National Recovery Strategy

for the

SOCKEYE SALMON

Oncorhynchus nerka

(Cultus population)

in

British Columbia

Draft – September 7, 2004

This DRAFT DOCUMENT is a product of the Cultus Sockeye Recovery Team. The information presented is preliminary and will change as further input is received from the Recovery Team, peer review and consultation. The final draft will also include maps, photographs and other illustrations.

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Range jurisdictions

The lead jurisdiction for the protection of Cultus Lake sockeye salmon and their habitat is Fisheries and Oceans Canada, under the *Canada Fisheries Act*. The Province of British Columbia has jurisdiction over the use of the sea floor and aquatic foreshore under the *B.C. Land Act* and for upland forest through the *Forest Act*. The Canadian Coast Guard has jurisdiction over the river and lake access through the *Navigable Waters Protection Act*. The Cultus Lake Park Board has jurisdiction over the Cultus Lake Park under a unique provincial statute, the *Cultus Lake Park Act (1932),* and B.C. Parks has jurisdiction over the provincial park through the *Park Act*, *Ecological Reserve Act* and the *Environment and Land Use Act.* Finally, The Fraser Valley Regional District provides local government services to the Columbia Valley and Lindell Beach under the *Municipal Act.*

Disclaimer

The National Recovery Strategy for the Cultus sockeye was prepared by the Cultus Sockeye Recovery Team in consultation with experts and observers. Its purpose is to identify recovery goals and objectives based on sound biological principles and deemed necessary to protect and recover the species. The Strategy does not necessarily represent either the official positions of agencies or the views of all individuals involved in its preparation. The goals, objectives, and recovery approaches identified in the recovery document are subject to all pertinent sections of the *Species At Risk Act* and represent consensus arrived at by the Recovery Team. Implementation of the recovery strategy will reflect the priorities and budgetary constraints of participating jurisdictions and organizations.

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EXECUTIVE SUMMARY

The Cultus population of sockeye salmon is unique and endangered. This Recovery Strategy first considers its status and the main threats to its viability, then proposes specific recovery goals, objectives and actions.

Cultus Lake is in the traditional territory of the Soowahlie Indian Band near the town of Chilliwack in the upper Fraser Valley. Its sockeye population has been monitored longer than any other in B.C. Cultus sockeye belongs to the *late run* – the latest-spawning of the four groups of Fraser sockeye. Adults enter the lake by way of the Fraser, Sumas, Vedder and Chilliwack rivers, finally connecting with the lake through Sweltzer Creek. They spawn on gravel beaches around the lake.

The abundance of all life stages of Cultus sockeye has declined significantly in recent decades. The most recent estimates are among the lowest recorded for the population. From historic abundances greater than 20,000, the population has declined to the point where the anticipated return for 2004 is less than 500 fish, and there is evidence that irreplaceable genetic diversity is being lost.

As a result of this continuous decline, Cultus sockeye was designated by COSEWIC as *Endangered* in 2002. What has caused the decline, and how can it be reversed? Although there is evidence that watermilfoil, stream channelization and foreshore development may interfere with prime spawning sites, freshwater habitat degradation is *not* the main cause of the population's recent decline. Instead, there are three main causes:

- Over-exploitation in mixed-stock fisheries before 1995;
- Poor marine survival in the early to mid 1990s; and
- Since 1995, high pre-spawn mortality caused by unusually early migrations into freshwater and an associated parasite infection.

Unfortunately, none of these causes work in isolation. For example, reductions in exploitation rates as long ago as 1998 have been confounded by higher than normal pre-spawning mortality. And there are other threats: emigrating smolts and returning adults run a gauntlet of industrial and residential development in the Fraser Valley; adults must pass through Sweltzer Creek at a time of heavy recreational use and high water temperatures; and freshwater survival is lower than normal, possibly due to predation.

As required by SARA, the Recovery Team identified the habitat it believes is critical to the population's survival and recovery. We propose the following as critical habitat:

- *Migratory corridors:* Sweltzer Creek, including where it joins Cultus Lake and the Chilliwack River;
- *Spawning and incubation areas*: the lake bed at depths from 1 to 20 m at Lindell Beach, Snag Point, Spring Bay, Mallard Bay, Salmon Bay and Honeymoon Bay, as well as the aquifers that feed these spawning areas; and
- *Juvenile rearing areas*: the lake pelagic zone.

Although the team did not identify freshwater habitat loss as the main cause of the decline, there are nevertheless many impacts on habitat. Since the 1970s, the clearest trend in freshwater habitat is the spread of Eurasian watermilfoil. Other trends include water quality impacts from summer boating and increasing water withdrawal from the Columbia Valley aquifer.

The relationship of Cultus sockeye to its freshwater environment is complex and needs much more study. We do know that salmon carcasses can be an important food source and a substantial contributor of nutrients to freshwater and terrestrial ecosystems and, because Cultus sockeye are lake spawners, nutrients from carcasses are probably directly available to plankton that drives primary producers in the lake. Seventeen fish species other than sockeye occur in Cultus Lake and probably feed directly on carcasses or eggs.

The team believes that the recovery of the Cultus sockeye population is biologically and technically feasible. We recommend a single species recovery strategy for Cultus sockeye that includes research to fill knowledge gaps; knowledge gaps include the reasons for early migration, timing relative to the late run, habitat requirements and impacts, relationships with predators and parasites, population dynamics, genetic trends and marine distribution. Fortunately, the scale of recovery can be broadened through cooperation with First Nations (especially the Soowahlie Band and the Sto:lo Nation), the Provincial and Cultus Lake parks bordering the lake, and stewardship groups. Recovery actions specifically related to harvest will be implemented through Fisheries and Oceans and the Fraser River Panel of the Pacific Salmon Commission.

Our Recovery Goal is to *halt the decline of the Cultus sockeye population and return it to the status of a viable, self-sustaining and genetically robust wild population that will contribute to its ecosystems and have the potential to support sustainable use.* We identify four sequential objectives:

Objective 1. *Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful adult spawners with no fewer than 500 successful adult spawners on any one cycle.* This objective secures genetic variability.
Objective 2. *Ensure growth of the successful adult spawner population for each generation (that is, across four years relative to the previous four years), and on each cycle (relative to its brood year) for not less than three out of four consecutive years.* This objective ensures the population is growing.
Objective 3. *Recover the population to the level of abundance at which it can be delisted (designated Not at Risk) by COSEWIC.*
Objective 4. *Recover the population to a level of abundance (beyond that of Objective 3) that will support ecosystem function and sustainable use.* This long term objective proposes candidate benchmarks for Cultus sockeye that correspond to options discussed in past consultations on DFOs draft Wild Salmon Policy and to our current understanding of the dynamics of Cultus sockeye.

Specific recovery actions may include control of harvest, short-term enhancement, control of predators and milfoil, and filling knowledge gaps. Maximizing freshwater survival is important, as are maintaining long-term population assessments and raising community awareness.

While further specific actions will be identified in the Action Plan for Cultus sockeye, many are already under way. They include control of exploitation through conservation-oriented fishing plans, population assessment, a captive breeding project, research on the cause of early migration and high pre-spawn mortality, assessment of littoral habitat, studies on the impact of predation and control projects for pikeminnow and Eurasian watermilfoil, and awareness materials including a brochure for the general public.

BACKGROUND

COSEWIC Species Information[1]

Common Name:
Cultus sockeye
Scientific Name:
Oncorhynchus nerka
Assessment Summary date:
May, 2003
Status:
Endangered
Reason for designation:
The Cultus population has unique genetic and biological characteristics (migratory delay of adults at the Fraser estuary, protracted lake residency before spawning, exclusive lake spawning, late spawning date, deepwater life of fry). The lack of success with previous attempts to transplant sockeye to Cultus Lake and other lakes suggests that Cultus sockeye are irreplaceable. The Cultus population has collapsed primarily due to overexploitation, including directed and incidental catches in mixed-stock fisheries at levels above those that can be sustained. An additional key source of impact on spawning adults since 1995 has been very high pre-spawn mortality, associated with unusually early migration into freshwater and with *Parvicapsula* parasite infestation. There are also ecological impacts to the lake habitat from colonization by Eurasian watermilfoil, land development, stream channelization, nutrient input, and recreational use. Under present conditions, there is a high probability of extinction of the Cultus sockeye.
Occurrence:
British Columbia Pacific Ocean
Status history:
Designated Endangered in an emergency listing in October, 2002. Status re-examined and confirmed May, 2003.

Distribution

Like most Pacific salmon species, Cultus sockeye is anadromous – it reaches maturity in the ocean but returns to its freshwater birthplace to reproduce. The population thus has life stages that can be found in both fresh and marine waters over a geographic distribution of thousands of kilometers. In some cases, the same waters will simultaneously be home to more than one life stage.

Freshwater distribution

The freshwater part of the Cultus sockeye life cycle takes place exclusively in Canadian waters. The adults spawn in Cultus Lake, 10 km south of the town of Chilliwack in the Fraser Valley. Cultus Lake is one of the more productive sockeye nursery lakes in B.C. and lies in the traditional

[1] A more detailed review of the causes of the decline in the Cultus sockeye population, including information subsequent to the COSEWIC assessment summary (May, 2003) may be found later in this Recovery Strategy (see *Threats to population viability and habitat*).

territory of the Soowahlie Band. It is small, with a surface area of only 6.3 km^2. Adult sockeye enter the lake by way of the Fraser, Sumas, Vedder and Chilliwack rivers, finally connecting with the lake by way of Sweltzer Creek. Following hatching and a period of feeding and growth in the lake, smolts return to the sea by the same route.

The distribution and behaviour of adult sockeye *within* the lake are poorly known. Spawning itself happens primarily on the lake foreshore at depths between 0.5 and 6 m, although recent observations show spawning as deep as 17 m in some areas. Fry emerge in May and move quickly into the deeper, open waters where they can be found at depths that vary with the season and time of day (Mueller and Enzenhofer 1991). They rear offshore for one and occasionally two years before leaving the lake as smolts. Because year classes overlap, there is a continuous population of immature sockeye in Cultus Lake. A small proportion (mostly males, termed *residuals*) never leaves the lake (Ricker 1938, 1959).

Ocean distribution

The ocean distribution of Cultus juvenile and adult sockeye is thought to be similar to other late run Fraser sockeye populations, a fact of life history and geography that affects the population's management, harvest and conservation (see *Population Structure* for an explanation of run timing groups). Smolts that pass through the Fraser River estuary and enter the Strait of Georgia in April and May turn northward into Johnstone Strait, then migrate northwest along the B.C. coast until late fall. They then move offshore into the Gulf of Alaska where they spend the next two years feeding with other sockeye populations in the area south and east of Kodiak Island (Burgner 1991). Maturing adults return via Juan de Fuca and Johnstone straits, meaning that a portion of the run swims through U.S. waters before entering the Fraser River. A life history that sees the species returning to spawn along the same migratory route means that the corridor between the mouth of the Fraser River and the feeding grounds in the Gulf of Alaska can contain juveniles year-round, and both juveniles and adults for much of the summer.

Distribution trends

Ocean distribution does not appear to have altered significantly since scientific records of the timing of spawning migrations through the marine environment began in the 1920s. For Pacific salmon, ocean distribution is affected by two separate migration events: migration *to the river mouth*, and *entry into freshwater*. For Cultus sockeye, timing of the second of these events has changed (see *Biological Limiting Factors* for a fuller discussion of the effects of migration timing on distribution).

In the freshwater environment, there has been an apparent reduction in the number of lakeshore areas where spawning occurs, although firm conclusions are difficult to draw because of changing survey methods. By the mid 1960s, Cultus sockeye appeared to have reduced their spawning activity from the six main sites where they had been observed for decades to a single beach (Lindell Beach, a year-round residential area). While this suggests a dramatic reduction in the freshwater distribution of the population, the real situation may be more complex. The recent use of a remotely operated underwater video camera shows that spawning actually continues at a number of the sites but is largely restricted to deeper off-shore waters. This deep water spawning may represent a true change in distribution or may always have happened and is simply more observable with better survey methods (see *Critical habitat* for a fuller discussion of spawning habitat). What is certain is that Lindell Beach itself receives fewer spawning visits than in the past. For example, only a few spawners were observed in 2003 in areas where dense spawning occurred as recently as 1991. There are a number of hypotheses: changes in the quantity and distribution of groundwater at Lindell Beach; encroachment of watermilfoil on the relatively shallow spawning area; more predators between the relatively shallow spawning area and the deep water refuges; and the possibility that shallow spawning areas are sub-optimal and used only when preferred deep water areas are occupied.

Population Structure

Spawning migrations into the Fraser River are protracted (June to October), so individual populations are assigned to one of four management groups based on similar migratory timing during their return from the ocean to the spawning grounds. Cultus sockeye belong to the *late run* – the latest of the four groups (COSEWIC 2003). The population is one of 52 that enter the river from early August with an historic peak in late September or early October. They spawn in the lower Fraser, Harrison-Lillooet, Thompson and Seton-Anderson systems. Cultus sockeye have the latest spawning timing of any Fraser River sockeye population.

In addition to differences in migration timing, Pacific salmon populations have multi-year life histories that result in several annual year classes or *cycles*. Fraser sockeye have four such cycles, reflecting a mainly four-year life span. They can have a cyclic pattern of abundance (termed *cyclic dominance*) where one year-class is larger than the other three, or abundance can be similar on all four cycles. Some scientists believe the cycle dynamics reflect biological interactions between populations and their ecosystems (reviewed by Cass and Wood 1994) while others feel cycles are merely a persistent effect of environmental events or harvest policies (Walters and Staley 1987). In the case of the Cultus population, cyclic dominance was not evident until the late 1960s when four distinct cycles were recognized. As Cultus spawners have declined in recent years (see *Trends in population abundance*), cyclic dominance is again less pronounced.

Genetic differences *between* sockeye populations can be large, reflecting both the post-glacial colonization of their habitats and the characteristics of the lakes where juveniles rear (Wood 1995). Cultus sockeye are highly differentiated from other populations. While the lower Fraser populations appear more similar to one another than to any upper river populations, the Cultus population stands out genetically even from its geographic neighbours (Withler *et al.* 2000). Its genetic isolation is mirrored in its distinctive life history (COSEWIC 2003).

Transplants among several Fraser sockeye populations have resulted in detectable genetic similarities between the donor and host populations (Withler *et al.* 2000). However, there is no evidence for this ever happening with Cultus following transplants of sockeye into the lake between 1911 and 1924 (R. Withler 2004, pers. comm.). Although the total number of introduced fry was relatively small (the progeny of about six million eggs) and there were no attempts to match behavioural traits in the transplanted population to those of Cultus sockeye, the apparent lack of genetic mixing suggests Cultus sockeye is irreplaceable.

There is also evidence for genetic differentiation *within* the Cultus sockeye population, as there is for most Fraser sockeye (Beacham *et al.* 2004). Based on limited DNA sampling, there are statistically significant differences in gene frequencies among cycles and among samples within cycles (S. Latham 2004, pers. comm.). While the amount of variation is much less than that between the Cultus and other populations as a whole, it may make recovery more difficult: population declines may further reduce genetic exchange among cycles, thereby increasing inbreeding and with it the likelihood of a cycle's extinction.

Trends in population structure

Populations lose genetic variation faster when fewer adults contribute to the next generation. The loss of genetic diversity can best be monitored by analyzing samples over time. Cultus samples are available for 1992, 1995, 1999, 2000, 2001.

Changes in the genetic diversity and population structure of Cultus sockeye may already be occurring. In the five years that returning adults were sampled there is a general negative trend in genetic diversity, and cycle-over-cycle changes in population structure are evident (S. Latham 2004, pers. comm.). For example, the 1992 sample is the most distinctive of the five and shows no relative affinity to the 2000 sample from the same cycle. Bearing in mind the beginning of abnormal migration behaviour in 1995 (see *Trends in population abundance*), this means that a distinct and important component of the population structure may already have been lost. We note that sample sizes for some years are small, and the declining trend may result from factors other than reduced population size. Continued sampling is needed.

Some changes in genetic structure may be offset by captive breeding (see *Actions Already Completed or Under Way)*. For example, increased genetic drift among cycles will likely be offset by the accelerated maturation schedule of the captive breeding project (D. MacKinlay 2004, pers. comm.). If that project succeeds, it should also limit the loss of genetic richness, and it may also make other analyses possible. For example, changes in genetic fitness can be evaluated by comparing the relatedness of the parents (the broodstock) to the fitness of their offspring (the returning adults). This would help us understand of the effects of population reduction on genetic traits that affect survival.

Population Abundance

Cultus sockeye have been studied for many decades. The lake is close to university and government research centres, and the existence of a population of sockeye salmon with noteworthy adaptations to local conditions has resulted in the longest historic series of physical and biological observations of any sockeye population in B.C. A hatchery on Sweltzer Creek (now the site of DFO's Cultus Lake Laboratory) operated from 1916-1936 and was the site of the first-ever comprehensive evaluation of hatchery operations (COSEWIC 2003). The counting fence on Sweltzer Creek has continued to operate since then, providing data on adult escapement and smolt migration extending back to the mid-1920s. Cultus smolts were the first ever to be enumerated in B.C. There is an extensive time series of smolt data through to 1978, although very few data exist from 1979 through the late 1990s.

