Chapter 11
Sockeye Salmon of the Chilko-Chilcotin River System: Smolts-Adults

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Abstract

The combination of effective spawners in the parental generation (specifically the number of eggs deposited in spawning gravel) and survival (freshwater and marine) determines the number of sockeye salmon (*Oncorhynchus nerka*) that return (escapement, catch & en-route loss) to the Chilko-Chilcotin River (CCR) system in any given year. This chapter examines the array of biotic interactions and conditions, resulting from physical processes, which affect the smolt through adult stages of the life cycle. The quality and quantity of available habitat, combined with the complexities in timing of the sockeye salmon life cycle, leads to considerable inter-annual variation in sockeye salmon returns. The importance of smolt outmigration from Chilko Lake, ocean residence, and the return migration of adults are described in detail. A conceptual model is presented that connects ecosystem inputs and processes to the survival of sockeye salmon.

Introduction

The rivers, tributary streams, and lakes of the Chilcotin region of British Columbia are an important component of the sockeye salmon lifecycle and provide valuable migration, spawning, incubation, and rearing habitats. The headwaters of the Chilko-Chilcotin River (CCR) system originate in the Pacific Coast Mountains that surround Chilko Lake, a remote and pristine area within the region that is renown for its natural beauty. Numerous glaciers replenish the lake, which is utilized by sockeye salmon as nursery habitat for at least one year after emerging from the gravel of the Chilko River, and prior to beginning their long journey to the Pacific Ocean. The river drains in a northeastern direction through the foothills of the Coast Range Mountains before turning south into the interior plateau of British Columbia. It joins the Chilcotin River just west of the town of Alexis Creek and from here flows downstream to the confluence with the Fraser River south of the city of Williams Lake. Specifically, Chilko Lake and the CCR system support healthy runs of adult salmon due to the relatively pristine nature of the area (located within Ts'yl-os Provincial Park), little exploitation, and open access to habitats that are essential for the successful completion of vital life cycle stages. The Chilko area is arguably one of the most varied ecosystems in North America, including some of the largest ice-fields, towering mountain peaks, alpine lakes, semi-arid grasslands, and extensive timber expanse including old-growth, a very healthy migratory fish spawning habitat, and untouched wildlife inventory.

In August 2011, an interdisciplinary research class from the University of California at Davis will travel to the headwaters of the Chilko River in southern British Columbia. The purpose of the visit will be to conduct fieldwork, related to the geology and ecology of the region, over the course of a 140-mile rafting expedition. Namely, the class seeks to describe the linkages between regional geologic and climatic events in controlling the type and distribution of aquatic and riparian habitat. The research team will perform various types of surveys along the route, including techniques to record the abundance and distribution of sockeye salmon (*Oncorhynchus nerka*) within upper reaches of the system. The researchers will also create different longitudinal profiles to capture a snapshot of ecological conditions and to develop a physical, chemical, and biological understanding of the ecosystem.

Students assembled a conceptual ecosystem model as a group to visually represent drivers, linkages, and outcomes based on the synthesis of relevant literature. The model may be used to predict and monitor change in the CCR system, both temporally and spatially. Ideally, the researchers will enhance this model with information gathered in the field and work to diminish uncertainties. The students also addressed specific components of the larger ecosystem model in detail through the development of individual sub-models and descriptive narratives. Sockeye salmon play an integral role within the model as a major source of marine derived nutrients, which increase the in-stream and terrestrial productivity for this relatively nutrient poor system. Furthermore, the seasonal abundance of sockeye is valuable for the native peoples of the Chilcotin region and for the economy of southern British Columbia. The sockeye salmon are an important part of the larger ecosystem model, but also require a separate sub-model (Figure 11.1 below) in order to depict specific factors affecting their survival in the CCR system.

