In this context, it is difficult to make inference as to the evolution of parameters like bank width, bank depth, wetted width or mean depth.

The survey shows that two "new" pools were found in 2009 on section 12 and section 15, these pools having been created by small dams. But the percentage of pool and pool frequency remained rated as poor, and none of them are considered as good holding pools despite the fact that the global percentage of wood in pools is rated as fair.

The number of off channel habitat remains constant between 2000 and 2009, as 5 sloughs, 2 side channels and one wetland with good access were found, for a total length of 50 meters. The presence of these off channel habitat indicates that there is good potential overwintering habitat for salmon fry in Calamity Creek.

In 2000 and 2009, the channel disturbances identified remained multiple channels, low pool frequency and extensive riffle zones. It seems that the eroding banks disturbance was greatly reduced between 2000 and 2009. Indeed, this disturbance was only identified on the lower part of the stream (section 1, 2 and 4) in 2009, while it was found all along the creek in 2000. This observation indicates that the stream banks became sturdier. Intense bank erosion followed by stabilization after logging is one of the phenomena described by Hartman and Scrivener (1982) in Carnation Creek, British Columbia.

The number of large woody debris increased significantly between 2000 and 2009, beside the fact that the number of woody debris per bank width was already rated as good in 2000. This observation could be a consequence of logging activities along the stream banks: logs or branches falling down into the creek become functional large woody debris when rotting after several decades. This increase in large woody debris after logging was also described by Hartman and Scrivener (1982). According to their observations, the next evolutionary step would be a lack of woody debris, because there would not be enough old trees in the riparian vegetation to provide debris. The restoration works carried out in 2001 likely participated in the increase of large woody debris in the creek, as woody debris where placed in pools to increase cover (Morgan and Ochman, 2001).

Concerning the riparian vegetation, the survey showed that the vegetation type was still shrubby in 2009, about 50 years after the area was logged. The riparian structure mostly remained shrub, except in section 1, 10, 12 and 15 where the riparian structure shifted to a pole-sapling stage. The Canopy closure only increased significantly on section 1, 2 and 3. This study showed that no important changes in the riparian vegetation occurred along Calamity Creek during the past 9 years. This statement leads us to expect, that the total recovery of the riparian zone after intensive logging practices is going to take at least a century. As described in chapter *3.2 Threats* p 15, riparian vegetation has a crucial influence on the stream ecosystem: canopy closure provides shade that regulates stream temperature and algal growth, provides woody debris and roots are regulating solid and liquid flows (Dale *and al*., 1999). Riparian vegetation is also participating in a significant part of Coho fry diet, as they feed on terrestrial insect falling off overhanging branches (Giannico, 1998).

Cover in Calamity Creek is provided by woody debris and overhanging vegetation. The total percentage of cover increased from about 20 to 28 % between 2000 and 2009. However the cover of the creek remains low according to Engel (1967) who found that natural coastal small streams (bankfull width <4m) in British Columbia had cover averaging 80%.

Two logjams constituting barriers for fish migration were identified in August 2000 on section 17. Restoration works completed in 2001 were efficient, as no barrier were found on this section in July 2009. However, two small logjams and one downfall were found in sections 12, 15 and 3 respectively. These barriers seems to be an obstacle to fish migration only during low water periods, so fish are able to swim through when water levels increase in spring and fall, periods during which migration of both adults and fry is the most important.

Despite the fact that fish migration was totally re-established by the works completed in 2001, the percent of pool and pool frequency were rated as poor in 2000 and 2009. Furthermore, the maximum pool depth recorded was 0.36 and 0.32 m respectively. So it can be assumed that the access to Calamity Creek and Lake to spawners is highly limited, even though the water level increases during the spawning period.

Dominant substrate observed along Calamity Creek in 2000 and 2009 was gravel but the spawning potential remained limited: in 9 out of 19 30m-sections, potential spawning gravel was absent or clogged by fines, sand or algae. In 10 of the remaining sections, only isolated pockets of suitable spawning gravel were present. Indeed, the gravel quantity in Calamity Creek was globally rated as poor by the habitat diagnosis, despite the fact that the sub-dominant substrate was rated as good along most of the stream.

- **Calamity Lake**

The fish habitat evaluation completed on June 22 2009 indicates that an extensive aquatic plant zone provide a potential good hideout for fry, but not as good as woody debris virtually non-existant in Calamity Lake.