The development of a recovery strategy for Cultus sockeye is a response to critical population declines. Coincidentally, the continued assessment of Cultus sockeye escapement since 1925, coupled with this small population having historically been intercepted in fisheries on larger, managed populations, means that it represents one of the few cases where the effects of conservation actions can be monitored against solid historic baseline data.

Trends in population abundance

The abundance of *spawners* and *smolts* is measured at the counting fence, while *fry* abundance in the lake is measured by acoustic surveys and sampling by trawl net. There are significant and disturbing downward trends in the abundance of all three life stages.

Spawners

There are two main trends in abundance of *spawners*: (1) between the 1920s and the late 1960s, and (2) from the late 1960s to the present. During the first of these periods, spawner abundance was initially variable, possibly a cyclic pattern but also perhaps reflecting the operation of the Sweltzer hatchery and the periodic control of predators feeding on fry in the lake. By the 1940s, abundance was generally strong in most years and showed a pattern of variability that was more random than cyclic.

The second period (since the late 1960s) is one of pronounced cyclic dominance and steady overall decline (see *Population Structure* for a discussion of sockeye population cycles). Declines are most pronounced on the two less-abundant cycles and probably reflect increased fishing on Weaver sockeye that became much more numerous after a spawning channel was constructed on that river. The strong cyclic pattern of Cultus sockeye since the late 1960s, therefore, is closely associated with a change in harvest policy for late run Fraser sockeye and is unlikely to be a biological attribute of the population.

Although the trends in abundance of each cycle vary, the most recent estimates for all four are among the lowest recorded for the population (COSEWIC 2003). And while a marked decrease in spawners is a warning sign for any salmon population, the situation in Cultus is further complicated by the fact that, in recent years, an unusually high proportion of late run adults has either died in the river on the way to the spawning grounds (*en route* mortality) or on the spawning grounds before spawning (pre-spawning mortality or PSM). Of the two kinds of freshwater adult mortality, PSM is likely the most important for Cultus; serious *en route* mortality has not been observed.

This unprecedented loss will be discussed in more detail in later sections. Here it is important only to say that, because not all of those escaping fish will survive to spawn, the loss of the population's reproductive potential is much greater than simply the decline in the number of fish that escape the fishery. The drop in the number of fish counted at the fence over the last three generations, for example, is 36%. But when the high PSM is considered, the rate of decline in successful spawners jumps to a much more alarming 92% (Schubert *et al.* 2002). Factoring PSM into recovery planning is especially difficult because it is far from constant, and because the method of estimation has varied between 1995 and the present (PSM was estimated either directly from the number of spent carcasses recovered in the lake or indirectly from the number of smolts produced by each spawner). Levels greater than 90% were reached in 1999 and 2000. In recent years, it has been more moderate, with recorded losses of 67%, 13% and 23% from 2001 to 2003, respectively.

Fry

There is also a downward trend in the abundance of *fry*, although the data are far less complete than for spawners and begin only in 1986. The populations declined from 0.5 - 2.4 million in 1986-1990 to around 250,000 in 1999 and 46,000 in 2000, the lowest for any monitored Fraser sockeye population (COSEWIC 2003).

Smolts

Assessment of the abundance of *smolts* is fairly complete from 1926 to the mid-1970s, although there are only three assessments from then until 1998. Trends parallel those already noted for adults: strong and variable until the 1960s, then declining. This decline has been dramatic, from a high of more than 3 million in 1937 to a low of 5,700 in 2002 (COSEWIC 2003).

Reasons for the downward trend in spawner abundance are discussed in later sections. There is no detectable decline in the productivity of the lake itself, so the reduced numbers of fry and smolts probably result from a combination of fewer adults returning to the lake, fewer successful spawners and predation on fry. It is difficult to discriminate between the latter two factors because we have no direct estimates of PSM and subsequent smolt production for most years. For example, there were too few carcasses to estimate PSM in the two years (1999 and 2000) when early migration affected late run populations the most. It is not until 2001, a year for which we have direct estimates of both PSM and subsequent smolt production, that we have evidence for predators also playing a role (see *Biological Limiting Factors* for a discussion of depensatory mortality caused by predators). Poor smolt production in that year, if it persists, will affect the rate of recovery.

Biological Limiting Factors

We have already discussed characteristics of Cultus sockeye that make it unique among Fraser River sockeye populations. For recovery to happen, it's important to look at the life and habits of this particular population and to identify any special things that put it in harm's way. The following section considers characteristics that need to be dealt with in the planning of recovery actions. Most of them are behaviour traits that are bound up with the concept of genetic uniqueness.

Co-migration

Cultus sockeye are part of a convoy of maturing adults from several Fraser populations, all of which can be intercepted by mixed-stock fisheries along the coast of B.C. and in the Fraser River. Specifically, Cultus fish are part of the late run that includes the more productive and numerically much larger Weaver and Shuswap populations. Any fishery on these larger groups along the migration corridor in August, September and October could also kill Cultus sockeye.

Migration timing

Cultus sockeye are believed to migrate from the North Pacific Ocean into the Strait of Georgia from late July through September, peaking in mid-August (see *Knowledge Gaps)*. Until about 1995, they delayed for up to eight weeks near the Fraser River mouth before resuming their migration into the river, an adaptive behavior thought to lessen exposure to unfavourable conditions in freshwater. Since 1995 and for unknown reasons, the late run began to migrate upstream earlier. The unfortunate result of this early migration has been high *en route* and pre-spawn mortality. Early migration is a biological limiting factor because the behaviour can lead to infection with the freshwater parasite *Parvicapsula minibicornis* (see *Threats to population viability and habitat*). Its possible causes of are being intensely investigated (Cooke *et al.* 2004).

Migration route

Both emigrating smolts and returning adults run a gauntlet of industrial and residential development in the Fraser Valley that has altered the water chemistry and shore habitat in the lower Fraser River and its estuary. Their unalterable route also commits adults to passing through Sweltzer Creek in late summer at a time of heavy recreational use.

A 1996 radiotelemetry study revealed that, because Cultus sockeye are relatively inefficient swimmers, they use up unusually high amounts of their limited energy on their freshwater migration (S. Hinch 2004, pers. comm.). Factors that increase their energy needs, such as in-river recreation, can reduce their subsequent spawning success (Hinch and Bratty 2000). Delays or disruptions caused by humans could increase energy use, exposure to high temperatures, stress and susceptibility to *Parvicapsula*.

Freshwater productivity

The ability of salmon populations to recover or sustain exploitation depends on a combination of freshwater and marine productivity that results in their producing more adult progeny than spawned in the previous generation. Historically, freshwater production of about 60 smolts per spawner coupled with a marine survival around of 7% yielded more than four returning adults per spawning parent – a number adequate to sustain the population. However, the recent decline in the number of smolts produced in the lake (COSEWIC 2003) prompted a review of the abundance data to determine whether changes in freshwater productivity could limit the recovery of the population. The review shows that, when there are more than 7,000 spawners, smolt production is variable at an average 68 smolts per spawner. When there are fewer than 7,000 spawners, however, smolt production drops to about half that level. Although the data are variable, there is a consistent pattern of survival throughout the period of record rather than any evidence of a recent decline in productivity associated, for example, with habitat or ecosystem changes. If the recent low freshwater production is due to predation, as is often suggested, the population may have trouble recovering or sustaining exploitation when abundance is below 7,000 spawners. Indeed, the historic data show that recovery has been a problem when the population has declined below 5,000 (see *Annex 1*). Continued monitoring is required to determine if low productivity will continue, or if higher rates of smolt production can occur at low spawner abundances.

Spawning behaviour

Cultus is one of the few B.C. sockeye populations that spawn exclusively on the lake shore. The population is also particular about the locations it uses for spawning, requiring areas of weathered gravel with a combination of well-circulated lake water and groundwater to maintain the right temperature and oxygen content. The population's preference for lake shores may also mean that infestation with Eurasian watermilfoil reduces access to spawning habitat.

Fry behaviour

Cultus sockeye have a unique adaptation to spawning time: eggs that are spawned later actually develop faster (Brannon 1987). The fry also behave unlike most other sockeye fry in that they school and move into deeper waters immediately after swimming up from the gravel - likely an adaptation to the many predators in Cultus Lake (Ricker 1941). The behaviour needs to be taken into account in the design of any predator control programs.

Threats to Population Viability and Recovery

Table 1. Summary of threats to the Cultus sockeye population.

Life Stage	Threat	Natural or Human Induced	Threat Class	Possible Severity	Identified by COSEWIC Status Report
1. Egg and alevin	a. Habitat alteration	Human	Potential	Unknown	Yes
	b. Predation (suckers, sculpins)	Natural	Known	Unknown	No
	c. Early migration (egg viability)	Natural	Potential	Unknown	No
	d. Pollution	Human	Potential	Unknown	Yes
2. Fry	a. Predation (pikeminnow, salmonids, sculpins)	Natural	Known	High	Yes
	b. Exotic species (Eurasian watermilfoil; incremental pikeminnow recruitment)	Human	Known	Medium	Yes
	c. Diseases and parasites (*Salmincola*)	Natural	Known	Unknown	Yes
	d. Habitat alteration	Human	Potential	Unknown	Yes
	e. Pollution	Human	Potential	Unknown	Yes
3. Smolt	a. Habitat alteration	Human	Potential	Low	No
	b. Pollution	Human	Potential	Low	No
	c. Predation	Natural	Known	Low	No
	d. Diseases and parasites (*Parvicapsula*)	Natural	Known	Unknown	No
	e. Diseases and parasites (*Salmincola*)	Natural	Known	Unknown	No
4. Marine juvenile and adult	a. Global warming	Human	Potential	High	No
	b. Environmental change	Natural	Known	High	Yes
	c. Diseases and parasites (aquaculture)	Human	Potential	Low	Yes
	d. Pollution	Human	Potential	Low	Yes
5. Pre-spawning adult	a. Over exploitation in fisheries	Human	Known	High	Yes
	b. Early migration (prespawn mortality)	Natural	Known	High	Yes
	c. High water temperatures	Natural	Known	Medium	Yes
	d. Recreational activities	Human	Known	Medium	Yes
	e. Habitat alteration	Human	Potential	Low	Yes
	f. Illegal harvest	Human	Known	Unknown	No
	g. Predation (seals, sea lions)	Natural	Potential	Unknown	No

6. Spawner	a. Exotic species (spawning habitat encroachment)	Human	Known	High	Yes
	b. Habitat alteration	Human	Potential	Unknown	Yes
7. All	a. Environmental variability	Natural	Potential	High	Yes

For many salmon populations, the loss of freshwater spawning and rearing habitat is one of the most important reasons for population decline, and the restoration of habitat has become a touchstone for biologists and community groups. Although there is evidence that watermilfoil, stream channelization and foreshore developments may interfere with prime Cultus spawning sites, freshwater habitat degradation is *not* thought to be the main cause of the population's recent decline. Data collected since the 1930s, although limited by the characteristics that were sampled in earlier years, suggest that the lake itself has changed little over six decades. It remains highly productive, even underutilized, although the watermilfoil population has increased dramatically (Schubert *et al.* 2002) and the effects of developments around the lake have not yet been assessed.

While the following section identifies some specific habitat concerns, the drastic decline in Cultus sockeye is attributed to three other primary causes (COSEWIC 2003):

- Overexploitation in fisheries before 1995, resulting in the population's increased susceptibility to other sources of natural mortality;
- Poor marine survival in the early to mid 1990s which further reduced population levels; and
- Since 1995, high PSM caused by unusually early migrations into freshwater and an associated *Parvicapsula* parasite infection. The high PSM has confounded recovery actions initiated in 1998, which have focused on large reductions in fishery exploitation rates.

The threats are described below in two categories (*natural* and *human-induced*). They are listed in descending order of severity within each category and are separated by life stage. Numbers (*e.g., Threat 5c*) are those in used in Table 1.

Natural threats

Early migration

Water temperature (Threat 5c). Metabolic processes in cold-blooded animals like sockeye are sensitive to environmental temperature. The early migration of Cultus and other late run populations since the late 1990s has lengthened residence time in freshwater at temperatures that make the already-stressed fish exceptionally vulnerable to the diseases and parasites they might normally withstand. For Cultus sockeye, this effect is worsened by the need to migrate through extreme changes in temperature when the fish move from Chilliwack River (moderate temperature) through Sweltzer Creek (high temperature) to Cultus Lake (low temperature). Hence, early migration, while not a threat in itself, has important consequences for Cultus sockeye.

Pre-spawn mortality (Threat 5b). While the cause(s) of the early upstream migration remain to be identified, the effect of the behaviour is well documented. High PSM related to *Parvicapsula* infection has resulted in an unprecedented loss of potential spawners that has pushed the Cultus population to critically low levels and complicates recovery by adding an uncontrollable cause of mortality. The parasite affects kidney function in adult sockeye once they have entered freshwater and may also depress the ability of migrating sockeye to recover from vigorous swimming. Historical PSMs of less than 10% increased in 1999 and 2000 to over 90%. If these levels continued in the future, each spawner would need to achieve more than six times the current level of production for the population to avoid extinction (COSEWIC 2003). There is hope, however, that these very high mortalities are transient: PSM has moderated since 2000, with a 67% loss in 2001, a 13% loss in 2002 and a 23% loss in 2003.

Egg viability (Threat 1c). Recent studies show that there is no evidence of vertical transmission of *Parvicapsula, i.e.,* infected parents do not pass the parasite on to their eggs and can and do produce viable offspring (A. Farrell 2004, pers. comm.). At present we do not know of any sub-lethal effects of parental infection on offspring fitness (D. Patterson 2004, pers. comm.).

Environmental change

Environmental variability (Threat 7a). The Cultus population is as susceptible as any other to natural climate cycles that occur over long time periods. The survival of all lake, stream and ocean dwelling salmon is linked to these cycles, and changes can affect survival at any life stage. Freshwater conditions can change independently of ocean events, affecting lake productivity and the proliferation of watermilfoil and predators. Given the already depressed condition of the population, a series of such events in freshwater or in the ocean would be a serious threat.

El Niño (Threat 4b). El Niño Southern Oscillation events are one of several periodic phenomena that can reduce the marine survival of Cultus sockeye. *El Niños* increase coastal temperatures and depress productivity (Beamish *et al.* 1997), and may effect migration timing.

Predation

Suckers, sculpins (Threat 1b). Newly hatched alevins may be prey for suckers (*Castostomus macrocheilus*) and sculpins (*Cottus asper*), which frequent the gravel nests or *redds* where the eggs incubate.

Pikeminnow, salmonids, sculpins (Threat 2a). Sockeye fry are prey for other salmonids, sculpins (*Cottus spp.)* and the northern pikeminnow (*Ptychocheilus oregonensis)*, a large cyprinid common in B.C. At Lindell Beach, schools of fry have been observed being attacked by sculpins before moving to deeper water (Brannon 1965). Pikeminnows are abundant and, while salmonids consume more sockeye fry per individual than do pikeminnows, the sheer numbers of pikeminnows make them the greatest threat to the population (Foerster and Ricker 1941; Ricker 1933; Ricker 1941; Foerster 1968; Friesen and Ward 1999). The pikeminnow diet varies from season to season and with the abundance of prey. In the fall, winter and early spring, sockeye fry and smolts are its most important food while, in the summer, pikeminnow spawners move close to shore where other species serve as prey. In years when sockeye are less abundant, pikeminnows may switch to other species, so it is unclear whether predation is significant at the recent low sockeye abundances. Previous attempts to control pikeminnows suggest that this is a promising recovery approach for the Cultus population (see Mossop *et al.* 2004, and *Approaches to meeting recovery objectives*).

Seals, sea lions (Threat 5g). Harbour seals and sea lions penetrate the migratory corridor as far as the Chilliwack River and may remove significant numbers of migrating salmon. While the impact on Cultus sockeye is not known, the low numbers of Cultus fish relative to other co-migrating sockeye populations and salmon species may limit the threat. Cultus sockeye would be most vulnerable in the Sumas, Vedder and Chilliwack rivers in August and September.

Diseases and parasites

Salmincola californiensis (Threats 2c, 3e). Cultus sockeye juveniles often become infected by *Salmincola californiensis,* a freshwater copepod that is a parasite on salmon and trout throughout the North Pacific (Kabata and Cousens, 1973). The impact of *Salmincola* on freshwater fish can be considerable, resulting in severe gill damage, reduced growth and smaller egg masses in spawners (Allison and Latta, 1969; Barnetson 2004, pers. com.; Gall *et al.* 1972; Johnson and Heindel 2001; Sutherland and Wittock 1985). Infection rates among fry collected from mid-lake trawl surveys in 2003 were 6% in September and 25% in November (J. Hume 2004, pers. comm.). In 2003, up to 70% of the daily smolt migration was infected with *Salmincola.* Whether the parasite continues to harm the smolts once they enter sea water is not known. In the wild, seawater may kill the parasite directly, kill its eggs or larval stages or result in the parasite's shedding its larvae without re-infecting the fish.