CONCEPTUAL MODEL

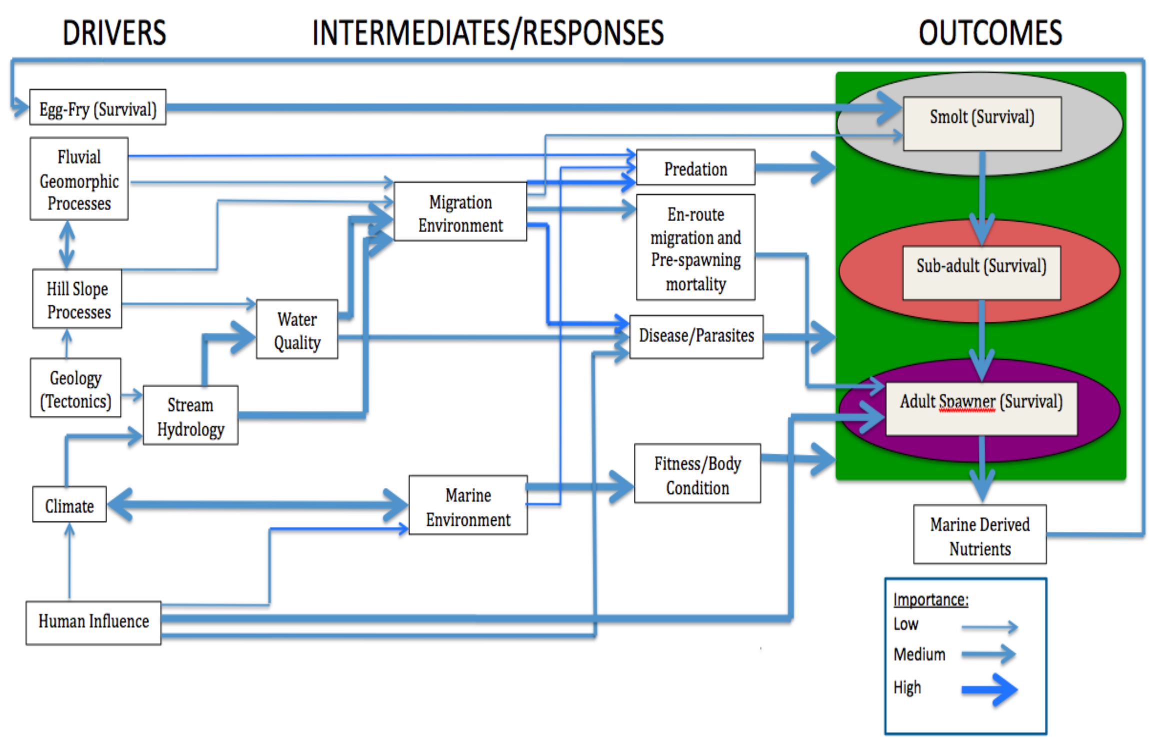

Figure 11.1. Conceptual model illustrating the drivers, intermediates and ecosystem level responses behind smolt to adult survival of sockeye salmon within the CCR system. Arrows represent linkages and arrows that touch the edge of the green box represent an affect across all included life stages.

CONTEXT

Sockeye salmon depend on a functional and healthy aquatic environment, described by critical thresholds and a narrow range of suitable conditions, to facilitate a successful life history strategy. The genetically distinct Chilko sockeye salmon stock is precisely adapted to the natural geomorphic characteristics of the CCR system as a result of long time-scale evolutionary processes. Rapid changes in the dynamics of the system could potentially outrun evolutionary responses and would negatively affect the abundance of sockeye salmon. This model accounts for biological and physical aspects of the system in an attempt to forecast the survival of sockeye salmon from smolts to adults while another model assesses the factors influencing the survival of eggs to fry (Chapter 10). Important physical drivers include tectonics, hill slope processes, fluvial geomorphic processes, and climate. Intermediate outcomes of these large-scale physical drivers are the physical characteristics of stream hydrology and water quality, which directly affect the suitability of freshwater conditions during migrations. In the end, biological responses such as predation, disease, parasites, body condition and fitness contribute directly to survival. Human influence and fry survival are major biological drivers. This model also includes the marine environment, although outside the scope of the CCR system, as an important component of survival since sockeye salmon spend over half of life cycle in the ocean. Outcomes of the model are smolt survival, sub-adult survival, adult survival, and marine derived nutrients. These outcomes sequentially affect one another in addition to direct inputs from the intermediates. Lastly, this model is intricately linked to many other sub-models including the tectonics model, glaciers model, geomorphology model, hydrology model, water quality model, invertebrates model, terrestrial plant communities model, terrestrial animals model, resident fishes model, and egg-fry survival model (Chapters 1,2,3,4,5,6,7,8,9, and 10).