On this survey, spawning gravel was found to be very limited in Calamity Lake as only 50 m² area of the lake could potentially allow spawning to occur. Zones without any organic sedimentation indicate that there is, at some time of the year, current or upwelling occurring in those zones. Water parameters measurements around the Lake on June 22^{nd} 2009 did not show any hyporheic circulation that brings cold and oxygenated groundwater through the sediments. This finding would have to be confirmed by recording water and temperature at the same location during the spawning period, in the fall, which is a wetter period when quantities of rain reaching the lake by run-off or sub-surface are more important. However, the important amounts of sand observed on those zones indicate that the flow would be relatively low even during the wet seasons. It also would be interesting to sample the deeper areas of the lake that cannot be studied visually, by using an Eckmann dredge for example. Possibly, there could be clusters of potential spawning substrate in the deeper areas where ground water inflows. Concerning the tributaries, which represent usually the main spawning zone in lakes, the substrate is heavily clogged by mud and vegetal debris. Hence, it seems that no salmon egg incubation is possible.

5.3.2 Fish population in Calamity watershed

5.3.2.1 All species

Many large Sculpins were captured during the first three sampling dates, with more than 10 fish captured in traps on May 17th. Most of the sculpins were bigger than 10 cm. As observed in prior minnow trapping carried out on Rousseau Creek (Clarke, 2008) or on the Sarita River (Ochman, 2005, 2007), large sculpins are eating fry once they are inside the trap or are scaring them away. The presence of important numbers of large sculpins in Calamity Lake and Creek seemed to have negatively impacted the capture of other smaller species like salmon fry in Calamity Creek.

The total number and size of sculpins captured decreased during the sampling period as captured sculpins were systematically eliminated. However, the fact that after 8 weeks of this “treatment” sculpins remain the most captured species in Calamity Creek indicates that sculpins are very abundant in Calamity Creek.

The number of Cutthroat trout captured in Calamity Creek greatly decreased from April 24th to May 23rd and remained insignificant until this end of the experiment on August 17th. This observation can be explain by the fact that the trout population left Calamity Creek in order to reach cooler, deeper zones, upstream in the Lake, but most likely they moved downstream to Pachena River. Indeed, Barnahrt (1986) found that a productive Cutthroat stream should have summer temperatures in the range of 10 to 15 °C and an upper limit of 20°C. Water temperatures recorded at 330 m indicated an important increase from 10°C on April 24th to 18.6°C on May 23rd (see chapter *5.3.1.1 Oxygen*, *Temperature* page 39) and remained between 18 and 20°C until the end of the experiment in August 17th. Main water level also dropped about 5 cm during the sampling period. The limited number of rainbow trout captured at the beginning of the experiment does not allow any conclusion on whereas these individuals were anadromous or resident populations.

Since a significant number of resident trout were captured in it, it can be assumed that Calamity Lake is suitable for salmonids. However, catches of Sculpins and Cutthroat greatly decreased between May 12th, 17th and the rest of the trapping period. This decrease in Cutthroat trout numbers can be explained by high temperatures encountered in the Lake (see *Chapter 5.3.1.1 Oxygen, Temperature* p 39). However, Sculpins can live in higher temperature and lower oxygen levels than trouts (Barnhart, 1986), so the observed decrease in numbers is not conclusive.

An important increase in Stickleback numbers was observed on May 31st , June 6th and 20th. This observation is probably due to the increase in activity during the reproductive period of the three-spine stickleback, which occurs from April to June in western Canada (Barnhart, 1986).

5.3.2.2 Coho salmon catches

- **Minnow trap efficiency and capture rates reliability**

The first parameter that has to be discussed is minnow trapping efficiency. For example, schools of Coho fry (10-15 individuals) were often observed swimming around minnow traps when none of them were actually trapped. Indeed, it is hard to provide a quantitative estimate of the number of Coho that remained in the lake, left and stayed in the creek, or reached Pachena River. This behaviour can be explain by the fact that the bait was not totally adapted to fry, because 5 mm salmon eggs is way to big for a 40 mm fry to swallow. Large sculpins hanging around or inside the trap may have inhibited fry from getting caught (Clarke, 2006). It also can be assumed that Coho captured once will avoid the trap as they “remember” the nasty “treatment” they went through the last time they got caught.

The second crucial component of this study is the trapping timing scale, as Coho fry have been observed migrating at rates of several kilometers a day (Johnson and O’Neil, 2000). One trapping session per week hardly allows conclusions concerning migratory timings. However, the trapping campaign realised between April 24th and August 17th on Calamity Creek and Lake made possible several estimates of released hatchery fry.

- **Wild Coho fry salmon in Calamity watershed**

The comparison of total wild fry catches versus hatchery fry shows that for every trapping date, the wild population is the greatest all along the creek. It seems that Calamity Creek is hosting a majority of wild Coho salmon in 2009 despite the fact that hatchery fry were released in the creek and lake. This statement seems to prove that hatchery Coho fry released in Calamity watershed did not impact negatively the wild population. As described in section *5.3.1.2 Habitat and spawning gravel* p 42, the spawning potential of the creek and lake is limited, so most likely, the wild fry captured in the creek emerged in Pachena River or in the lower Calamity creek and migrated upstream.