Parvicapsula minibicornis (Threat 3d, 5c). The effects on adults encountering *Parvicapsula* in the estuary have been discussed earlier in this section. This parasite does not appear to infect juveniles in Cultus Lake (none of the 21 smolts sampled in 2001 were infected). Rather, examinations of Fraser River (but not Cultus) sockeye smolts in the Strait of Georgia in 2000-2001 show that the parasite is picked up in the estuary, but that severity is low and the impact minimal. Very few infected individuals return to the river as adults; however, we don't know whether the smolts die, recover or carry the infection at a barely detectable level. *Parvicapsula* could add to the cumulative risk of PSM among returning adults in years when Cultus sockeye enter the Fraser River with earlier migration timing, and in years when they spend longer in freshwater.

Human-induced threats

Over- exploitation

Threat 5a. Fraser sockeye are intensively managed using a complex regulatory system involving both Canada and the U.S., in which capture levels set by various bodies depend on the geographic area being fished. Historically, Cultus sockeye adults have been captured in mixed-stock commercial fisheries along their migratory corridor from Alaska to the mouth of the Fraser River.

The term maximum sustainable yield (MSY) is used by fisheries biologists and managers to describe the largest long-term average catch that can be taken without impairing a population's sustainability through natural growth or replenishment (Gulland 1983). MSY for any population reflects a certain exploitation rate (ER). The effect of different ERs is complicated by the varying strength of each cycle and the populations that are being actively managed for a particular year. Mathematical models suggest that the maximum sustainable yield for Cultus sockeye is achieved at an ER of 56% (Schubert *et al.* 2002).

Until the mid-1990s, ERs for Fraser (and most other) sockeye populations were based on the largest and most productive ones; as a typical smaller population, Cultus was not managed as a discrete unit. Because Cultus has been less productive than its numerically dominant co-migrant populations it has been subjected to ERs significantly above the level associated with MSY. The long term, cycle-specific ERs for Cultus sockeye have ranged from 67-77% and have frequently been over 80%. Comparison of these rates with the 56% associated with MSY points to fishing as being the single most important reason for population decline in the period before 1995.

Eurasian watermilfoil

Incremental pikeminnow recruitment (Threat 2b). Eurasian watermilfoil (*Myriophyllum spicatum*) is an invasive plant introduced to North America more than a century ago and first observed in Cultus Lake in the late 1970s (COSEWIC 2003). By 1991, it covered nearly half of the lake's total littoral (near-shore) area. The lake is now heavily infested with the plant, which colonizes the bottom to the depth of light penetration. This affects sockeye fry by providing shelter and rearing habitat for juvenile pikeminnow, the adults of which are major sockeye predators. Sporadic control projects in Cultus Lake have shown that mechanical removal of watermilfoil can be effective, although techniques need to be refined and monitored long enough to demonstrate which works best (Mossop and Bradford 2004).

Spawning habitat encroachment (Threat 6a). Dive surveys in 1982 found that dense patches of Eurasian watermilfoil had displaced sockeye from areas previously utilized for spawning. After a removal program in 1983, large numbers of spawners returned to cleared areas (K. Morton 2002, pers. comm.). The effect of watermilfoil, however, is not completely understood. For example, the remote video surveys did not indicate that spawning was actually disrupted by watermilfoil colonization (B. Fanos 2004, pers. comm.). However, it is possible that the deep-water areas are sub-optimal for spawning and are being used simply because they are free of milfoil. The impact at current sockeye and watermilfoil population sizes is not known.

Recreation

Threat 5d. Cultus Lake has been heavily used for summer recreation for a century and now receives millions of visitors each year. Apart from habitat alteration and loss (see next section), such heavy recreational use can affect spawners that must make their way through Sweltzer Creek and hold in the lake before finding suitable lakeshore spawning areas. The relatively warm water at the shallow lake outlet and in Sweltzer Creek makes these areas magnets for swimmers in the summer months (typically until Labour Day), and disturbance by swimmers at the lake outlet sometimes delays fish for several hours. Similarly, activity at a campsite beside the creek could disturb fish that are migrating during daylight hours. The sockeye's habit of travelling through the creek mostly at night provides some protection, although nocturnal migration may simply be their way of avoiding disturbance. Angling in the Chilliwack, Vedder and Sumas rivers may also delay migration.

Habitat alteration and loss

Following the arrival of European settlers in the late nineteenth century, human activities at Cultus Lake changed from a First Nations spiritual focus to a recreational one. There are a number of potential impacts to the lake associated with today's two main recreational activities,boating and swimming. In the 1950s, sailboats and small inboards were replaced by speedboats, then jet-skis. Boating's main impacts are pollution (hydrocarbons and metals), the construction of piers, and the inadvertent introduction of watermilfoil. Swimming has had a number of impacts, including placement of sand on beaches near the lake outlet, the addition to the lake (until 1976) of copper sulfate to control *swimmers' itch* and the mechanical removal (since 1979) of watermilfoil from swimming beaches.

Threats from habitat alteration are best understood in the context of the history of watershed development in four geographic areas: the *north* or outlet end (Sweltzer Creek); the *east and west sides*; and the *south* end.

The area around the lake outlet and Sweltzer Creek (*north end*) has the longest human history, with evidence of occupation by First Nations for hundreds and perhaps thousands of years (Brown and Flack 2004). The north end of the lake has been popular for recreation since the late 1800s. A road there was constructed some time between 1882 and 1912, and was extended to the south end before the mid-1930s. Development began in earnest in the 1920s, with the construction of boat-houses, a gas station, summer residences and businesses. The lowland areas near the lake outlet were logged in the early 1900s; logging continued at higher elevations, especially on Vedder Mountain, from the 1930s through the 1970s.

In 1924, the Crown granted land to local municipalities to create a park. Cultus Lake Park was established as a self-governing entity in 1932 on what is now 259 ha at the north end of the lake. Habitat alteration associated with the park includes the removal of shoreline vegetation for beaches, campsites and boat launches, the addition of sand to beaches and the construction of piers. When the park was established, its borders had already been partially logged and included a number of summer residences and commercial developments. Consequently, the Park was granted the power to provide services (water, sewage, roads and electricity) and to establish by-laws to control further development. Since 1980, developments include golf courses, water slides, boat and jet-ski rentals and riding stables. Today the Park has 459 residences, 37 businesses and a year-round population of over 900 in a community that occupies 48% of the park area (Urban Systems 2003).

The Cultus Lake Park Board is currently consulting with governments and the local community regarding a change in governance. The proposed change would permit the Board to borrow money to fund infrastructure projects such as upgrades to water and sewage systems. Such projects could spur further development in areas that have not been designated for park use (*e.g.,* the east side of Sweltzer Creek). Water for the community is supplied by a single well that, until recently, was supplemented by surface water from Hatchery Creek. A recommendation for a second well is under consideration (Urban Systems 2003). The community is serviced by a primary sewage treatment system that includes a collection system and three disposal fields; the system was installed in 1979 and has now exceeded its operational life span. The Sunnyside Campground and Mountainview Road and Park Drive residences are serviced by individual septic systems. There have been problems with some septic systems and there is a potential for seepage into the lake. Although water quality effects have not been detected, a survey of local and traditional knowledge noted that the water is less clear, the rocks are black, and there is often a bad odour in these areas (Brown and Flack 2004). There are also several storm water runoff systems that discharge directly into the lake.

Early development along the *east and west sides of the lake* was limited by the steep slopes that largely confine the lake shore. In 1948, the 656 ha Cultus Lake Provincial Park was established on both sides of the lake, and the 2,080 ha International Ridge Recreational Area, established in 1969, extends the protected area from the Park's eastern boundary to the watershed boundary. The west side remains largely undeveloped. On the east side, the road to the south end of the lake was upgraded in 1950, and visitor services (campsites, boat launches, administrative centre) were developed on four alluvial fans (Entrance Bay, Delta Grove, Honeymoon Bay, Maple Bay). Habitat alterations at these areas include the removal of shoreline vegetation for beaches, campsites and boat launches, the construction of wharves, creek channelization, storm water runoff and the potential for septic system discharge.

At the *south end* of the lake, the Columbia Valley was first settled in the 1890s and subsequently developed as a sparsely populated agricultural area. There is no evidence of prior settlement by First Nations. The valley was logged in the 1920s and the timber shipped south by rail into the U.S. Logging on the U.S. side of the Frosst Creek drainage continued at least until 1986. A debris torrent that year swept log jams into the lake and deposited large amounts of rubble and fine sediments at the delta; extensive dyke improvements followed. The residential community of Lindell Beach, located at the head of Cultus Lake, began to develop in the late 1940s when the original homestead was subdivided into small lots. At about this time, Frosst Creek was diverted from the middle of the beach to the west side of the valley. Today, the Columbia Valley and Lindell Beach comprise a community of 357 residences with a year-round population of about 600 that is serviced by a number of businesses and a golf course. Most of Lindell Beach's lakeshore residents have constructed piers into the lake. The newer residences are serviced by new septic systems; older ones have septic systems that extend to the lake's edge and probably leach into the lake. The community draws water from the Columbia Valley Aquifer, which drains north into Cultus Lake and south into the U.S. The water is largely uncontaminated, although nitrate-nitrogen concentrations (from manure and fertilizer) are higher than normal (Zubel 2000). Current water use consumes less than 1% of the annual recharge. The Lindell Beach water system was upgraded in 1995, with a new well and distribution system. Until recently, Lindell Beach was a heavily utilized sockeye spawning area (see *Distribution trends*). The movement of spawners away from Lindell Beach may reflect changes in the groundwater hydrology resulting from activities such as concentrated residential development, creek diversions and dyking, the construction of piers on the spawning grounds, and the draw-down of the aquifer where it enters the lake. There are anecdotal reports that the amount and distribution of groundwater along the beach has changed since the late 1980s (Lindell Beach residents; K. Peters 2004, pers. comm.).

Potential threats from habitat alterations are described by life stage below.

Eggs and alevins (Threat 1a). Habitat alterations that pose a threat to eggs and fry include those that affect water and spawning gravel quality. A preliminary test of subsurface water quality shows contaminant levels that may threaten the population (K. Shortreed 2004, pers. comm.). Surface water quality may be affected by sedimentation from logging and other developments in the Frosst Creek watershed, leachate from septic tanks and storm drain runoff.

Fry (Threat 2d). There is no obvious change in the physical and biological characteristics of the lake. Removal of riparian (shore-dwelling) plants could affect the lake's temperature profile, and adding sand to popular swimming beaches near the lake outlet could affect ecosystem linkages.

Smolts (Threat 3a). Habitat alterations that pose a threat to smolts occur along the freshwater migratory route. An active gravel mine on Parmenter Road produces sedimentation that enters Sweltzer Creek and could harm migrating sockeye. A mine expansion proposed for the vicinity of Hatchery Creek may reduce habitat and water quality, including increasing turbidity and pollution from fuels and lubricants. The applicant is expected to undertake further work to satisfy DFO and the Ministry of Energy and Mines with respect to erosion and sediment control.

Pre-spawning adults (Threat 5e). Potential threats to adults along the freshwater corridor include gravel mining in the Vedder River and Hatchery Creek, as well as alterations to Sweltzer Creek that reduce habitat quality or force the fish to delay in sub-optimal habitats. These may include the blockage of cool water seepage channels from the Chilliwack River and the structure at the lake outlet that controls lake water levels.

Spawners (Threat 6b). Habitat alterations that pose a potential threat to adults resemble those identified under *Threat 1a* (wharf and pier construction, alteration of creek channels, addition of sand to beaches). Increased withdrawal from the Columbia Valley aquifer by the new Lindell Beach well may reduce groundwater percolation into the spawning areas.

Pollution

Eggs, alevins and fry (Threats 1d and 2e). Sockeye rely on high quality, well-oxygenated water for incubation. There are a number of potential pollution sources in Cultus Lake and its basin that could degrade lake water quality. Inadequately treated sewage from residences and campsites may enter the lake and, although there is no agriculture adjacent to the lake, farms in the Columbia Valley, golf courses and residences around the lake use fertilizers and other chemicals that may enter the lake directly or through groundwater. Goose feces contain nitrogen and phosphorus as well as coliform bacteria, and the number of Canada geese using the lake as a nighttime refuge and feeding area has increased with the increase in open green areas around the lake. Feces from waterfowl could increase the nutrient load in the lake causing productivity shifts that could affect juvenile sockeye.

Summer boat traffic has increased to a level where the Canadian Coast Guard is considering imposing traffic control regulations. Boat engines, particularly 2-cycle outboard motors, emit hydrocarbons and metals; sub-surface samples of water in spawning gravel show levels of several sediment-bound metals that exceed criteria for open water (Hume *et al.* 2004).

Smolts and marine juveniles and adults (Threats 3b and 4d). Effluent from communities and industry can pose a threat to Cultus juveniles and adults in the lower Fraser and in estuarine and coastal waters.

Illegal harvest

Threat 5f. Illegal harvest or poaching in the Fraser River and associated migratory corridors has long been known about but never completely controlled. As noted with the threat of predation by marine mammals (*Threat 5g*), the low abundance of Cultus sockeye relative to other co-migrating species and populations limits the impact in most areas. Cultus sockeye are at greatest risk when they outnumber other populations, namely in the Sumas, Vedder and Chilliwack rivers in August and September and at any time in Sweltzer Creek and Cultus Lake.

Diseases and parasites

Aquaculture (Threat 4c). Juvenile sockeye that migrate through areas of intensive coastal net-pen salmon aquaculture may be susceptible to elevated levels of sea lice infection (Gardner and Peterson 2003). The severity of this threat is controversial and the subject of intensive research (PFRCC 2003).

Global Warming

Threat 4a. In contrast to natural long term shifts in ocean temperatures, longer term human-induced changes in climate may have profound impacts on the distribution of salmon and other aquatic species. The most common current hypothesis has salmon populations shifting northward.

Habitat Identification

General habitat requirements

Section 2(1) of the *Species at Risk Act* (*SARA*; see http://www.sararegistry.gc.ca) defines the habitat of aquatic species as *"spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced.*" This definition clearly applies to species such as Cultus sockeye whose habitat requirements are geographically wide-ranging and cover a variety of ecosystems. In common with most Pacific salmon species, the population divides its life cycle between freshwater (for spawning, egg incubation and hatching, fry rearing and smolt migration) and the ocean (growth from smolt to adult, followed by return migration to the natal freshwater location). As the *SARA* definition implies, each of the major life stages has different habitat requirements.

The *marine* habitat requirements for Cultus sockeye are those generic to all Pacific salmon species and include unrestricted ocean corridors and feeding grounds with the right temperature and productivity (Foerster 1968; Burgner 1991). Although climate-driven natural variability in ocean productivity will influence the survival of Cultus sockeye, the management of marine habitats other than the migratory corridor is probably impossible, and we do not discuss these habitats further. The following sections of the Recovery Strategy relate solely to *freshwater* habitat and describe what Cultus sockeye need for survival and recovery.

Critical habitat

Section 2(1) of *SARA* defines critical habitat as *"the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species."* Section 41(1) further requires that recovery strategies identify critical habitat to the extent possible and provide examples of activities that are likely to result in its destruction.

Determining which habitats are critical to Cultus sockeye – or to any aquatic species that ranges widely for feeding, growth and reproduction – is not easy. Watersheds differ in their hydrology, temperature regime, sediment transport, nutrient cycling, physical structure and biological processes, so there is no "one size fits all" definition of aquatic habitat that can be applied to Pacific salmon in general. And because all fish populations develop unique adaptations to the environmental conditions they encounter and to the species with which they share their habitats, the habitat that is critical for each population is correspondingly unique.

It is also hard, when considering several examples of the same category of habitat, to decide which ones are actually critical. For example, when a single population of fish uses a dozen beaches for spawning, do you single out one beach as the most important, gamble that losing it will be the straw that breaks the population's back, and invoke all the relevant measures for its protection? Or do you include all the beaches as critical because it's impossible to predict which will be used most by a population so diminished that spawning pairs are hard to spot at all? Precaution may dictate treating them all as critical and meriting the protection provided for under the *Fisheries Act* and *SARA*.

The following discussion concerns freshwater habitat that the Recovery Team proposes as critical for recovery of Cultus sockeye. The Team terms such habitat *proposed critical habitat*. Our discussion focuses on three types of proposed critical habitat: juvenile and adult migratory corridors; spawning and incubation areas; and juvenile rearing areas. We describe in a general way the requirements for each type of habitat, comment on specific characteristics of the habitats used by Cultus sockeye, and propose habitats that we believe are critical to the population.

Habitat in migratory corridors

Migrating adult sockeye require holding or resting sites, suitable water flow and acceptable water quality. In large unregulated rivers, sockeye migrate near the bottom or the shore and are generally unimpeded except by fast water or predators. In smaller rivers, the fish swim in bursts through shallow areas and rest in deeper pools. Consequently, flows must be sufficient to allow passage over riffles and barriers, and large woody debris and boulders are needed to provide resting areas and cool water refuges. Riparian vegetation moderates water temperature and can provide protection from predators. Excessive temperatures, turbid or otherwise poor quality water can cause delays and promote disease. Key habitat attributes for adults, therefore, are water depth, quality, temperature and flow, with resting areas and refuges.