DRIVERS

CLIMATE:

The Chilcotin area of British Columbia is situated close the Pacific Ocean and accordingly, the regional climate is largely affected by ocean moisture. Climate is also influenced by weather patterns and mountain topography (Chapter 3). Additionally, a cold past climate resulted in formation of glaciers which, along with snowmelt, provide steady runoff of cold water into Chilko Lake (Chapter 3). Particular aspects of climate such as the amount, type, and timing of precipitation are strongly correlated to the annual hydrograph and thus, indirectly affect sockeye salmon. Changes in climate could lead to rapid spring runoff, low summer or winter flows, and less snow pack in the future. Such climatic effects could increase the in stream water temperatures and flows which govern the stress levels of adult migrating sockeye salmon. However, this direct influence of climate on the physiology of sockeye salmon remains uncertain and is beyond the scope of this paper. In general, regional climate maintains an important influence on the stream hydrology of the CCR system (Chapter 3).

Longer-term fluctuations in salmon population have been linked to broad changes in ocean climate that begin with changes in major pressure systems over the Pacific, affecting ocean temperatures and productivity (Nelitz 2011). Two key indices of the climate-ocean system include the Aleutian Low Pressure Index (ALPI) (Beamish et al. 1999) and the Pacific Decadal oscillation (PDO) (Mantua et al. 1997). Positive ALPI and negative PDO’s represent improved ocean conditions for salmon. Regional-scale climate processes related to conditions in the ocean such as sea surface have also been used to predict survival rates in salmon (Mueter et al. 2005).

GEOLOGY:

The ancient geological history of the CCR system is important in understanding the course of the river and the stream power associated with different stretches of the river. The development of the CCR system over the last 100-1 million years is a result of large-scale and long-term tectonics as well as small-scale regional geologic and geomorphologic processes (Chapter 1). Though these processes may only have an indirect effect on local ecosystems along the modern rivers, they ultimately control the geomorphic and hydrologic landscapes of southern British Columbia (Chapter 1).

HILLSLOPE PROCESSES:

In time, hillslope processes may have cumulative impacts on fish habitat through sediment deposition in channels, channel instability, and the destabilization of stream banks (Rood and Hamilton 1995). Mast wasting and erosion could directly impact the freshwater migrations of CCR sockeye salmon under extreme conditions. Although rare, landslides or earthquakes could develop partial barriers to fish passage as evidenced by Hells Gate slide of 1913. The productive hillslope ecosystems of the CCR contribute large woody debris (LWD) in the form of fallen logs and sediment from erosion (Chapter 7). Such inputs can lead to the formation of islands that will alter river flows and could potentially disorient returning salmon or hinder the time sensitive migration upriver. On the other hand, large woody debris and isolated backwater habitats could serve to protect sockeye salmon during floods. Migrating sockeye salmon could also seek refuge to conserve energy either en route or upon arrival at the spawning grounds, which would improve chances for successful spawning.

FLUVIAL GEOMORPHIC PROCESSES:

The active fluvial geomorphic processes of the Chilcotin region carve out the physical CCR channel (Chapter 4). These processes also introduce boulders, fine and coarse sediment, and debris which could improve or worsen conditions for migrating sockeye salmon. Large influxes of sediment increase the turbidity of the water and out migrating sockeye smolts could experience cover from predation levels as a result of the reduced visibility. However, more turbid water is able to absorb more sunlight, leading to higher temperatures (Chapter 5). Increased water temperatures have not been suggested to impair smolt out migrations but may have an effect on returning adult sockeye salmon (Quinn 2005). Furthermore, the interaction of large boulders and stream flow could provide deep-pool refuge habitat for out migrating smolts.