Calamity Creek provides a relatively good summer rearing habitat for hatchery Coho fry, because they actively established themselves up to trap C3 situated 460 meters downstream of the lake outflow. Consequently, no large barriers to fry migration seem to be present.

The fact that only one wild Coho fry was captured in the lake (when their presence is proven all along the stream) leads to think that Calamity Lake does not represent a good potential summer habitat for Coho and that fry do not migrate toward the lake in late spring and summer.

- **Wild Coho fingerling population in Calamity Creek**

Fingerlings of Coho captured in Calamity Creek were either wild or hatchery fry released in 2008 as no fry were fin-clipped, making them impossible to distinguish from wild fish. The total number of fingerlings captured in Calamity Creek decreased after the first two trapping dates (April 26th and May 17th) and the rest of trapping session. Fingerlings are known to migrate downstream toward ocean from May of June during smoltification (cf chapter *3.1.4.4 Smoltification process* p 15). However, Coho fingerlings were captured until the last sampling on August 17th, this observation suggests that some Coho fry stay two years in fresh water before going to the ocean.

The fact that no two-year-old Coho were captured in the creek could by due to the sampling method: Fish larger than 15 cmn which is the minimum size observed for 2 year old fingerlings according to Neave and Wickett (1959), do hardly get caught in minnow traps. Two-years-old fingerlings may have already migrated in late April before the sampling started, or perhaps the stream is too small to host such large Coho fingerlings.

- **Hatchery Coho salmon fry behaviour in Calamity watershed**

During the whole trapping campaign, only one wild Coho salmon fry was captured in the Lake. This suggests that no salmon reproduction occurs in Calamity Lake. Since there is a lack of deep pools in the Creek and spawning area in both the Lake and Creek. The non-marked Cohos fingerlings captured in the Lake probably originated from the non-marked Sugsaw hatchery fry released in spring 2008.

The total number of hatchery Coho adipose fin-clipped captured in the lake greatly decreased from two days after their release (28 individuals on May 17th) and the rest of the experiment. This seems to indicate that most of the adipose fin-clipped Coho released in 2009 in the Lake migrated toward the creek or died. But Coho fingerlings and Cutthroat trout catches also decreased from there. The reduction of fingerling catches can be explained by smoltification process and migration toward ocean, but not the trout catches decrease. In this context, these limited numbers could be explained by a shift in fish behavior. As food is more abundant in summer, the bait provided may be less efficient in attracting fish.

The water temperature increase observed during the summer (*see chapter 5.3.1.1 Oxygen, Temperature* page 39) could have led to a reduction the fish activity in the shallow, warmer parts of the Lake where most of the traps were set. However, the efficiency of traps set in the deepest zones from June 20th (L16 and L7) at depths of 2, 4, 6 meters was really low during the whole trapping period as only two trouts were captured. But is it difficult to make inferences as to the presence of salmonids in deeper zones with only two trapping points.

Calamity Lake may be only used as over-wintering habitat and the Creek used as late spring and summer habitat. Fry and fingerlings may migrate upstream toward the Lake when water temperature decreases and conditions become “harsh” in the creek. This behavior was observed in Coho fry in Oregon (Chapman, 1965).

The result of the trapping campaign realised between May 17th and August 17th indicates a quick active migration of the hatchery Coho fry released in Calamity Lake. Indeed, two days after the release date, some fry had moved to the other side of the Lake or were found in the upper section of Calamity Creek at 20 m of the lake outflow. At this stage, fry were showing their exploratory behaviour, trying to find good rearing zones. The greatest number of Coho fry taken during summer 2009 in Calamity Lake was 8 individuals captured at trap L14 on May 17th. This trap was situated at the beginning of the narrowing channel leading to the creek. This observation seems to indicate an active migration of the fry toward the Creek, immediately after their release.

Eight days after they were released, two Coho adipose clipped were captured at trap C3, situated 460 m downstream of the lake and 56 m from Pachena River, and a total of 7 adipose-clipped fry were captured along the Creek the same day. These fry showed a quick and downstream migration of about 500 m in 10 days. During the rest of the trapping campaign, adipose-clipped fry were captured in Calamity Creek. This indicates that at least some of the fry released in Calamity Lake (and may be all of them) migrated toward the Creek and established themselves in good rearing habitats during the rest of the summer in Calamity Creek and probably in Pachena River.

Of the 150 pelvian-clipped Coho fry released under the bridge on May 17th (260 m from the Pachena River), 15 of them were captured during the entire trapping campaign. They seem to have migrated downstream (at trap C7, 175m) and upstream (at trap C15, 327 m). Once again, trapping efficiency was really low on these fry. For example, two days after the release, only 1 out of 150 pelvian clipped individuals was trapped. Since data collected on the Pelvian fin-clipped released in 2009 is so limited, it is not possible to conclude much about the behaviour or growth of these hatchery fry.