Migrating juvenile sockeye require similar habitats as well as specific water temperature regimes to trigger the change to smolts at the appropriate time. A normal range of stream flows maintains the temporal pattern of migration, and physical structures such as undercut banks and large woody debris provide rest areas and cover from predators. Key habitat attributes for juveniles, therefore, are water depth, flow and temperature, with cover and channel complexity.

How do Cultus sockeye fit this pattern? The population uses a freshwater corridor that extends from the Fraser River estuary to Cultus Lake itself. In the *lower Fraser River*, fish migrate through an unobstructed shipping channel that is dyked and regularly dredged. They are vulnerable to any fishery during their migration, and may be especially so to poaching and predation by marine mammals if they hold at the mouth of the Sumas River. They are also affected by high water temperatures (up to 20° C) if they migrate into the river earlier than normal; such temperatures increase their vulnerability to disease and parasites and can lead to increased mortality (Schubert *et al.* 2002).

Risk increases as Cultus sockeye leave the Fraser River and move into the Vedder and Chilliwack rivers, the middle legs of the freshwater corridor. The lower *Vedder River* is closely confined by dykes, while the upper river has set-back dykes that allow it to meander over a broad floodplain.

Both parts of the river suffer from regular gravel removal, channelization, bedload movement, sediment deposition and the loss of riparian vegetation. Here, predation and poaching become more of a threat because the camouflage effect of large co-migrating populations has largely evaporated and the channels are shallower and more open. Although temperatures in the Vedder and Chilliwack rivers are normally moderate (<18° C), migration can be slowed or halted for hours to days by high flows caused by heavy rain (Hinch 2004, pers. comm.) or by angling and other recreation like kayaking and canoeing. The Vedder River becomes the *Chilliwack River* at Vedder Crossing, just downstream from its confluence with Sweltzer Creek. It provides holding habitat before the sockeye migrate into *Sweltzer Creek,* the final leg of the freshwater corridor.

Sweltzer Creek is short and relatively shallow with little channel complexity or large woody debris. Water temperatures can exceed 25° C in August and September, although cut-off seepage channels from the Chilliwack River and groundwater infiltrating pools may provide cooler refuge areas. Prolonged exposure to such temperatures can be lethal to sockeye. Any delays while swimming up Sweltzer Creek may decrease spawning success or increase mortality. Some activities of concern are angling near the mouth, swimming at a campsite in the middle reaches, swimming in the upper reaches and around the lake outlet, boating and the operation of a low level weir (to control lake levels) at the lake outlet. The population is more vulnerable here than at any other point on the migratory corridor (with the possible exception of net fisheries), so the maintenance or improvement of creek habitats is critical to its survival and recovery.

The Recovery Team proposes Sweltzer Creek, including where it joins Cultus Lake and the Chilliwack River, as *critical habitat* for Cultus sockeye. For the population to have a chance at recovery, these areas need to be minimally obstructed or disturbed so that the fish pass through the three kilometers as quickly as possible. Further study is required to mitigate the effects of habitat alterations and to optimize key habitat attributes such as temperature, resting areas and cover. Activities likely to destroy habitat include changes to channel morphology that reduce water depth or pool frequency, removal of riparian vegetation, water extraction and sedimentation. Activities that may threaten the population are those that would delay fish in the creek, including recreation in and near the creek and at the lake and creek outlets.

Habitat used for spawning and incubation

Sockeye choose spawning and incubation habitat based on substrate composition and permeability, water quality (*e.g.,* oxygen content), temperature and water flow through the substrate. Some populations, such as Cultus, spawn exclusively along lake shores where the presence of upwelling groundwater and circulating lake water are key attributes.

The timing of salmon life cycles reflects the chemical, physical and biological characteristics of their habitats. The timing of fry emergence, which is key to subsequent growth, is a genetic characteristic of the population and is hence the major evolutionary determinant of the timing of spawning (Brannon 1987). Cultus sockeye spawn late in the year, from early November to early January, and thus may require incubation areas where warmer groundwater (8°C) mixes with cooler lake water (average 6.4° C, but as low as 2.5° C) so that eggs can develop fast enough for emergence in April and May (Ricker 1937a, Brannon 1987. K. Shortreed 2004, pers. comm.). Thus, groundwater is important to the development of those eggs that are deposited late in the year, and may have a more general importance when the winters are colder. It also removes the fine sediments and metabolic wastes that, in river spawning populations, are removed by the current.

Because it takes 50 years for rain water to seep through the Columbia Valley aquifer and into the lake, groundwater has little or no oxygen (M. Zubel 2004, pers. comm.). The population, therefore, also relies on oxygenated lake water. In Cultus Lake, spawning areas are irrigated by the vertical mixing of highly oxygenated surface water that begins in December when surface water cools and becomes denser and the strong north or north-west winds promote its mixing with deeper water (Ricker 1937a). The process is called *winter circulation,* and continues until March or April. Because wind intensity varies across the lake, the strength of circulating lake currents may also vary from place to place. Consequently, the substrates selected for spawning in areas with less circulation may have to be more permeable to permit oxygenated water to reach the eggs. Thus, the key attributes of spawning and incubation habitat reflect a complex interaction between temperature and oxygen regimes and substrate permeability.

Current and historic spawning areas in Cultus Lake comprise about six hectares of weathered cobble and gravel along the lake shore at Lindell Beach, Snag Point, Spring Bay, Honeymoon Bay and Mallard Bay. Only about half of those sites were used in 2002, mostly at Spring Bay, with a few spawners at Lindell Beach, Salmon Bay and Honeymoon Bay. Spawning has been observed at depths of 0.5 to 6 m, and more recently in much deeper water (10 to 17 m).

Because the deeper waters have not been assessed until recently, it is not possible to determine the type of spawning habitat Cultus sockeye prefer. Two possibilities exist. On the one hand, if the shallower areas where spawners were historically observed are the preferred habitat, then recent impacts such as the encroachment of watermilfoil, changes to the aquifers and physical alteration of the beaches may have caused spawners to move to deeper water. If this is the case, the shallower areas require urgent attention. On the other hand, if the deeper habitats are preferred and the shallower habitats are used only when abundance is high (as it was until the late 1960s), then the total spawning area may be underestimated. Either way, while there may be enough habitat available for the current low spawning populations, it may be both quantitatively and qualitatively inadequate for the larger ones envisaged by the Team.

The Recovery Team proposes areas of lake bed at depths from 1 to 20 m as *critical habitat* for Cultus sockeye at the following locations: Lindell Beach, Snag Point, Spring Bay, Mallard Bay, Salmon Bay and Honeymoon Bay. Given the dependence of the population on groundwater, the Team also proposes the aquifers that feed these spawning areas as *critical habitat*. Further study is required to determine the precise location and extent of habitats with the appropriate combination of substrate and water quality (particularly temperature and oxygen). Such habitats will need to have an acceptable level of impact from watermilfoil encroachment and land and water use activities, and be large enough to support the nember of sapwning pairs envisaged in this strategy. Activities likely to destroy spawning and incubation habitat are those that would increase sedimentation in the lake (*e.g.,* removal of riparian vegetation or forest cover near the lake shore and tributary creeks, mining, road construction), alter the quantity and quality of the groundwater (*e.g.,* water withdrawal, leaching of fertilizers or sewage), alter the quantity and quality of surface water (*e.g.,* septic seepage) or physically disrupt the spawning areas (*e.g.,* foreshore development).

Juvenile rearing habitat

To identify the habitats that are important to sockeye juveniles, especially those in Cultus Lake, it is necessary to have a basic understanding of how lakes function. Cultus is a *warm monomictic* lake, which means that its surface and deeper waters form distinct layers in spring, summer and fall and mix only when the surface waters cool to the temperature of the lower depths. Mixing brings nutrients to the surface and returns oxygen to the lower levels (see *Spawning and incubation habitat*). In spring, the surface water heated by the sun becomes less dense and "floats" on the cooler, denser water below. As heating continues, the surface layer's temperature and density inhibit mixing. The lake is then said to be *stratified*, with a warm upper layer (the *epilimnion*), a transition layer (the *metalimnion*) where temperatures decrease rapidly with depth and a lower layer of cold, dense water that extends to the lake bottom (the *hypolimnion*). Because the lake has a zone where temperature drops rapidly it is said to have a *thermocline*.

In Cultus, warming begins in April and the thermocline that is established by late May persists until November. The epilimnion typically goes down 6 to 8 m and its temperature can exceed 22° C in August. The metalimnion is normally several meters deep. Hypolimnetic temperatures are cool (5-8° C) throughout the year (Ricker 1937a).

Cultus' small size and its typically calm and warm summer weather result in temperatures in the epilimnion that approach the lethal limit for sockeye. Because it is also an unusually clear lake where enough light to support plant growth can penetrate the cooler waters of the hypolimnion as deep as 16 m, water clarity is an important habitat attribute. Photosynthesis is controlled by the availability of nitrogen and phosphorus as well as light, and is one of the key factors controlling a lake's capacity to rear juvenile sockeye. Cultus has unusually high nitrogen and phosphorus concentrations that, along with its favourable light conditions, result in the highest photosynthetic rate of any sockeye nursery lake in the Fraser system and permit zooplankton (organisms that prey on the phytoplankton and are in turn eaten by sockeye fry) to flourish in a community structure favourable to sockeye fry. Although zooplankton are scarce in the upper 5 m where the water clarity makes them highly visible to hungry sockeye, they are abundant to greater depths than in most lakes. Ricker (1937b), in the only assessment of the vertical distribution of Cultus zooplankton, estimated their summer daylight range at 5 to 15 m, an area that includes the lower part of the epilimnion, the metalimnion and a narrow strip of the hypolimnion. Thus, water clarity is a key habitat attribute that allows sockeye to avoid the unfavourable summer conditions in the epilimnion.

The habitats used by juvenile sockeye are determined by their behavioral responses to key habitat attributes. These attributes are physical (*e.g.*, water temperature, lake stratification, water transparency), chemical (*e.g.*, oxygen) and biological (*e.g.*, plankton, competitors, predators; Foerster 1968). Fry reside in cool, deep waters (probably near the bottom) during the day and migrate upward at dusk when the light diminishes enough to reduce their detection by visually feeding predators. They actively feed in the upper part of the lake, including the epilimnion when temperatures are favourable, when light levels are sufficient for them to detect their prey. During the spring, summer and fall, they form a nighttime layer 5 to 10 m deep just below the epilimnion (Schubert *et al.* 2002). When stratification breaks down in the winter, they are found at all depths at night. When dawn approaches, they again feed in the upper water column before descending to the bottom for the day. Such pronounced vertical migrations are often used by fish to maximize feeding opportunities, avoid predators, and reduce metabolic costs (Bevelhimer and Adams 1993). Cultus sockeye fry face very little competition for food from other species; freshwater survival and growth rates are adequate at all densities observed to date (Ricker 1937b; J. Hume 2004, pers. comm.). Thus, adequate food, while a key habitat attribute, does not appear to limit sockeye fry populations in Cultus Lake.

The predator community is another key habitat attribute of Cultus Lake. Predation is the most important source of mortality in the lake and occurs all year. Prickly sculpins eat sockeye fry before and during emergence; Dolly Varden char, trout and salmon eat them in the spring and summer; pikeminnow join the list of predators in the fall and winter and during the smolt migration in the spring (Mossop *et al.* 2004). Despite such mortalities, the current ability of the lake to produce sockeye smolts is generally good, although sockeye production would be higher if the predator populations were reduced. While the lake appears to retain its ability to support the offspring of up to 80,000 adult sockeye, predation on small populations (such as now exist) may limit the ability of the population to recover – a special worry given the apparent doubling of the pikeminnow population since the 1930s which may in part result from improved habitats provided by Eurasian watermilfoil. Thus, the predator community is a key habitat attribute that may limit recovery.

The Recovery Team proposes the lake pelagic zone (*i.e.*, open water areas where light does not penetrate to the bottom) as *critical habitat* for Cultus sockeye. The thermal structure of the lake in relation to the fry's food supply results in a precarious balance that allows the young fish to avoid lethal water temperatures while retaining access to food. Activities that could destroy this habitat are those that influence water clarity (like increased turbidity from land and water use and increased phosphorus loading from fertilizer runoff) or sewage effluent that could produce undesirable phytoplankton blooms. Further study is required to understand and mitigate predation impacts at small population sizes.

Habitat trends

Since the 1970s, the clearest trend in freshwater habitat is the spread of Eurasian watermilfoil. The plant propagates rapidly by fragmentation, and there are now so few spawners that the substrate cannot be kept clear by the fish themselves. Newly observed spawning below the limit of watermilfoil growth may be a response to the overgrowth of previously preferred spawning areas. With the number of spawners so low, however, it is unlikely that spawning area is limiting, although there clearly need to be sufficient spawning sites for the increased numbers of adults expected from the actions outlined in this Recovery Strategy.

Other habitat trends include water quality impacts from the expanding summer boating community, and increasing water withdrawal from the Columbia Valley aquifer.

Habitat protection

The fact that most of the riparian zone is already parkland is a mixed blessing for Cultus sockeye. On the plus side, much of the park riparian zone is still natural, certain kinds of development are already prohibited and there already exists a park administration for communicating with visitors. On the negative side, parks – especially those as close to major urban populations as Cultus Lake – attract visitors at just the time of year when a precarious adult sockeye population needs undisturbed access to high quality migration corridors and spawning habitats, and when spills of oil and gas are most likely.

We have identified three habitats that must be protected to ensure the viability and recovery of the population: the key spawning areas and the aquifers that feed them; the migratory corridor of

Sweltzer Creek; and the lake's highly productive pelagic zone. In addition to protection, there are several kinds of restoration that could ensure quality habitat remains available for the recovering population: removing watermilfoil (Newroth 1993); creating new spawning areas or rehabilitating existing ones (M. Foy 2004, pers. comm.); and improving the creek channel to facilitate migration.

The protection and restoration of habitats will benefit from raising awareness among people who can affect the lake, its riparian zone and associated streams. Awareness is a prerequisite to motivating stakeholders to reduce habitat impacts. People who would be receptive include farmers, recreational boaters and swimmers, cottage owners and Soowahlie Band members. Possible tools include signs, brochures, media coverage, meetings with community leaders and park managers and increased enforcement of the *Fisheries Act*.

Ecological Role

It is well documented that salmon carcasses can be an important food source and a substantial contributor of nutrients to freshwater and terrestrial ecosystems (Naiman *et al.* 2002). Since over 95% of a salmon's adult weight comes from the ocean, its life cycle is a mechanism for the upstream transport of marine nutrients such as phosphorus (9 g/adult) and nitrogen (65 g/adult). Thus, the decomposition of carcasses is an important source of both food and nutrients and can make up a significant proportion of the annual nutrient load in a lake (Schmidt *et al.* 1998). Because Cultus sockeye are lake spawners, these nutrients are probably directly available to the lake phytoplankton and less available to the terrestrial ecosystem than would be the case for a population that spawns primarily in streams. The nutrients can increase the productivity of microscopic plants and animals growing on underwater surfaces (Shortreed *et al.* 1984), with subsequent benefits to invertebrates and ultimately to fish. Many of the bird and animal species of Cultus Lake are known to feed on salmon carcasses or eggs (*e.g.*, eagle, gull, waterfowl, Steller's jay, raccoon, mink and otter); 17 fish species other than sockeye occur in Cultus Lake, and in other lakes or streams a number of these feed on carcasses or eggs. In addition, when sockeye spawners are abundant there are more juveniles available as food for predators. Although the effect of the decline of the sockeye population on other components of the ecosystem will be difficult to quantify, for most species a decline in the food supply usually results in a reduced population size.

The direct contribution of Cultus sockeye spawners to the lake ecosystem has never been studied, although their possible importance has long been acknowledged (Ricker 1937b). Nutrient models (Vollenweider 1976) show that the amount of phosphorus available to phytoplankton in Cultus Lake would increase by about 5% for each 10,000 sockeye spawners. The highest recorded spawner population (73,000) would thus have increased the phosphorus levels by one-third, suggesting that detectable increases in productivity of the lake's limnetic zone would happen only with higher escapements.

Cultus sockeye are presently a candidate indicator species for ecosystem monitoring (Fraser Basin Council 2002), and the Chilliwack watershed will be part of a pilot federal-provincial project to develop a watershed fish sustainability plan (M. Johnson 2004, pers. comm.).

Importance to People

Cultus sockeye are harvested in commercial, recreational and First Nations fisheries along the south coast of B.C. and in the lower Fraser River. These fisheries have substantial economic importance. While Cultus sockeye are a minor component of these fisheries, their harvest contributes to and makes possible the much larger harvests of the other salmon stocks.

The population is particularly important to the Soowahlie Band of the Sto:lo First Nation. Historic colonization of the area by First Nations was strongly influenced by sockeye in the lake and Sweltzer Creek. Cultus sockeye is prominent in Soowahlie cultural expression and its recovery is a high priority with the Band. The population also has great importance for other Sto:lo nations.

The extraordinarily long-running role of Cultus sockeye as a subject for scientific study means that the population has special significance for naturalists and for the scientific community as a whole. There has been considerable basic research using the population as a model to understand the general biology and ecology of sockeye. There are few populations of any animal that have been monitored as long as Cultus sockeye and the data currently being collected, especially at such a perilous time for the population, are invaluable for the understanding of extinction and recovery processes in general.