EGG-FRY SURVIVAL:

Freshwater life history stages account for a significant portion of overall mortality, and variation in total mortality (>40%), in sockeye salmon species, with average survival from the egg to smolt stage estimated at only 2% (Bradford 1995). The type, abundance, and availability of food within the fry stage of the sockeye life cycle will affect their growth. Freshwater growth in the nursery lake is critical to the process of smoltification, where young sockeye undergo physiological and behavioral changes in preparation for life in salt water. Some studies showed that when both mysids (large invertebrate planktivores) and juvenile sockeye inhabit the same lake, sockeye suffer from a competitive disadvantage and mysids consume 80–90% of the available zooplanktonic food production (Hyatt 2004). In general, fry in lakes feed on crustacean zooplankton and aquatic insects in littoral zones and on zooplankton species in the limnetic zone (Burgner 1991). The availability of these important food items is driven by the quality of rearing habitat that is primarily related to factors like lake temperature (Chapter 10). At Chilko Lake, recorded fluctuations in fry growth have been directly correlated to the temperatures during lake residence (Quinn 2005). Furthermore, any decrease in food availability due to changes in the bottom-up producing capacity of the environment could lead to decreased survival.

Human Influence

Sockeye salmon are an icon in British Columbia and an important species for human, marine, freshwater, and terrestrial communities. For human communities they are a cultural cornerstone providing food, social, and ceremonial values to First Nations, while contributing $2.5 to $250 million annually in financial benefits to commercial fisheries depending on abundance of returns to the Fraser River (Nelson 2006). The Chilko River sockeye salmon stock consistently registers the third largest adult spawning escapement in British Columbia (DFO, Stock Assessment). There is very little forestry, urbanization, mining, or industrial development other than a few small towns, roads, and stream crossings in the CCR system watershed. However, there is a considerable amount of ranching, grazing, and agriculture that requires water withdrawal on the order of 10-15% of average monthly August and September flows in the Chilcotin River above the Chilko confluence (Rowland 1996). The Chilko River has minor human impacts including the salvage of beetle-killed timber (forestry), low levels of open range grazing (agriculture), Nemiah Valley Indian Reserves (urbanization), and both native and recreational fisheries (Cariboo-Chilcotin LUP). The Fisheries and Oceans Canada Chilko River Sockeye Spawning Channel located approximately one kilometer downstream of the Chilko Lake outlet has been operationally unsuccessful since its construction two decades ago (Holmes, 1991). The largest fishing pressure will be observed at traditional native spots such as Farwell Canyon on the Chilcotin River and below Henry's Bridge on the Chilko River (Nelitz et al. 2011).

The large production of salmon farms in the Strait of Georgia region is associated with infestations of sea lice on wild juvenile salmonids, especially sockeye salmon (Price 2010). Crowded conditions facilitate parasite and disease transmission within the salmon farms, and enable exponential population growth of pathogens and release to the surrounding environment where juvenile sockeye salmon are migrating out to sea. Sea lice feed on surface tissues of their hosts and may compromise osmoregularity, in addition to inducing behavioral changes that increase predation risk (Price 2010). There is also evidence that Fraser River sockeye migrating through the Strait of Georgia with salmon farms hosted an order of magnitude more sea lice than Skeena River populations, where there are no farms (Price 2010). Although this investigation is recent, increase in the number of salmon farms could lead to higher levels of pathogens exposure for sockeye salmon during a critical and already physiologically demanding stage of life (Quinn 2005).

Intermediates/Responses

Water Quality:

Water quality is an important intermediate for migratory corridor habitat quality. Excess turbidity increases the hormone cortisol, which is a biomarker of stress in salmon (Redding, *e*t.

al., 1987). Juvenile salmon exposed to high levels of turbidity are also at greater risk for infection (Redding, et. al., 1987). The relatively high gradient of Chilko River in Lava canyon may have an impact on dissolved oxygen (DO) concentration due to aeration of water caused by rapids (Chapter 5). While dissolved oxygen is primarily dependent on water temperature, the aeration may slightly affect DO concentrations (Chapter 5). The sockeye salmon of the Chilko-Chilcotin system have consistently escaped to the spawning grounds in large numbers, and, thus, the turbid nature of the stream does not seem to affect their homing ability. High water temperatures can increase fish energy expenditures, increase the progression of diseases and parasites, and decrease fecundity of eggs (Crossin et al. 2008). Fisheries and Oceans Canada suggests that Fraser River water temperatures above 18-20^{o}C can degrade spawning success, while water temperatures above 24^{o}C can be fatal (DFO, 2011).