5.3.2.3 Hatchery and wild Coho growth in Calamity watershed

The first observation that can be made is that Coho fry captured during the sampling showed a wide range in size and weight. For example, on the last sampling on August 17th, the largest wild fish was 8 cm and 4 gr when the smallest was 5.5 cm and 1.5 gr. This difference in size can be explained by the hatch date since eggs can be deposited in the sediment from November until January. Territorial behaviour also influence the size of the fry as dominant fry occupy good rearing habitats were the food abundance is the greatest and the growth the highest.

Hatchery fry captured during the sampling did not seem to show higher growth rate or size than wild fry. This observation indicates that hatchery fry released in Calamity Lake and established in Calamity Creek did not dominate the wild population. In other words, it seems that the hatchery fry did not compete and impact negatively the wild population in 2009.

5.3.2.4 Habitat utilization by Coho salmon in Calamity Creek

Statistical analysis of the data collected in Calamity Creek suggests that Coho salmons were distributed along the entire creek, prefentially in high periphyton cover percentage zones. This result differs from Clarke (2006) who carried out a similar study on hatchery Coho salmon on Rousseau Creek that is also a tributary of the Pachena River. Clarke found that the distribution of Coho salmon along Rousseau creek was mostly influenced by velocity, cover percentage and substrate. The very low catches rates recorded in traps C2, C4, C8 and C16 had not been explained by characteristics of the trapping zone.

5.3.2.5 Zooplankton population in Calamity Lake

Zooplankton survey in Calamity Lake was qualitative, so the volume of plankton available was not estimated. However, the Secchi depth monitored showed a decrease from May 23rd (2.5m) until August 17th. This observation shows an increase in plankton density, consequence of the water temperature increase monitored during summer 2009 in Calamity Lake. Chapman (1965) found that less than 11% of the lake-dwelling Coho population had zooplankton in their stomach. His conclusions indicate that zooplankton populations are not crucial in evaluating the suitability of a lake for Coho rearing.

6 Conclusion

The data collected suggests the following conclusions concerning hatchery Coho fry behaviour in the Calamity watershed:

– Calamity Creek hosts a population of wild Coho fry and fingerlings along its entire length. This information suggests, despite the habitat assessment results, that Calamity creek is a good rearing stream for juvenile salmon.

– The Coho fry population in spring 2009 was dominated by wild individuals. Hatchery Coho captured in the Creek do not seem to grow faster than wild ones. These observations indicate that the release of hatchery Coho did not impact negatively the wild populations.

– A significant number of hatchery Coho salmon released on May 15th in the lake migrated during the first days and established themselves in Calamity Creek and presumably in Pachena River.

– Calamity Lake does not seem to be a good summer rearing area for Coho fry since very few wild Coho fry were captured. No hatchery Coho fry were captured in the Lake two week after release and during the rest of the summer. However, a significant number of Coho fingerlings, presumably from hatchery fry released in spring 2008, were captured in May 2009.

– Suitable spawning gravel availability and access for spawners remained poor in both lake and creek, suggesting no salmon reproduction in Calamity watershed despite the fact that fish migration was reestablished in 2001.

In order to confirm these conclusions and to ensure a better understanding of hatchery fry fate released in Calamity Lake, the capture method should be redesigned. Since Coho fry migration seems to occur immediately after release, it could be interesting to place a barrier-trap at the lake outflow. This kind of sampling would allow a better estimate of the percentage of hatchery Coho leaving the Lake. An electro-fishing session would be more expensive, but more reliable in order to complete a fish population survey in Calamity Creek, where a minimal depth of 20 cm required for minnow trapping is sometimes hard to find. In Calamity Lake, which is relatively small and where substrate in mostly muddy and the quantity of submerged logs is very low, a large seine net could be used.

Despite the fact that the behavior and fate of hatchery fry released in Calamity Lake cannot be entirely described, several prescriptions can be suggested:

– Since this study proved that at least a part of hatchery fry released in the Lake do not stay there and will interact and compete with wild populations, it seems advisable to find a new fry release area where access for fry is limited.

– In order to improve the habitat quality of Calamity Lake, a low-budget and efficient solution could be to take down into the lake some trees constituting the riparian forest. To be efficient, a relatively important number of trees (one every 10-15 meters for example) would have to be cut. Dead or dying trees could be selected and riparian ecotone would not be negatively impacted.

– Recovering of the riparian vegetation along Calamity Creek banks is going to take decades anyways. But reforestation works should help and accelerate the natural recolonization process.

This internship allowed me to use knowledge learned during my Master Course and to carry out an autonomous fisheries study including the design of the study, data collection and technical report writing. This placement was also en excellent opportunity to learn about Salmon fisheries issues in western Canada and to improve significantly my English language.

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