Finally, people in British Columbia place high value on healthy habitats with viable salmon populations, and many community groups have worked for years to restore habitat and promote conservation of salmon biodiversity. For these people, the prospects for Cultus sockeye are of great interest.

Knowledge Gaps

Despite intensive study of Cultus sockeye over many decades there are still significant knowledge gaps that affect its potential for recovery. The main ones are listed below, with an indication of how filling them will affect recovery.

Early migration

Reasons for the early upstream migration of late run sockeye are not known and there is only limited understanding of how early migration relates to high pre-spawning mortality (PSM) for the Cultus population. The roles of parasites and disease (*e.g., Parvicapsula*) in causing high mortality need to be investigated, as do the effects of early migration on the fitness of subsequent generations. An understanding of the causes of early migration and the ability to predict the severity of PSM are critical to the development of the fishing plans and in-season management tools required to recover the population.

Timing and productivity

Our understanding of the productivity of Cultus sockeye is based on the assumption that they are exploited at the same rate as other late run populations. This implies that they return from the North Pacific Ocean to the Strait of Georgia and into the Fraser River at the same time and pass through the fisheries in the same pattern. There is evidence to suggest that this assumption may be incorrect: a fin–clip study in the 1930s shows that Cultus sockeye may actually return from the North Pacific a week or two later and over a longer period than other late run populations, and assessments at Mission and Sweltzer Creek similarly show a later (by one month) and more protracted migration of Cultus sockeye into the river. These assessments may mean that Cultus sockeye have a later and broader marine migration pattern and that they delay for several weeks in the estuary or the lower Fraser River. If this is true, then historic catch estimates are wrong. For example, fisheries that would catch the earlier-migrating late run populations might be closed before most of the Cultus fish arrive.

This is a significant knowledge gap that affects our understanding of the population's susceptibility to fisheries in different areas and at different times and directly affects our understanding of its productivity. What we know about productivity is important for planning fisheries on co-migrating summer and late run populations and is central to our assumptions of how such fisheries affect recovery. For the recovery strategy to be effective, adult migratory timing needs to be investigated using modelling, improved stock discrimination techniques and the use of acoustic tags that are applied to smolts but activate on the return spawning migration.

Habitat requirements and impacts

When it comes to understanding the threats to the population, the weakest links may be our knowledge of habitat capacity and the impacts of habitat change. The overall importance of such impacts is difficult to assess because there are significant knowledge gaps about how habitat is used by various life stages of Cultus sockeye. Measures for protecting habitat will be much better designed and justified if they are based on solid data. Some of the more important knowledge gaps related to habitat are:

- *Amount and distribution of spawning habitat:* Although spawning areas are generally known, their extent is not well documented and other important areas may have gone undetected. Quantifying and mapping habitats based on characteristics such as appropriate substrate and the presence of circulating lake and subsurface water will improve our understanding of spawning capacity and help us protect critical habitat;
- *Spawning habitat utilization:* We require information on the amount of spawning habitat required by a single spawning pair. This will allow us to quantify the amount of spawning habitat that is critical to a recovered population;
- *Eurasian watermilfoil distribution:* There is a need to map the watermilfoil distribution in the lake. This will improve our understanding of its potential impact on spawning distributions and fry survival and allow us to develop actions to mitigate the threat;
- *Recreational boating:* Cultus is a small lake with a very large recreational boating community; its habitat may be the most affected of any lake in B.C. The ecosystem role of hydrocarbons and metals from recreational boating needs to be evaluated to determine if they pose a threat to the population;
- *Columbia Valley Aquifer:* There is anecdotal evidence that the apparent redistribution of spawners away from Lindell Beach may be associated with a reduction or loss of groundwater percolation on parts of the beach. Because we believe that groundwater plays an important role in the successful incubation of eggs, we need an improved understanding of the Columbia Valley aquifer. Specifically, we need to know the impact of precipitation patterns, water

extraction and habitat development on the Columbia Valley aquifer, and we need better knowledge about how the aquifer supports spawning habitats. There is also a need to identify other aquifers that may be important to the population. Installation of an observation well and mapping of groundwater extrusion into the lake will provide the information necessary to identify, protect and improve critical spawning habitat;

- *Migratory corridor:* There is uncertainty about adult migration behaviour throughout the freshwater corridor and the distribution of adults in the lake before spawning. We need to know more about those habitats in the mainstem Fraser adjacent to the Sumas/Fraser confluence, and in the Vedder and Chilliwack rivers and Sweltzer Creek. Activities along the migratory route, especially in the Sumas and Vedder-Chilliwack rivers and Sweltzer Creek, need to be evaluated to control those that may delay migration to the lake or expose the population to predation by marine mammals or poaching. The behaviour of adults after they enter the lake needs to be evaluated to determine whether they are vulnerable to any threats;
- *Land use patterns:* We need to know more about the impact of current land uses, and there is a need to model potential land uses and their impacts to protect critical habitat in the system;
- *Lake production dynamics and carrying capacity:* Lake productivity is an important component of the population's productive capacity. While known in a general sense through evaluations of photosynthetic rate, further assessment of the affects of competition, habitat limitation and predation, especially at current low spawner populations, is required. Such studies could also investigate the linkages between sockeye and other species in the freshwater ecosystem. An improved understand of lake productivity would help to qualify the role of depensation as a threat to recovery and to set long term population abundance targets.

Predators and parasites

The relationship between sockeye fry and pikeminnow and the role of watermilfoil in providing pikeminnow refuge need to be better understood. We need to document the current distribution and abundance of predators and watermilfoil to enable us to develop long term, effective removal and assessment processes (see *Actions Already Completed or Under Way*) that will promote recovery by improving freshwater survival.

The impact of poaching and predation by marine mammals along the migratory corridor is unknown. An improved understanding would help guide recovery actions.

The impact of the copepod *Salmincola californiensis* on freshwater and marine survival is also unknown. A better understanding of the latter is important because the treatment of smolts is a potential recovery action.

Genetic trends

Trends in the population's genetic structure should be monitored continuously by sampling returning adults. Evaluations of fitness would benefit from comprehensive sampling, coordination with the hatchery program, and analysis of parentage and grand-parentage. The empirical effects of captive breeding have been little documented and an evaluation of this project could also benefit from DNA sampling and comparison with the wild population. This information will improve our assessment of population viability and our understanding of recovery processes in general.

Marine distribution

The survival and distribution of Cultus sockeye in the Fraser River and near-shore marine areas have not been documented, nor has the distribution of the population in the North Pacific Ocean.

BIOLOGICAL AND TECHNICAL FEASIBILITY OF RECOVERY

The recovery of the Cultus sockeye population is biologically and technically feasible. Given its current status and the combined effects of low productivity, periodic declines in survival, high PSM and capture in the fishery, recovery will involve many sectors including government agencies, First Nations, researchers, managers, harvesters, NGOs and the public. It will involve a combination of actions to address threats to Cultus sockeye, including a significant building of awareness of the biological, social and cultural issues affecting the population.

Biological feasibility

The biological feasibility of recovery depends on the intrinsic ability of the population to remain viable. For Cultus sockeye, this essentially means its ability to increase and depends on its reproductive capability and society's ability and willingness to control or mitigate threats. Luckily, sockeye salmon have high biotic potential (high survival resulting in more adult offspring than in the parent generation), are relatively short lived (they mature, spawn and die at age 4 or 5), and are resilient to natural or human-induced pressures. However, Cultus sockeye is less productive than other Fraser River sockeye populations and has been intercepted in mixed-stock fisheries at greater than sustainable levels.

The Recovery Team assessed the biological feasibility of recovery of the Cultus population using a simulation model based on the historical stock-recruitment relationship. The model determines the minimum viable population (MVP) given a continued pattern of recent PSM and minimal harvest levels. Populations smaller than the MVP will have a significant risk of extinction even in the absence of human-caused mortality. The model makes several assumptions[2] and includes random variation in survival. It does not attempt to capture the dynamics of, or genetic effects associated with, very small population sizes.

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[2] *Extinction* (technically termed "pseudo-extinction") is defined as four consecutive years with <100 successful spawners, a number chosen because population dynamics are unknown at small abundances. *MVP* is defined as the initial number of adult spawners that keeps the extinction probability below 5% over 100 years with minimal exploitation and prescribed PSM. ERs up to 15% are considered because it may be impractical to prevent all fishing-related mortality (*e.g.*, international treaty obligations, by-catch and test fisheries that occur over a wide geographic area and time period). *PSM* is stipulated because it is not controllable; a pessimistic scenario is that the 1995-2003 PSMs will persist. All other threats are assumed to be either controllable (*e.g.*, Eurasian water milfoil) or subsumed in the historic stock-recruitment profile (*e.g.*, pollution). The reliability of the MVP estimates depends on the assumption that stock recruitment estimated from historical 1948-1997 data can be applied to future spawning stocks. For example, climate change or recent changes in the stock-recruit function (*i.e.*, ecological or genetic changes affecting productivity or carrying capacity) have not been considered.

The MVP estimate produced by this model was 250 successful adult spawners in any given year. The fact that this figure is below the current average per generation suggests that recovery is feasible. Moreover, because the estimate includes measurement error of catch assigned to Cultus and assumes pessimistic PSM values, populations smaller than 250 successful spawners in any year may still be viable. The possibility for genetic damage at these low abundances, however, was not modeled. Also, we noted simulation periods where single, double and triple cycle lines fell below 100 spawners. This suggests that minimum acceptable spawning levels should also be set for individual cycle lines, not just for each generation.

Technical feasibility

The technical feasibility of recovery reflects the availability of appropriate tools and the willingness of responsible organizations and jurisdictions to use them. Human-induced threats can be mitigated by government or stakeholder actions. For example, fishing can be modified or minimized through gear modifications, time and area closures, selective techniques and other actions. Recreational activities that affect adults in freshwater (*e.g.*, during their migration through Sweltzer Creek or in Cultus Lake itself) can also be modified.

While some natural impacts such as poor marine survival due to climatic variations cannot be mitigated directly, there are technical tools for reducing some of the natural threats to the Cultus population. For example, recovery actions to improve freshwater survival by removing Eurasian watermilfoil, controlling predators or identifying potential contamination are technically feasible. Hatchery technologies for captive breeding are also available.

Recommended Scale for Recovery

We recommend a single species recovery strategy for Cultus sockeye. This recommendation is based on the unique set of physical, biological and social circumstances surrounding the population. While there is currently one other B.C. sockeye population listed by COSEWIC as endangered (Sakinaw), the threats to the two populations are sufficiently different to warrant dedicated recovery strategies for each. A multi-population recovery strategy has, however, been adopted for a constellation of Interior Fraser coho salmon populations where genetics, geography and environment are more homogeneous.

Recovery of an endangered species or population depends greatly on the contributions of various sectors of society, which have a synergistic effect. Fortunately, the scale of recovery of Cultus sockeye can be broadened through cooperation. First, the importance of the salmon to First Nations means there should be close cooperation with the Soowahlie Band and the Sto:lo Nation on all recovery activities. Second, administrative systems for the Provincial and Cultus Lake parks offer many opportunities for outreach, awareness and enforcement. Close contact with the Cultus Lake Park Board will need to be maintained. Third, management plans developed by DFO and the Fraser River Panel of the Pacific Salmon Commission represent the formal reflection of any recovery actions related to harvest; the population itself represents something of a test case of the principles of *SARA* and DFO's draft Wild Salmon Policy. Finally, involvement of the general public by way of stewardship groups that contribute to recovery planning or take on some of the recovery activities will ensure that anyone passionate about Cultus sockeye will have the opportunity to contribute.

Recovery efforts for Cultus sockeye will need to be coordinated with any developed for the endemic pygmy sculpin (*Cottus sp.*), presently listed by COSEWIC as *Threatened* and by the Province of B.C. as *Critically Imperiled* (Cannings *et al.* 1994). Watermilfoil removal will need to be coordinated with any provincial government policy on the control of this species.

RECOVERY

The listing of species by COSEWIC reflects several kinds of information, including quantitative criteria developed by the International Union for the Conservation of Nature (IUCN; www.cosewic.gc.ca). Most relevant to Cultus sockeye are IUCN Criterion A (declining total population), Criterion C (small total population size and decline) and Criterion D (very small population or restricted distribution).

The science of conservation biology is intimately concerned with the concept of the minimum viable population (MVP). Behaviour, reproductive biology and population genetics affect what this number will be, and there is a large literature on factors that need to be considered in determining MVPs for salmon. Above all, small populations face unique risks. For example, the following processes present little risk to large populations but pose much more of a problem for small populations like Cultus sockeye:

- **Immediate threats** such as *density effects* (*e.g.,* depensation – a decline in productivity that accelerates the population's decline, difficulty in finding a mate when there are few animals around, or increased effectiveness of predators as the prey population declines) and *random environmental variation* (*e.g.,* changes in ocean conditions or catastrophes like landslides); and
- **Longer term threats** such as *genetic processes* (*e.g.,* inbreeding depression and loss of variability), *random demographic effects* (*e.g.,* a large imbalance in the sex ratio, or there being few survivors in a particular year even though environmental conditions are unchanged) and *ecological feedback* (*e.g.*, important ecological functions like lake fertilization through carcass decomposition).

All of these processes must be taken into account when modeling the MVP for Cultus sockeye; if they are not, extinction risk will be underestimated. MVPs chosen for other species or in other jurisdictions provide useful comparisons:

- The number of Snake River chinook spawners required to avoid **random environmental variation** was estimated to be between 1,000 and 5,500 per generation (250-1,375 per year; NMFS 1995);
- Extinction risk from **random demographic events** increases exponentially as populations decline and should be considered a risk factor for any population of only a few hundred individuals (Goodman 1987);
- **Genetic effects** are dealt with by the concept of *effective population size*, which is usually smaller than the observed number of breeders (Frankham 1995). Allendorf *et al.* (1997) used genetic evidence to conclude that salmon populations with fewer than 2,500 spawners per generation would be at high risk where the effective population size is 20% of the number of breeders, a common assumption for Pacific salmon. The Washington Department of Fish and Wildlife (1997) recommended a minimum spawning size of 3,000 per generation.

Recovery Goal

Our goal is to halt the decline of the Cultus sockeye population and to return it to the status of a viable, self-sustaining and genetically robust wild population that will contribute to its ecosystems and have the potential to support sustainable use.

Recovery Objectives

We identify four objectives that are sequential steps toward the recovery of the population. Objective 1 secures genetic variability, Objective 2 ensures the population is growing, and Objective 3 achieves delisting by COSEWIC – the change in designation from *Endangered* to *Not at Risk*.

Once the population is delisted, conservation objectives should be consistent with (*i.e.,* not less than) those specified for other sockeye populations. We make the assumption that conservation benchmarks will be defined in DFO's Wild Salmon Policy. Objective 4 proposes candidate benchmarks that have been discussed in consultations on the draft Wild Salmon Policy and correspond to our current understanding of the dynamics of Cultus sockeye.

Progress toward achieving all four objectives will be assessed annually by engaging local communities through workshops, websites and other media, and recommending further studies required to address knowledge gaps.

Objective 1. Ensure the genetic integrity of the population by exceeding a four-year arithmetic mean of 1,000 successful adult spawners with no fewer than 500 successful adult spawners on any one cycle.

Notes: A *successful spawner* is one that fertilizes eggs (male) or deposits eggs (female). The number of successful spawners is based on fence counts and carcass recoveries from spawning ground surveys in the lake. Because success among males cannot readily be determined from the carcasses, the estimate of female success is applied to the entire population.

The genetic consequences of small populations include the random loss of genetic and phenotypic variation and the loss of evolutionary potential associated with a reduction in genetic diversity (Allendorf and Ryman 2002). To avoid negative genetic impacts, population abundance must be maintained above the *minimum* genetically effective population size of 1,000 per generation. Applying conventional assumptions (Waples 2002) to the life history of Cultus sockeye, this implies that the average annual spawning abundance should exceed 1,000 fish, with no fewer than 500 spawners in any one year.

How do the adults produced by captive breeding figure in this total? The number of successful Cultus sockeye spawners in any given year is deemed to include all naturally spawning sockeye, including the progeny of captive broodstock that have survived in the wild since their release as juveniles. However, adults collected as broodstock for artificial propagation will not be included in the estimate of successful spawners produced for that year.

Although the target levels in Objective 1 eliminate genetic risk to the population (preserve genetic resources) and are adequate to avert listing under IUCN Criterion D, they are not adequate to avert listing under criteria A or C unless population abundance is increasing. Delisting should be assured by meeting the following objective (Objective 2).

Objective 2. Ensure growth of the successful adult spawner population for each generation (that is, across four years relative to the previous four years), and on each cycle (relative to its brood year) for not less than three out of four consecutive years.