Stream Hydrology:

The hydrology of the Chilko-Chilcotin River (CCR) system plays a defining role in physical habitat maintenance, water quality and timing cues for sockeye salmon (Chapter 3). July and August usually experience the highest flows of the year ranging from 70 - 125 m3/sec (Burley, in this volume). These summer flows dictate the accessibility of spawning grounds and the amount of energy required to reach those spawning grounds. High flows put more stress on the adults migrating up river. However, sockeye salmon may be considered an inherently resilient species as defined by multiple, independent reproducing populations, high reproductive capacity, metapopulation structure, high genetic diversity, phenotypic plasticity, variable life history tactics, and opportunistic use of habitat (Healey 2009). In rivers, temperature, flow and light commonly stimulate fish migration, but high or low temperatures or flows can delay or even halt fish passage (Jonsson 1991). Low water flows can seriously impact fish survival by increasing temperatures, lowering oxygen concentrations, and hindering spawning and migration. The current predicted hydrograph for 2011 suggests that the sockeye may encounter higher flows during their upstream migration (Chapter 3). CCR sockeye typically arrive at the mouth of the Fraser River in late July or early august before traveling a distance of 596 km and covering an elevation of 1200m to reach the spawning grounds (Burgner 1991). The fish cover around 35 km/day and the run lasts 18 days, while the sockeye average 25 days on the spawning grounds before death (Killick 1959).

Marine Environment:

Pacific salmon sustain heavy and highly variable losses in the ocean, with natural mortality rates generally exceeding 90-95% during their marine life (Bradford 1995). Most of this mortality is thought to occur during two critical periods: an early predation-based mortality that occurs within the first few weeks to months following ocean entry and a starvation-based mortality that occurs following their first winter at sea (Beamish and Mankhen 2001). In particular, it is hypothesized that during the early ocean entry period salmon are particularly vulnerable to predation due to their small size and that reaching a critical size is the key to over-winter survival (Beamish and Mahnken 2001). For Chilko sockeye, which enter the Strait of Georgia as smolts and then rapidly migrate northward through the Johnstone Strait, along the continental shelf and out into the North Pacific (Tucker et al. 2009; Welch et al. 2009), there is a broad area over which these fish will be particularly vulnerable to early marine mortality.

Migration Conditions:

Outmigrating sockeye smolts are vulnerable to predation during passage through CCCR system, which supports a diverse assemblage of resident fish. These predatory fish include rainbow trout, coho salmon, chinook salmon, dolly varden, and bull trout (Chapter 9). It is a dangerous stretch through the CCR system and Fraser River until smolts reach the estuarine environment in the Strait of Georgia. The stream morphology, hydrology, and riparian corridor inputs along the river system will provide different refuge habitats for migrating smolts, and it will be important to map out the quality and quantity of such habitats on our expedition as a way to index the threat of predation. The smolts are vulnerable to predation from marine organisms immediately upon entry into the Strait of Georgia, where behaviors including schooling may help reduce mortality (Quinn 2005). Sockeye salmon smolts show daily vertical migration patterns for dawn and dusk feeding, while remaining at safe depths otherwise, to help avoid predation just prior to the migration out of Chilko Lake and into the CCR system (Brett 1971). Furthermore, Chilko smolts tend to migrate at night en mass such that most of the population exits the rearing lake over a short period of time with visible peaks on particular days (Crittenden 1994). Outmigrating smolts move down the river at night and school in deep pools or hide during the day. This period of outmigration to the mouth of the Fraser River at Johnstone Strait has been thought to last approximately 7-14 days (Crittenden 1994).

On the return migration, a combination of homing behavior and timing of river entry leaves the seasonally abundant sockeye vulnerable to marine mammal predation close to the river mouth. Namely, pods of resident killer whales and large populations of sea lions and seals readily feed on the seasonal abundance of salmon. This threat of predation stresses the maturing adults, which have already ceased feeding upon entering the Strait of Juan de Fuca some 200 miles from the mouth of the Fraser River and an additional 550 miles from the Chilko River and Chilko Lake spawning grounds (IPSFC XXII). These migrating adults rely on stored energy reserves and are vulnerable to predation by grizzly bears, bald eagles, and osprey in the upper reaches of their freshwater migration.