Notes: The time series of spawner abundance information shows that generation size rarely increases unless there is cycle over cycle growth (*e.g.,* 1994 is bigger than 1990) on at least three of the four cycles. Historical records from 1930 to 2003 show a generation growth rate of 54% when growth occurred in three out of four years. Given the uncertainties in forecasts and in-season processes, managers should target growth on *all* cycles during the recovery phase to increase their likelihood of achieving positive generation-over-generation growth. If one or more of the previous three years declines, more stringent measures will be required to ensure positive growth in the current year. A numeric target for population size and a time frame for achieving it would permit recovery implementation groups to establish growth rate targets for the population.

Objective 3. Recover the population to the level of abundance at which it can be delisted (*i.e.*, designated *Not at Risk*) by COSEWIC.

Notes: COSEWIC uses the quantitative IUCN criteria as guidelines to assess the status of wildlife species in Canada. Because the IUCN criteria are not always appropriate for regional (*versus* global) application, COSEWIC also considers other biological characteristics and threats when designating species status. We acknowledge that such assessments and designations are COSEWIC's mandate. Here we provide advice for future COSEWIC reassessments in the context of the recovery goal for Cultus sockeye. For this population to be recovered, the following questions will have affirmative answers:

- *Have objectives 1 and 2 been achieved?* A recovered population must exceed the minimum abundances identified in Objective 1 and must have shown the growth in successive generations identified in Objective 2.

- *Have the causes of the decline identified by COSEWIC been addressed?* The COSEWIC status report identifies three principal causes: *over-exploitation in fisheries, recruitment failure* and *high pre-spawn mortality.* Regulatory agencies must develop short and long term management plans that include harvest rules and escapement policies for the sustainable use of Cultus sockeye. These plans must be consistent with the Team's goal and objectives and explicitly address uncertainties in population dynamics and management imprecision while protecting the population from unanticipated catastrophic PSM. The population must be able to withstand at least one cycle of poor environmental conditions without declining to a generation average of less than 1,000 successful spawners and 500 successful spawners on any cycle. This means managers must deliver a big enough escapement to the counting fence to achieve these population sizes on the spawning grounds. To do so, they must consider forecasting and in-season run size errors as well as uncertainty about PSM. For example, Objective 1 could be achieved despite 93% PSM (the most extreme ever observed) provided the management plan delivered an escapement of no fewer than 7,100 adults to the fence.

- *Is freshwater productivity adequate to support recovery?* Analysis of historical data provides some evidence that, when spawner abundance is less than about 7,000 fish, freshwater productivity is lower (20-30 smolts/spawner) than in years of higher abundances (>60 smolts/spawner; see *Biological Limiting Factors*). The low productivity at current abundances will limit the population's potential for recovery or sustainable use. An increase in productivity as the population recovers is, therefore, an important indicator of recovery.

- *Have emergency mitigative measures been relaxed?* A recovered wild population would safely allow stopping supplementation and thereby eliminate it as a source of genetic risk. A recovered population in its natural ecosystem would not require ongoing predator control measures. We note, however, that the productivity of predator populations may have increased as a result of the invasion of Eurasian watermilfoil. Consequently, plant or predator removal may need to continue.

Objective 4 (long term objective)**.** Recover the population to a level of abundance (beyond that of Objective 3) that will support ecosystem function and sustainable use.

Notes: This objective addresses ecosystem and sustainable use goals. Choosing an appropriate level of abundance requires the weighing of scientific advice in the context of broad policy objectives for salmon management which often must consider conflicting societal values. This target level of abundance must reflect the unique characteristics of the Cultus population and its ecosystems, *i.e.*, represent some reasonable proportion of the population's productive capacity. Setting the target level of abundance is beyond the Team's mandate and should be addressed by government policy-makers in consultation with the stakeholders. It is expected that the DFO's Wild Salmon Policy, to be released in 2005, will provide an appropriate framework.

The choice of a long-term target level of abundance must be based on our current understanding of the production dynamics of the Cultus population. Potential reference points include the following benchmarks, all of which are described in detail in Annex 2:

- The abundance providing maximum sustainable yield (S_{MSY}) or some proportion of S_{MSY};
- Some proportion of the productive capacity of the lake;
- Historic abundance; and
- The abundance at which ecosystem function is maintained.

Approaches to Meeting Recovery Objectives

Table 2. Summary of approaches to the recovery of the Cultus sockeye population.

Objec -tive #	Approach	Threat	Anticipated Effect	Status
1.	a. Captive brood stock program for 2000-2007 brood years.	Mul-tiple	Increased successful spawners, reduced threat of extinction.	Under-way
	b. Control harvest to achieve 1,000/500 objective.	5a	Increased successful spawners, reduced threat of extinction and of detrimental genetic effects.	Proposed

	c. Improve freshwater survival of 2004 and 2005 broods by removing watermilfoil.	2b, 6a	Reduced pikeminnow recruitment, decreased predation, increased number of sockeye smolts, increased spawning habitat.	Under-way
	d. Improve freshwater survival of 2004 and 2005 broods by removing predators.	2a, 3c	Reduced predator populations, increased number of sockeye smolts.	Under-way
	e. Identify the causes of the early migration phenomenon.	1c, 5b	Increased number of successful spawners.	Under-way
	f. Focused enforcement where the population is most at risk.	5f	Increased number of successful spawners.	Proposed
	g. Identify imminent risks from habitat destruction, pollution affecting each life stage.	Mult-iple	Improved survival at all life stages.	Proposed
	h. Maintain assessments of fry, smolt and adult populations.	Mult-iple	Maintain ability to assess threats and recovery progress.	Under-way
	i. Eliminate activities that cause migratory delay in Sweltzer Cr.	5c, 5d	Increased successful spawners.	Proposed
	j. Identify and eliminate risk from marine mammal predation.	5g	Increased number of adults through Sweltzer fence.	Proposed
2.	a. Lake stocking using fry, smolts surplus to the captive brood stock program during the period 2003 to 2009.	Mult-iple	Increased number of smolts, increased successful spawner populations, reduced genetic risk.	Under-way
	b. Control fishery harvest to levels that permit generational growth.	5a	Increasing successful spawner populations.	Under-way
	c. Develop an integrated water-milfoil, predator control project.	5b, 6a, 2a, 3c	Maintain larger fry, smolt populat-ions established by 1c and 1d.	Proposed
	d. Focused enforcement to reduce the threat of poaching.	5f	Increased number of successful spawners.	Proposed
	e. Mitigate effects on habitat.	Mult-iple	Improved survival at all life stages.	Proposed
	f. Determine the effects of *Salmincola* on marine survival.	2c, 3e	Increase marine survival, increased number of successful spawners.	Proposed
3.	a. Develop sustainable harvest rules and escapement policies that are consistent with Team goals and objectives and explicitly address uncertainties	5a	Maintain a viable, self-sustaining and genetically robust population over the long term.	Under-way
	b. Evaluate freshwater productivity during recovery.	1a, 1d 2d, 2e	Improved understanding of threat to recovery posed by depensatory mortality, predator pit and habitat alteration.	Under-way
4.	a. Identify the adult migration timing of Cultus relative to other Fraser Late Run sockeye.	n/a	Improved understanding of the stock-recruitment relationship may change approaches to recovery.	Proposed
	b. Identify the role and contribution of sockeye to the Cultus Lake ecosystem.	n/a	Improved long term population goal.	Proposed

0	a. Promote stewardship and improve public awareness.	n/a	Increased awareness of population status, and improved stewardship initiatives.	Under-way

Control of exploitation

Controlling exploitation means developing short and long term harvest management plans that specify sustainable harvest rules and escapement policies for Cultus sockeye. These rules and policies must be consistent with the Team's goal and objectives and explicitly address uncertainties in population dynamics as well as management imprecision. For Objective 1 *(Approach 1b)*, this means implementing extreme conservation measures if forecasts of returning adults are below 500. For Objective 2 *(Approach 2b)*, managers have greater latitude based on pre-season abundance forecasts and anticipated PSM levels. Objective 3 *(Approach 3a)* requires an explicit statement of the short term plans described above in conjunction with explicit long term plans that fully address the Team's goal in the context of DFO's policy objectives.

Maximizing freshwater survival

The control of predators (*Approach 1d*), including reduction of Eurasian watermilfoil (*Approach 1c*), could provide the increase in fry and smolt survival that is crucial small juvenile populations such as those likely to result from the 2004 and 2005 brood years. Mossop *et al.* (2004) reviewed pikeminnow control projects from 1935-42 and in the 1990s (Hall 1992). They concluded that predator removal may be most effective if it targets specific areas and appropriate times, such as on the spawning grounds at the time of emergence and in the lake near Sweltzer Creek during the smolt migration. The latter may be most feasible and have the greatest benefit. They also recommend investigating pikeminnow predation during periods of low sockeye abundance and the impact of other predators, although they note that the removal of salmonid predators may no longer be socially acceptable. Key knowledge gaps that need to be filled to optimize predator control have already been discussed (see *Knowledge Gaps*).

Because freshwater productivity is key to the recovery of the Cultus population, further research is needed in areas that range from understanding how depensation *(Approach 3b)* and habitat degradation *(Approaches 1g, 2e)* contribute to current low smolt production rates to ongoing assessment of adult abundance, pre-spawn mortality and smolt abundance *(Approach 1h)*. Details of these and other knowledge gaps related to population dynamics and utilization of freshwater habitat have already been provided (see *Knowledge Gaps*).

A demographic modelling approach will help identify and quantify critical habitat. Such models are useful because they articulate the relationships between the population and its habitats, and Cultus is particularly suitable because of its long time series of assessment data that describe survival rates at different life stages.

Other approaches to recovery that are identified in *Knowledge Gaps* include the causes of early entry of adults into freshwater *(Approach 1e)*, the evaluation of activities along the migratory corridor that may delay the migration to the lake *(Approach 1i)*, and the control of predation by marine mammals *(Approach 1j)* and poaching *(Approaches 1f, 2d)*.

Maintaining assessments over the long term

The time series of assessment data for Cultus sockeye adults, fry and smolts is among the longest in existence for any Pacific salmon population. Keeping these assessments going will be essential for monitoring recovery of this population *(Approach 1h)*.

Fish culture

Technical methods used for salmon recovery include habitat restoration, which provides habitat where fish can spawn and rear naturally, and techniques that involve greater human intervention in the actual acts of spawning and rearing. For Cultus sockeye, an example of habitat restoration is the removal of watermilfoil from spawning beaches. An example of the second, more intensive kind of intervention is fish culture.

Fish culture methods include *conventional supplementation* and *captive breeding*; the key difference lies in the length of time in captivity. Conventional supplementation (*Approach 1b*) uses hatcheries to incubate fertilized eggs taken from returning adults, after which juveniles are released to the wild as fry or smolts. The fish then grow and mature in the ocean and return to spawn in natural habitats in the system from which they originated, thus integrating with and contributing to the recovery or maintenance of the wild population. Key practices such as the use of native spawners, prescribed spawner collection methods and spawning practices, and evaluation of subsequent survival help to maintain the genetic characteristics of the parent wild population.

A captive breeding project (*Approach* 1a) is a more intensive method that rears captured wild juveniles or the progeny of hatchery-spawned parents in captivity, all the way to their own maturation and spawning. *Their* progeny are then released to the wild. The main feature of this method is the enormous increase in egg-to-adult survival (more than a thousand-fold), thereby permitting the rapid recovery of the population. Such projects are usually regarded as methods of last resort, an experimental approach to be used only as part of an integrated recovery plan in situations where the natural population is at risk of extirpation. Although specific concerns have been expressed about the potential genetic and environmental drawbacks of captive breeding, including the risk of domestication selection (Allendorf and Ryman 1987; Waples 1999), most of these can be alleviated by carefully designed mating strategies (Hard *et al.* 1992). In the case of Cultus sockeye, genetic concerns about a small founder population (potential inbreeding depression leading to loss of genetic diversity) are alleviated by using a breeding plan that actually increases genetic diversity. The increased survival inherent in captive brood programs also decreases the potential loss of genetic diversity in hatchery fish compared to wild fish.

Emerging DFO policies for the use of captive breeding include limiting the technology to the recovery of endangered populations, the use of mating strategies that minimize the potential loss of genetic variability in captivity and the use of the technology for no longer than is necessary to fulfill stated recovery goals (C. Cross 2004, pers. comm.). The following guidelines apply to Cultus sockeye:

- The objective is to produce 500 breeding adults each year for two consecutive cycles (eight years), followed by a full review of the program in 2007;
- Only wild spawners will be used, and those fish will not be counted as part of the naturally breeding population when evaluating progress toward recovery;

- When adults produced from the captive spawners are themselves spawned in captivity, they will not be counted as part of the natural breeding population when evaluating recovery. Their progeny that are released into the wild and return to spawn naturally, however, *will* be included;
- All fish produced in the program and released to the wild will be marked with an adipose fin clip. An awareness program will be mounted to ensure that anglers understand the difference between a marked sockeye (which must be released) and a marked coho (which can be retained).

There are operational risks associated with hatcheries, including the possibility of mechanical failure and disease. Preventive measures include culturing Cultus sockeye at two facilities (Inch Creek and Rosewall Creek), redundant water deliver systems, emergency response readiness (standby staff), site security and operational protocols that minimize disease outbreaks. Furthermore, hatchery managers are authorized to acquire eggs in excess of those required to produce 500 spawners under average survival conditions. Any production above the needs of the captive breeding project is planted in the lake as fry or smolts to supplement the wild population. Thus, in the case of Cultus sockeye, supplementation and captive breeding work together.

Community awareness

The present status of the population means that good stewardship is vital. Residents, park visitors, farmers, businesses and resource industries in the watershed need to understand the fragile state of Cultus sockeye and be prepared to do their part in promoting recovery. Also, a special effort needs to be made to ensure that recreational anglers are aware of conservation issues that set Cultus sockeye apart from other species and stocks. Partners interested in raising awareness are needed to work with all stakeholders represented on the Recovery Team *(Approach 0a)*.

Potential Impacts of Recovery Strategy on Other Species

The impacts of recovery actions on other species and ecological processes need to be identified and prevented, particularly for the threatened Cultus pygmy sculpin. The pygmy sculpin is a small, relatively abundant fish (populations of 3,000-10,000). It lives in the deeper parts of the lake where it feeds on zooplankton and other fish and is preyed on by char (Coffie 1997). There are few known conflicts between pygmy sculpins and the recovery of Cultus sockeye: the selection of prey species appears sufficiently specialized to avoid direct competition; a recovered sockeye population may "swamp" char populations and reduce predation on the sculpins; and the focus of recovery activities along the shore means that most of them (*e.g.,* watermilfoil removal or predator control) will not affect the sculpins.

Actions Already Completed or Under Way

Population assessment

Population assessment focuses on the fry, smolt and adult life stages. Fry are assessed in the fall using hydroacoustic and mid-water trawl surveys to produce estimates of population size and, recently, fin clip incidence. These data are useful in evaluating survival bottlenecks in Cultus Lake.

Assessments at the counting fence in the spring provide data on numbers of wild and enhanced smolts as well as on smolt size and the incidence of parasites. This information is used to assess freshwater and marine survival, the success of enhancement strategies and predator removal experiments and possibly the impact of parasites if wild and enhanced smolts have different levels of infestation. Under extreme PSMs, smolt data can also serve as an alternate assessment of PSM.

Adults are assessed in the fall and winter at the counting fence, by spawning ground surveys conducted by foot or boat, and by underwater video. Sweltzer Creek is patrolled at least twice weekly to identify and eliminate sources of migratory delay. The assessment provides counts of wild and enhanced adults and jacks, spawner size, sex and spawning success and spawner distributions. The information is used to assess marine survival, enhancement strategies and PSM, and to forecast future abundance.

Agency: DFO

Fish Culture ***(Approaches 1a, 2a)***

The captive breeding and supplementation projects (see *Approaches to Meeting Recovery Objectives*) have been under way since 2000; progress is described in Annex 3 and is summarized in Table 3 below. A supplementary project has been the *ex situ* collection of cryopreserved sperm that began in 1995 and has continued as part of the captive breeding project. The collection provides an historic record of genetic variability in the 2003 cycle.

Table 3. Summary of enhancement results, captive breeding and supplementation projects.

Brood year:	2000	2001	2002	2003	2004	2005	2006	2007
Adults captured								
Male	n/r	n/r	89	105	-	-	-	-
Female	n/r	22	177	141	-	-	-	-
Adults spawned								
Male	10	11	70	100	-	-	-	-
Female	5	9	120	132	-	-	-	-
Eggs taken	13,385	24,458	438,100	464,038	-	-	-	-
Brood year +1								
Fry release [a]	0	3,715	227,029	32,740	-	-	-	-
Year-end balance	3,892	1,880	3,296	-	-	-	-	-
Brood year +2								
Smolt capture [b]	2,014	881	0	-	-	-	-	-
Smolt release [a]	3,891	3,166	2,135	-	-	-	-	-
Number mature	0	184	-	-	-	-	-	-
Eggs taken [c]	0	16,000	-	-	-	-	-	-
Year-end balance	1,070	1,564	-	-	-	-	-	-
Brood year +3								
Number mature	89	-	-	-	-	-	-	-
Eggs taken [c]	46,000	-	-	-	-	-	-	-
Year-end balance	928	-	-	-	-	-	-	-
Brood year +4								
Number mature	-	-	-	-	-	-	-	-
Eggs taken [c]	-	-	-	-	-	-	-	-

[a.] Supplementation.
[b] Captive brood augmented for genetic purposes.
[c] Captive breeding production.