Predation:

Sockeye salmon are exposed to various sources of predation throughout each stage of their life cycle. In order to avoid this constant threat, sockeye salmon must adjust their behavior, and, ultimately, face a critical tradeoff between survival and growth. Sockeye may hide and limit the risk of predation, which results in little food consumption and a slow growth rate. Alternatively, sockeye may remain in the open and risk predation, yet consume larger quantities of food and experience rapid growth. This dilemma is largely influenced by the abundance of predators, and sockeye salmon have evolved a complex life history strategy that includes moving between habitats varying in predation risk (Groot 1995). In fact, minimizing the risk of predation plays a very important role in this strategy during critical periods of growth.

En-route Migration and Pre-Spawning Mortality:

Variable numbers of Fraser River sockeye salmon die each year during the en-route migration to native spawning areas, although specific data for the CCR system is not available. This en route loss is a result of physical factors such as water temperature, discharge, sediment and harvest

(Crossin et al. 2008; Macdonald 2000). These physical factors interact with biological factors to include energy status, disease condition, pathogens, predators, and cumulative stress. (Cooke et al. 2006; Bradford et al. 2010). The relative contribution and interaction among these factors varies on an annual basis, and are mediated by the over-arching influence of water temperature. Notably, premature mortality during freshwater migration and spawning routinely exceed 20% (Gilhousen 1990). Recent mortality estimates for out migrating Chilko sockeye smolts exceeded fifty percent (Hinch 2009).

DISEASE/PARASITES:

A diverse range of pathogens including viruses, bacteria, fungi and parasites can infect sockeye salmon (Bennet et. al. 1998). Disease can present itself in CCR sockeye salmon lethally or sublethally (e.g. changes in swimming ability, growth, osmocompetence and reproduction) (Nelitz et. al. 2011). It is difficult to predict the occurrence and severity of disease due to its complex nature. However, scientists have directly observed various pathogens in CCR sockeye salmon including the infectious hematopoietic necrosis virus (IHNV) and Parvicapsula minibircornis (Bennet et. al. 1998). The first IHNV mortality event within the Fraser River watershed occurred in the spring of 1973 at Chilko Lake and resulted in an estimated loss of 23.7 million fry (Williams 1976). This event was detrimental to smolt survival for that cohort but other similar events have not been observed in the CCR system. The myxozoan parasite *Parvicapsula minibicornis* is more prevalent in the CCR system and adult migrating sockeye are exposed to it when they enter the lower Fraser River from the ocean (Nelitz 2011). Research shows the probability of survival of adults from arrival at the lake to spawning was negatively correlated with the intensity of the *P. minibicornis* infection at death and findings demonstrate significant gill pathology associated with the infection (Bradford et al. 2010). Therefore, Parvicapsula-induced kidney and gill disease is arguably contributing to the premature mortality of migrating sockeye salmon in the Fraser River through mechanisms of respiratory stress and ion imbalance.

FITNESS/BODY CONDITION:

The freshwater migration of sockeye salmon, also known as the escapement to spawning grounds, requires high levels of energy. Reproductive adults expend much energy in the process of spawning successfully and die afterwards, a strategy known as semelparity. The salmon lose protein and muscle storage during migration while they gain water (Groot 1995). Research suggests that spawning occurs in a narrow range of constituent percentage values, between 5% and 26% of the fat and 40% to 70% of the protein remain in dead sockeye, with males retaining more than females (Gilhousen 1980). Body muscle decreases in relative weight during river migration, while trimmings (head, skin, fins, bones) increase in relative weight (Gilhousen 1980). Sockeye salmon derive 95% of their energy for migration and gonad enlargement by eviscerating their bodies (Groot 1995). Furthermore, populations embarking upon distant, high elevation migrations begin their upriver migrations with higher densities of somatic energy and fewer numbers of eggs compared to populations completing less difficult migrations (Crossin 2004). Longer distant migrants are also more energy efficient during the migration and the CCR sockeye have greater aerobic scope, larger hearts, and better coronary supply which has lead to relatively stable production over time (Eliason 2011).

OUTCOMES

Smolt Survival, Sub-Adult Survival, and Adult Spawner Survival:

The transition and migration between habitats at critical life stages expose sockeye salmon to high levels of mortality. Smolt survival is inherently dependent on the success of previous life cycle stages and namely egg-fry survival (Chapter 10). In turn, sub-adult survival in the ocean foremost depends on the number of smolts that successfully complete the long migration through the CCR system, up through the Strait of Georgia, and out to the open sea. Although the smolts leave the oligotrophic nursery lake in an effort to exploit the highly productive marine environment, they become the bottom of the food chain and also require rapid early marine growth in order to survive the first winter at sea. Sub-adult survival in the open ocean as a result of migratory patterns to productive areas, along with the genetics to be able to navigate homeward to a specific location, is critical to the adult survival. These parts of the life cycle intuitively affect each other in a direct manner due to mortality experienced at each stage. However, there are numerous indirect and direct processes that govern the abundance of sockeye salmon returning to the CCR system. Predation, parasites and disease, and body condition were all described as important variables relevant to the smolt though adult stages of the life cycle. In the end, many of the outcomes are the result of large-scale conditions in the marine and freshwater migratory environments that were suitable for the highly evolved timing cues of the CCR sockeye salmon life history strategy.

Marine Derived nutrients:

In coastal areas of the North Pacific Ocean, annual returns of spawning salmon provide a substantial influx of nutrients and organic matter to streams and are generally believed to enhance the productivity of recipient ecosystems. Loss of this subsidy from areas with diminished salmon runs has been hypothesized to limit ecosystem productivity in juvenile salmon rearing habitats (lakes and streams), thereby reinforcing population declines (Holtgrieve 2011). For freshwater and terrestrial communities, they provide a means of transferring marine nutrients to watersheds that support subsequent generations of salmon, aquatic animals, riparian forests, and wildlife (Naiman et. al 2002). The Chilko River sockeye salmon run has an annual mean return upwards of 1.6 million adults from 1974-2008 (DFO, Stock Assessment). This large escapement suggests the salmon are capable of depositing nutrients directly into the stream system as well as up to 20 km into the terrestrial ecosystem via terrestrial vectors (Chapter 8). These nutrients have been shown to affect salmon populations in freshwater, including increasing basal food resources and elevating juvenile salmon growth rates and condition (Adkison 2010). The nutrients play a crucial role in feeding back to egg-fry survival as the availability of food in the rearing lake habitat ultimately determines the rearing success and consequently survival of sockeye fry (Chapter 10).

Uncertainties

There is likely a complex set of conditions in both the freshwater and marine environment (temperature, food availability, and predation) covering a broad temporal and spatial scale, which determine survival and total recruitment for CCR sockeye salmon. These conditions likely vary interannually, and therefore, no one factor such as predation along migratory corridors or sea-surface-temperature in the Strait of Georgia is sufficient to explain variability in CCR sockeye recruitment. There are also uncertainties regarding size thresholds and growth relationships leading up to the process of smoltification as well as the process of maturation. Sockeye salmon exhibit the most life history strategy variation of all seven species of Pacific salmon (Burgner 1991). Large uncertainties exist regarding the influence of climate on ocean productivity, the resulting length of time spent in the marine environment for sockeye salmon, the potential impacts of future change in climate on the pristine upper reaches of the system, and the magnitude of human influence on CCR sockeye salmon as the human population will continue to grow in southern British Columbia.

SUMMARY

The health and long-term well-being of wild sockeye salmon is inextricably linked to the availability of diverse and productive freshwater, coastal, and marine habitats. Sockeye salmon's complex life history and physiology allows them to thrive in vastly different conditions in marine and freshwater environments, and traverse the large distances in between. Watershed processes provide a high level of variability in environmental conditions (e.g., climate, vegetation, stream conditions), which help salmon express diverse life history tactics, metapopulation structure, and genetic and phenotypic diversity that are evident among populations (Bisson et al. 2009). For instance, sockeye salmon populations will vary their life history tactics and physiology in response to differences in migration distances to natal streams, water temperatures on spawning grounds, or rearing conditions in nursery lakes (reviewed by Burgner 1991). The Chilko-Chilcotin River system possesses a highly variable, but sustained abundance of sockeye salmon, on a year-year basis while responding to continuing changes in the physical and biological conditions of the ecosystem. Stream hydrology, water quality, human influence, and fry-smolt survival are primary drivers in this model. These primary drivers, in addition to the importance of a suitable migration and marine environment, will affect both the intermediate and final outcomes. The most sensitive aspect of the model relating to *O. nerka* is the quality and quantity of those intermediate habitats that result in continued reproductive success of the species in the Chilko-Chilcotin River system.

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