Agency: DFO

Early migration/high mortality *(Approach 1e)*

Of the several competing hypotheses to explain early migration, two are presently being studied: a behavioural hypothesis that late run sockeye become caught up in numerically much larger summer run populations; and a physiological hypothesis that early entry into freshwater is related to unusual kidney and osmoregulatory function linked with low salinity plumes in coastal waters. The first hypothesis is being investigated through analysis of historic run size and timing data. The second is the focus of most of the work in 2004-05.

Most of the physiological research on the second hypothesis is through a multi-university, multi-agency research project funded through the Natural Sciences and Engineering Research Council of Canada. DFO is contributing personnel and facilities at their Cultus Lake and West Vancouver laboratories, and the Pacific Salmon Commission is providing staff, sockeye from test fisheries and vessel time. Previous studies suggest that high freshwater mortality is caused by *Parvicapsula*-induced osmoregulatory malfunction, and by high water temperature which hastens the depletion of energy reserves. Early-entering fish have poorer blood clotting ability, poorer swimming performance and higher *en route* mortality close to spawning grounds than do those entering at the normal time. Accumulated exposure to elevated temperature affects the severity of the *Parvicapsula* infection and mortality rates, and *Parvicapsula* may reduce the survival rates of fertilized eggs.

In 2004, researchers will investigate the reasons for the onset of early migration and its immediate and inter-generational consequences. They will examine migration behaviour and linkages with physiological state as well as the behavioural energetics of spawning and swimming performance in relation to disease and temperature.

Agencies: UBC/DFO/PSC

Assessment of littoral habitat *(Approaches 1c, 1g, 4b)*

A project is underway to identify, characterize and map spawning habitat, Eurasian watermilfoil distributions and groundwater sources. The project has three components:

- Dominant vegetation and substrates in the littoral zone will be mapped using a towed dive sled. This information will be used to identify potential spawning habitat and to develop a strategic watermilfoil control strategy for implementation later in the year;
- Water quality and groundwater assessments will be conducted in the fall and winter; and
- The results of acoustic surveys of the littoral zone will be compared to underwater visual survey results to identify a cost-effective strategy for the annual monitoring and removal of watermilfoil.

Agency: DFO, Cultus Lake Park Board, B.C. Parks, Lindell Beach Residents' Association.

Impact of pikeminnow predation *(Approaches 1d, 2c)*

A project is being carried out to improve our understanding of the predation threat and produce a strategy to combat it. The project has four components:

- The development of a predation model based on the literature review conducted in the spring of 2004 (Mossop *et al.* 2004) that will be used to develop a long term predator control strategy;
- An assessment of the abundance of northern pikeminnow in Cultus Lake. About 2,000 tagged fish have been released, and a second sample will be taken in spring 2005;
- A community-based pikeminnow derby in June 2004 that collected information on size and diet and reduced abundance; and
- A removal project in the spring and summer of 2005 that focuses on the sockeye smolt migration and pikeminnow spawning periods.

Agencies: DFO, Fraser Valley Salmon Society.

Marine survival ***(Approach 2f)***

The level of infection of *Salmincola* will continue to be recorded at two sampling points: during mid-water trawl assessments of fry abundance, and during the smolt emigration at the counting fence. The smolts retained for captive breeding are also treated orally and through the physical removal of parasites. Although stressful (it causes about 10% mortality), treatment is necessary for the production of healthy fish. Because of the observed level of mortality, there are no plans to similarly treat wild smolts until the parasite is proven to be a threat to marine survival.

In a more general assessment of in-river and early marine distributions and survival, acoustic tags applied to 50 smolts in the spring of 2004 are being tracked as they pass through detection arrays in the lower Fraser River and along the coast as part of the Pacific Ocean Shelf Tracking (POST) project (Welch *et al.* 2003).

Agency: DFO, Vancouver Aquarium Marine Science Centre

Control of exploitation ***(Approaches 1b, 2b, 3a)***

Pre-season management planning: None of the fisheries that incidentally intercept Cultus sockeye have been managed with the explicit object of controlling its ER. The population has benefited, however, from measures to conserve Fraser late run populations in general. Since 1998, management plans have focused on the harvest of summer run populations but have also responded to concerns about the early migration and high PSM of late run populations by taking measures to reduce ERs (Schubert *et al.* 2002).

In 1998-2000, while no specific guidelines were established for the harvest of late run sockeye, restrictions on fishing during August and September resulted in ERs of 19%, 13% and 44% respectively. In 2001-2003, specific guidelines were established to limit late run ERs to 17% in 2001 and 15% in 2002. In 2002, managers also excluded from the ER calculation any late run sockeye caught in the Fraser River before August 17. In 2003, fisheries were managed to an ER of 25% based on pre-season expectations of late run timing and abundance. On August 22, after the cessation of commercial fishing, the ER objective was reduced to 15% based on in-season revisions to estimates of abundance, migration timing and *en route* mortality. The application of these guidelines in 2003 resulted in the closure of all commercial sockeye fisheries in mid-August and in sockeye non-retention fisheries directed at pink salmon in late August and September. Late run ERs in 2001-2003 were 18%, 17% and 33%, respectively.

In 2004, the management planning and in-season processes established ER limits of 15% for the late run aggregate and 10-12% for Cultus sockeye. As of late August 2004, the actual ER for both groups was around 17%.

Long term management planning: DFO is developing a formal framework for considering conservation and management objectives for Fraser sockeye. The new process (the Fraser River Sockeye Spawning Initiative) includes senior representatives from First Nations, the commercial fishing industry, recreational fishing, environmental non-government organizations, and the provincial and federal governments. The initiative has several goals:

- Ensure conservation while respecting social and economic values;
- Improve consultation processes through proactive stakeholder discussion of targets and implementation guidelines rather than reactive, in-season decision making;
- Develop reference points and escapement policies for Fraser sockeye;
- Develop implementation guidelines to achieve long-term spawning objectives, including appropriate in-season adjustment mechanisms; and
- Develop processes for reviewing and modifying the targets, reference points and guidelines.

The initiative will initially develop a long-term escapement strategy and management reference points for 15 representative populations (including Cultus) from the four run-timing groups. This result will serve as a template for escapement strategies and management reference points for all Fraser sockeye populations. The new method for setting spawning escapement targets will be implemented in 2005 and reviewed through consultation early in 2006.

Fishery assessment: A management boundary near the Sumas River mouth has been established to help reduce interception of Cultus sockeye in Fraser River First Nations and recreational fisheries. In 2004, the effectiveness of that boundary will be evaluated by genetic and other sampling in upstream fisheries.

Agencies: DFO, PSC.

Community awareness *(Approach 0a)*

A number of initiatives are underway to raise local awareness of the status of Cultus sockeye. Community meetings sponsored by DFO and the Soowahlie Indian Band were held in November 2001 and July 2003; such meetings will continue intermittently. A *SARA* information meeting was held in the Columbia Valley in the fall of 2003; although not specific to Cultus sockeye, the meeting did outline the measures and resources associated with the *SARA* legislation. Other specific community awareness activities include:

- A brochure detailing the status of Cultus sockeye was printed and distributed in 2004;
- The Soowahlie Band is distributing information during fishery assessments and other projects to raise the awareness of residents and recreational fishers; and
- Notices have been posted throughout the Cultus and Chilliwack areas to raise awareness regarding the status of the population and the difference between adipose-clipped sockeye and coho salmon.

Agencies: DFO, Soowahlie Band.

Action Plan Statement

A recovery implementation group will form following the approval of the Recovery Strategy. Within one year of approval, the implementation group will complete an Action Plan outlining specific programs, costs and timelines. In the interim, projects identified above that address many of the known threats to the population will continue.

Evaluation

The success of recovery actions will be reviewed annually by the Recovery Team. The Recovery Strategy itself will be reviewed within five years and every five years thereafter, starting from the time the Recovery Strategy is accepted. During this review, our objectives will be re-evaluated to determine whether they have been achieved and if species recovery remains feasible.

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ANNEXES

Annex 1. Freshwater Productivity

The recent decline in the number of smolts produced from Cultus Lake (COSEWIC 2003) has prompted an update and review of available smolt production data. Annex Figure 1 shows the complete Cultus Lake smolt production data with the following notes:

- *ESpawners* refers to those counted at the fence;
- The 1926-42 broods affected by hatchery operations or predator control are excluded;
- The 1988-1991 spawner estimates were adjusted upward to account for a particularly short period of operation of the adult counting fence;
- The 1989-1990 broods affected by predator control are included but highlighted in red;
- The 1999-2000 broods with very high PSM are excluded (about 5 smolts/spawner in each year);
- The 2001 brood was probably affected by PSM, but no direct estimates are available;
- The 2002 brood suffered a 13% loss due to PSM which is not accounted for in the figure; smolts/effective spawner would be correspondingly higher;
- For clarity the figure is cut off at 40,000 spawners; the two broods with higher escapement are not shown, but are included in the calculation of the averages; and
- Age data are not included in the most recent smolt runs, which will introduce small errors.

Visual examination of these data suggests two groupings: at spawner abundances greater than 7,000 spawners the smolt production rate is variable but has an arithmetic mean of 68 smolts/spawner (range 16-125); and at abundances less than 7,000 the production rate is 32 smolts/spawner (excluding the 2 predator control years) or 41 smolts/spawner (including the predator control years).

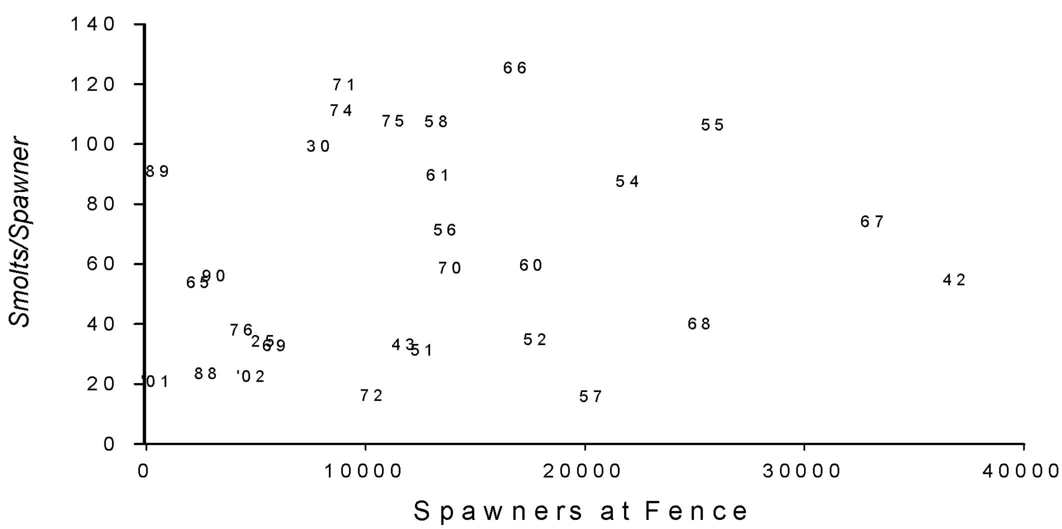

Figure 1. Relation between smolts/spawner and spawners for Cultus sockeye. Points appear as brood years. Red indicates years affected by pikeminnow removal program that removed an estimated 10-20% of the population. See text for other notes.

While the low-productivity data cluster includes some recent years in which unknown rates of PSM may have contributed to low smolts/spawner, it is noteworthy that small broods from as early as 1925 have experienced low productivity. The available data thus do not support the hypothesis of a recent declining trend in productivity associated with habitat or ecosystem changes, but rather suggest a consistent pattern of salmon survival. Alternatively, the apparent pattern in the data could be simply due to chance, given the inherent high variability in the data.

A common explanation for the observation of low survival when abundance is low is depensatory predation, where the predator population consumes a relatively constant number of prey even when prey abundance is low. This phenomenon has been observed in salmon spawning streams where emigrating smolts were preyed upon by large fish that aggregated at the stream during the migration (Peterman and Gatto 1978).

If the hypothesis of depensatory mortality is confirmed (by the collection of more monitoring data), then the Cultus sockeye salmon population may have limited potential for rebuilding or sustaining exploitation when abundance is below the threshold of 7,000 spawners. Indeed, analysis of the trajectories of the 4 cycle lines (Fig. 2) does suggest that recovery from below 5,000 spawners is difficult. As an illustration of the problem, consider the case of a brood producing 30 smolts/spawner, with a 5% smolt-adult survival, 15% exploitation rate and 15% prespawning mortality. The expected rate of population growth is only 8% per generation compared to 116% if the smolt production is 60 smolts/spawner. A small increase in any of these mortality factors could lead to population decline if smolt production rates remain low.

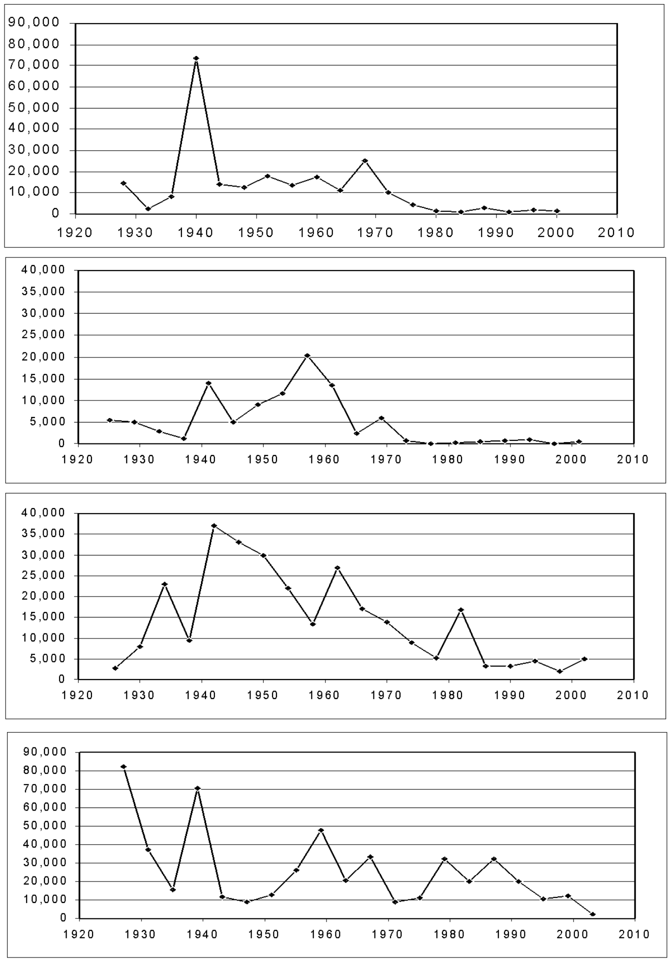

Figure 2. Time series of the 4 cycle lines of Cultus sockeye salmon, labelled in the text as the 1999-2003 cycle lines. Most broods between 1926 and 1942 were affected by either hatchery operations or predator control.

Annex 2. Target levels of abundance for Objective 4.

Objective 4 refers to the setting of a target level of abundance that will support ecosystem function and sustainable use. The ultimate reference point is the theoretical maximum production that can be achieved by a stock under ideal conditions with no harvest – a number that can be estimated using stock recruit curves and methods based on freshwater habitat capacity at various life history stages, including spawning ground capacity and lake rearing capacity. Below this theoretical level are other potential benchmarks, four of which are described below. Their relative merits must be evaluated in the context of broader societal objectives.

Lake productive capacity as a benchmark (the photosynthetic rate model)

Predicting the production capacity for fish in a particular body of water is an important objective of North American freshwater fisheries management (see Leach *et al.* 1987 for a review). It has relevance for management of recreational and commercial fisheries (sustainable yield) and for enhancement (the amount that recruitment to a lake can be increased). Biological reference points are most commonly based on fishing mortality rates or stock abundance derived from stock-recruit relationships (Mace and Sissenwine 1993, Mace 1994). In many cases, however (*e.g.*, B.C. steelhead trout), the stock-recruit relationship is either poorly defined or not known (Johnston *et al.* 2002). In the case of steelhead trout, these authors show how the β parameter (carrying capacity or the asymptotic number of smolts produced at very large spawner numbers) in a Beverton-Holt stock recruit model is closely related to estimates of habitat capacity in moderately productive steelhead trout streams. In practical terms, however, this correlation has not been very useful for developing milestones or reference points.

Productive capacity estimates for Cultus sockeye that use stock-recruit relationships are also unreliable. The spawning ground capacity of the lake has not been determined and cannot, therefore, be used to estimate productive capacity. However, there have been attempts to develop empirical relationships between lake productivity and fish yield, and estimates of juvenile lake rearing habitat have been made using a model based on photosynthetic rate (the PR model; Hume *et al.* 1996, Shortreed *et al.* 2000).

Since a direct measure of productivity (*i.e.*, photosynthetic rate) is not usually available, investigators use a number of other limnological variables as surrogates for PR. These include mean depth and total dissolved solids (Ryder 1965), summer average chlorophyll concentration (Oglesby 1977; Jones and Hoyer 1982), lake area (Youngs and Heimbuch 1982), euphotic zone depth (Koenings and Burkett 1987), and total phosphorus concentration (Stockner 1987; Downing *et al.* 1990).

Fee (1985) and Downing *et al.* (1990) reported that PR measurements were positively correlated with fish yield. Further, Downing *et al.* (1990) found that PR was more closely correlated with fish yield than with other variables commonly used as indices of lake productivity (chlorophyll, total phosphorus). Shortreed *et al.* (2000) investigated the relationship between lake area and primary production to the maximum observed juvenile sockeye biomass in Alaskan and B.C. lakes. They found that lake area alone explained 65% (r^2) of the variation in sockeye biomass. Including primary production as total seasonal carbon production (PR_{total}, tonnes C/lake) improved this relationship considerably, and explained 91% of the variation. Annual variability in PR_{total} for a wide range of B.C. lakes averaged ±8% 2SE.

The PR model (Hume *et al.* 1996) was derived from the euphotic volume (EV) model (Koenings and Burkett 1987; Koenings and Kyle 1997) which was itself developed using data from a number of Alaskan lakes. Both models provide predictions of optimum escapement, optimum spring fry recruitment and maximum smolt output. The EV model uses euphotic zone depth as a surrogate for productivity. In B.C. lakes, euphotic zone depth is not an appropriate surrogate for productivity (Hume *et al.* 1996). The PR model uses a direct measure of lake productivity (photosynthetic rate) and so is applicable to a wider range of lakes. Shortreed *et al.* (2000, 2001) revised the PR model, tested the model predictions, discussed model assumptions, and presented model estimates for many B.C. lakes. These estimates have been used as the basis for estimating sockeye stock status in most rearing lakes in the Fraser, and Skeena watersheds (Cox-Rogers *et al.* 2003, Hume *et al.* 1996, Shortreed *et al.* 2000, 2001).

The relationship between adult spawners and smolts used in the PR model is equivalent to 54.2 smolts per adult and is based on experimental stocking experiments (Koenings and Burkett 1987). Smolt size at maximum smolt biomass is assumed to be 4.5 g, which is the average size of smolts at higher spawner densities. These values are used to produce the current estimate for Cultus Lake.

PR model predictions are based on the capacity of the lake to rear juvenile sockeye and compensate for competition from other mid-water fish, but not for other factors such as spawning ground limitation or predation. Shortreed and Hume (2004 pers. comm.) estimated the productive capacity of Cultus Lake from monthly limnological samples through two growing seasons from April 2001 to March 2003. They adjusted the PR model for the diversion of productive capacity into limnetic fish other than sockeye (see Cox-Rogers *et al.* 2003) using midwater trawl (species composition and size) and hydroacoustic target strength data to estimate the biomass of non-sockeye species. These species, which include pygmy sculpins, threespine stickleback, kokanee and redside shiner, comprise about 9% of the total limnetic biomass. Assuming that these fish are direct competitors of sockeye, they used this proportion to reduce the primary production available to sockeye. In Cultus Lake, total seasonal carbon production (PR_{total}) was 447 tonnes in 2001 and 535 tonnes in 2002.

The predicted optimum escapement resulting from these estimates was 83,000 in 2001 and 100,000 in 2002 (average: 92,000). *After adjustment for non-sockeye competitors, predicted optimum escapement was reduced to 75,000 in 2001 and 91,000 in 2002 (mean: 83,000).*

S_{msy} as a benchmark

S_{msy} is the spawner biomass or abundance that will yield the maximum sustainable yield (MSY) over the long term. For most populations, S_{msy} will be a fraction (often 0.3-0.6) of the un-fished equilibrium biomass. S_{msy} is usually estimated from population models or, in the case of salmon, from a stock-recruit relationship. Less exact estimates of S_{msy} may be derived from habitat capacity or from other surrogates for productive capacity. *For Cultus sockeye, S_{MSY} is 32,000 successful spawners.*

Fisheries managers use S_{msy} as a benchmark or reference point to evaluate the status of stocks and establish rules for management actions (Richards and Maguire 1998). Fishery management policies in various jurisdictions use S_{msy} in different ways once the status of the stock has been established, and provide examples of how S_{msy} might be used for Cultus sockeye salmon.

One way is to consider S_{msy} a target reference point (TRP), a desired state at which the stock should exist or exceed. In this case, fishing mortality rates are chosen to maintain the stock at or above S_{msy}. However, because fisheries can overshoot their targets and cause stocks to fall below S_{msy}, some researchers have suggested that S_{msy} should instead represent a limit reference point (LRP) below which the stock should rarely go, and that would trigger drastic management actions if it did (Caddy and Mahon 1995). Between the LRP and TRP is an area of intermediate management actions usually devised to maintain or increase the abundance of the stock to the TRP over a specified time frame (Restrepo and Powers 1999). Using S_{msy} as a limit reference point (LRP) signifies a greater level of conservation concern for stocks when they fall below this point. For example, the North Atlantic Salmon Conservation Organization (NASCO) recognizes S_{msy} as a Conservation Limit (see http://www.nasco.int/pdf/nasco_res_decision.pdf) for the NASCO definition of this LRP).[3]

The *Sustainable Fisheries Act of the US* provides an example of S_{msy} as a benchmark for stock rebuilding. The Act specifies that a stock below S_{msy} is considered over-fished and a plan must be articulated for its recovery. The management plan will have a harvest control scheme that will result in the rebuilding of the stock to S_{msy} in 10 years, if biologically feasible, or longer if the biology of the population constrains rebuilding. In the case of mixed-stock fisheries, it is recognized that some populations will likely be over-fished when more productive stocks are the focus of the harvest. The Act states that MSY must be estimated for each stock, but over- fishing (defined as an exploitation rate that "*jeopardizes the capacity of the stock to produce MSY on a continuing basis*") can be permitted if the following conditions are met (paraphrased from SFA s600.310(d)(6):

- The overall benefits from over fishing some stocks within the mixed-stock fishery are greater than would be achieved from a lower level of harvest that would not result in over-fishing;
- There is no other means to achieve similar benefits from the fishery without over-fishing (*e.g.*, through the modification of fishing practices, techniques or equipment);
- The resulting over fishing will not result in the stock becoming threatened so that Endangered Species Act protection is required.

In a final example, the abundance that allows the population to return to S_{MSY} in one generation or more is a limit reference point used for the management of steelhead trout in British Columbia. *For Cultus sockeye, this number is 10,300 successful spawners.*

The exploitation rate at which S_{MSY} is achieved (56%) can be more precisely estimated than the actual spawner abundance at S_{MSY}. In addition, ER values can be more easily meshed with broader based policy objectives developed by Government, stakeholders and interested parties. Consequently, Cultus sockeye population milestones could be based on $ER(S_{MSY})$, or some fraction of $ER(S_{MSY})$ for the Cultus population.

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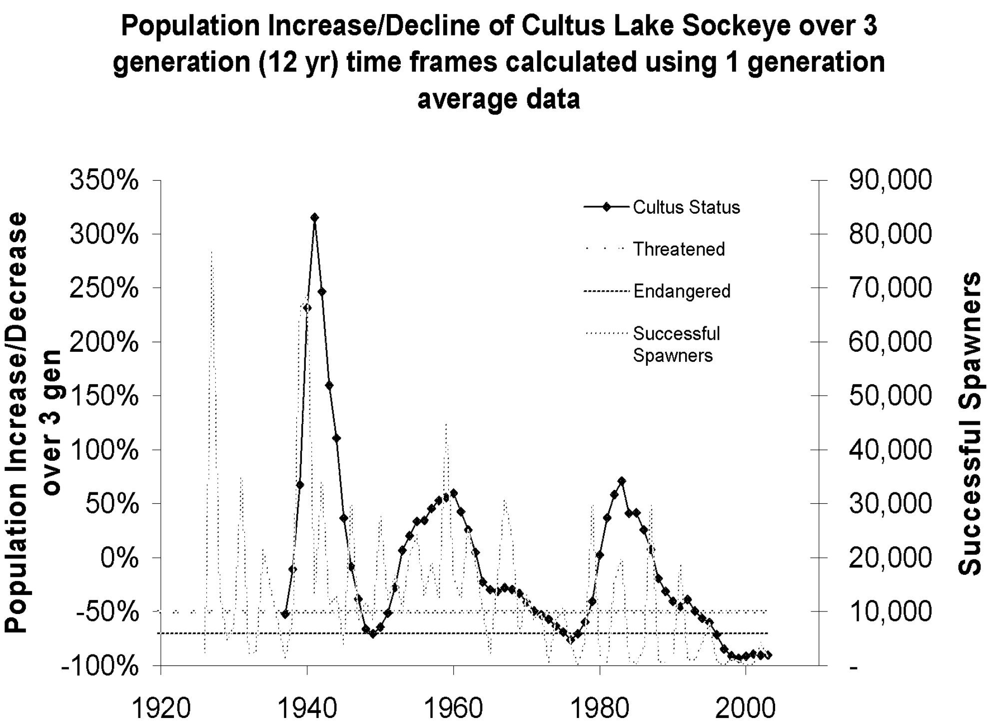
[3] Conservation limits demarcate the undesirable spawning stock level at which recruitment would begin to decline significantly. The level cannot be used in management without also defining the acceptable probability (*e.g.*, proportion of years) when the stock may be permitted to fall below the conservation limit. Currently NASCO and ICES define the conservation limit as the spawning stock level that produces maximum sustainable yield (formerly referred to as Minimum Biologically Acceptable Level or a Spawning Target).

Historic abundance as a benchmark

Historic spawner abundance during periods of relatively low exploitation has been used to set long term management goals by agencies in Alaska, Washington and Oregon (Knudsen 1999). While the Cultus population has been exploited at relatively high levels in most years since 1953 (COSEWIC 2003), reconstructions for earlier periods (1892-1944) suggest that exploitation rates rarely exceeded 50% (Gilhousen 1992). The average spawner abundance between 1925 and 1952, corrected for return years influenced by early enhancement interventions (1930, 1932-33, 1936-37) and predator control projects (1938-40) could, therefore, serve as a target level of abundance for the Cultus population. The average spawner population during this era was about 20,000, with decadal averages of 16-25,000. This era represents a long period of stable abundance during which dramatic declines (to 10,000 spawners or less) were rare. *Consequently, the 20,000 average spawner population size during the era of lower exploitation could serve as a long term goal for Cultus sockeye.*

In conjunction with historic abundance, insights can be gained by evaluating earlier periods of population decline that *would have triggered designations of Endangered* had IUCN criteria been available or applied at the time:



There were three such periods: the 1938-49 decline in generational abundance from 36,000 to 15,000; the 1965-76 decline from 15,000 to 5,000; and the further decline to 2,000 during the current evaluation period. The earliest decline can be generally discounted because the initial high abundances likely resulted from short term increases in freshwater productivity resulting from predator removals.

The 1965-76 decline is more significant. Its principal cause, namely over-fishing following the construction of the Weaver spawning channel, is among the reasons cited by COSEWIC for the current status of the population. It was during this period that the population fell below the threshold of spawner abundance associated with dramatically reduced smolt production from the lake (see *Biological Limiting Factors*). Significantly, the population has since been unable to recover to previous levels of abundance (rather than true recovery, the improved status in the figure reflects the movement of the 12-year sliding assessment period beyond the high initial abundances of the 1960s). The average population levels of the mid-1960s had been stable for several decades, while those of the late 1970s have proven to be unsustainable, allowing the population to continue declining to levels where extinction is now a real threat. Consequently, *the average population size at the start of this earlier decline, 15,000 (one generation average) to 19,000 (two generation average), could serve as a long term goal for Cultus sockeye. Given that the population abundances of the lower exploitation era were maintained in the 1950s and into the 1960s, however, the goal could be placed in the context of the full data set by adopting the 1925-1968 average, namely 20,000, as a long term goal.*

Ecosystem function as a benchmark

Ecological relationships place constraints on the planning, execution and evaluation of sustainable harvesting. Recovery of Cultus sockeye should aim to maintain ecological relationships (*e.g.*, predator-prey and competition) among species, within the bounds of natural fluctuations, and to minimize the risk of changes to those relationships that are difficult or impossible to reverse.

While the abundance at which ecosystem disruption occurs could be considered as a milestone, there is presently great difficulty in quantifying not only the ecological relationships that involve Cultus sockeye, but also the level of abundance at which these relationships are unacceptably jeopardized. What we know about the ecological relationships of Cultus sockeye is discussed earlier (see *Ecological Role*) and includes:

- carcasses are probably directly available to primary producers in the lake, and could result in increased periphyton productivity with benefits to benthic invertebrates and littoral fish species. Such nutrients, however, would probably cause detectable increases in productivity only at higher escapements;
- many bird and animal species at Cultus Lake feed directly on salmon carcasses or eggs (*e.g.*, eagle, gull, some waterfowl, Steller's jay, raccoon, mink, and otter);
- fish species other than sockeye may feed directly on carcass flesh or salmon eggs; and
- juvenile sockeye represent a food supply for a number of other fish species such as juvenile coho, cutthroat, rainbow, sculpins, and pikeminnow, so that sockeye may function to regulate the abundance of other species in the ecosystem.

At what level of spawner abundance are the above relationships affected? Is there a level of abundance that can be quantitatively linked to ecosystem disruption? At present, neither of these questions can be answered without further scientific study. DFO's *Draft Policy on Fishery on Forage Species* may provide some relevant guidelines for maintenance of ecosystem relationships in fisheries.

Annex 3. The Cultus sockeye captive breeding project.

The captive breeding project began on an *ad hoc* basis in 2000 when very few spawners returned to the Sweltzer Creek fence and those that did were in very poor condition. Five females and six males were captured and the survivors (PSM was very high) were spawned, with the progeny incubated and reared at the Cultus Lake Laboratory over the next 18 months. Because the small number of spawners limited genetic diversity, all of these fish were marked with an adipose clip and released as smolts; they were replaced by wild smolts emigrating through Sweltzer in the spring of 2002. These fish were moved to the Chilliwack River Hatchery for disease screening and parasite removal (they suffered high mortality from parasitic copepods), and subsequently to the Rosewall Creek Hatchery.

A small number of adults were captured in 2001, again with high PSM. They were incubated and initially reared at Cultus Lake, then transferred to the Chilliwack River Hatchery for disease screening and parasite removal and finally to the Rosewall Creek Hatchery on Vancouver Island for rearing to maturity. Juveniles that were surplus to the requirements of the captive breeding project were released into Cultus Lake as fry in the fall of 2002 and as smolts in the spring of 2003. Ninety percent of the released fish had their adipose fin clipped. Also in the spring of 2003, 881wild smolts were retained for captive breeding to broaden the genetic diversity of the captive population. These fish were moved to the Inch Creek Hatchery for disease screening and parasite removal (there was very little mortality thanks to lessons learned with the 2000 brood year smolts) and subsequently to the Rosewall Creek Hatchery.

In the fall of 2002, the project was redesigned, with larger brood stock targets to permit testing various methods to reduce PSM and maximize subsequent survivals. The egg-take used a matrix spawning technique to produce almost 500 separate mating families and over 400,000 eggs. Both pre-spawn and incubation mortality were much lower than in the previous two years. Ten eggs selected from each mating were retained in the captive breeding project; the remainder (227,000 4 g fry) were incubated and reared at the Inch Creek Hatchery before release into Cultus Lake as marked fry in October.

In the fall of 2003, another large egg-take permitted about 500 mating families. Again, fish in excess of the requirements of the captive breeding project will be released into Cultus Lake in 2004.

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Annex 5. Record of cooperation and consultation

Integral to the recovery planning process under SARA is involving local communities at every step along the way to recovery. The Recovery Team has worked hard to develop a comprehensive recovery strategy that provides advice on protection and long term recovery measures for the Cultus sockeye population. As the recovery strategy is turned into action plans, the contribution and participation of communities and individuals will play a key role in helping to rebuild this population. At this stage, it is important for Canadians to learn more about the strategies and provide input prior to final strategy development.

Fisheries and Oceans Canada and the Cultus Lake Sockeye Recovery Team would like your feedback on the draft Recovery Strategy for Cultus Lake Sockeye. The draft recovery strategy was developed by a multi-stakeholder recovery team of experts, and will form the key component to recovering this Species At Risk, under Canada's new *Species At Risk Act*.

We Want to Hear From You!

Fisheries and Oceans Canada is holding a series of community dialogue sessions around the Province of B.C. in October and November, 2004. Information for the dialogue sessions, including the draft recovery strategy, meeting dates and locations, agendas, and registration and background information is all posted on the following website:

http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/consultation2004/main_e.htm

The following consultations and information sessions have already been completed:

Date: November 14, 2001
Group: Public Meeting
Location: Cultus Lake, B.C.

Date: July 2, 2003
Group: Public Meeting
Location: Cultus Lake, B.C.

Date: April 29, 2004
Group: Multi-stakeholder Consultation Workshop
Location: Vancouver, B.C.

Date: June 4, 2004
Group: Commercial Salmon Advisory Board
Location: Vancouver, B.C.

Date: June 8, 2004
Group: Lower Fraser Aquatic Resource Management Forum
Location: Chilliwack, B.C.