

An aerial photograph showing the Somass River estuary. The river flows from the top left towards the bottom right, where it meets a large body of water. The surrounding area is a mix of urban development, including a grid of streets and buildings, and natural terrain with some vegetation. A large, dark, irregular shape is visible in the lower right quadrant, possibly a large building or a natural feature. The overall scene is a blend of urban and natural environments.

AQUATIC HABITAT IN THE
SOMASS RIVER ESTUARY:
A SELECTIVE REVIEW
AND IMPLICATIONS TO
CHINOOK SALMON

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Abstract	This report reviews some of the information concerning changes to habitat in the Somass River estuary and the consequences to juvenile Chinook salmon which temporarily reside there during migration to the Pacific Ocean. Since the early 1970s the progeny of juvenile Chinook salmon from adults that spawned in the Somass River system have been augmented by releases of larger-sized hatchery-reared fish. Differential survival to adulthood is a concern for the respective groups of fish, and the quality and sufficiency of estuarine habitat have been implicated as two potential causes. Accordingly, comments in this report are presented to assist in understanding how "wild" (river-origin mix of wild and hatchery-origin vs. hatchery-reared) juvenile Chinook salmon may interact with, and be influenced by, habitat in the Somass River estuary and the inherent challenges to their survival to adulthood.
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PREFACE

Industrial and urban development has occurred at the head of Alberni Inlet and now it is estimated that only 33.5% of the “natural” Somass River estuary exists. This has occurred despite concern being expressed over almost 70 years for protection of salmon which are dependent upon the estuary during part of their lives.

The construction and modifications to the Port Alberni pulp mill in the estuary of the Somass River in the late 1940s - 1950s, associated shoreline urban development, the treatment and disposal of sewage and other wastes, and industrial use of the intertidal areas for log handling and storage etc., have all contributed to changes to habitat which aquatic organisms depend on and, consequently, some adverse effects would be expected.

Decades ago the magnitude and extent of changes that were expected due to industrial and urban development were not fully understood, and it was predicted that the waters of Alberni Inlet would assimilate the demands upon them without unduly constraining ecological functions and impacting valuable salmon resources. Unfortunately, subsequent studies revealed that these expectations had not always been met and changes had occurred which impacted aquatic organisms, and especially so at the head of Alberni Inlet in the estuary of the Somass River where impairment of habitat was most obvious in the shallow and deepwater habitats.

This report reviews some of the information concerning changes to habitat in the Somass River estuary and the consequences to juvenile Chinook salmon which temporarily reside there during migration to the Pacific Ocean.

Since the early 1970s the progeny of juvenile Chinook salmon from adults that spawned in the Somass River system have been augmented by releases of larger-sized hatchery-reared fish. Differential survival to adulthood is a concern for the respective groups of fish, and the quality and sufficiency of estuarine habitat have been implicated as two potential causes. Accordingly, comments in this report are presented to assist in understanding how “wild” (river-origin mix of wild and hatchery-origin vs. hatchery-reared) juvenile Chinook salmon may interact with, and be influenced by, habitat in the Somass River estuary and the inherent challenges to their survival to adulthood.

This review covers many topics but of necessity it has been selective and limited in scope and detail; some aspects are explained more fully to assist comprehension. Our deductions are a reflection of information reviewed and trust that they are accurate. Comments are provided on specific habitat issues that have been identified through studies of Alberni Inlet, and also the current circumstance. Information on the use of estuaries by juvenile Chinook salmon is anticipated to assist efforts to maintain and rehabilitate fish habitat in the Somass River estuary; it is hoped that the information will also aid in the development of co-ordinated projects in this regard.

(Cover: Aerial photograph, Somass River estuary and Alberni Harbour; from BC Government, Victoria, BC.)

TABLE OF CONTENTS

	Page
CITATION AND REPORT AVAILABILITY	i
PREFACE	1
TABLE OF CONTENTS	2
LIST OF TABLES	8
LIST OF FIGURES	8
SUMMARY	9
INTRODUCTION	15
BRIEF PERSPECTIVE	16
Pulp mill location, effluent discharge, water quality and concern for salmon	16
Effluent discharge and dissolved oxygen (DO)	16
Consideration for the wellbeing of salmon	17
Effluent dispersion and the settlement of particulate matter	18
Upper Alberni Inlet and Harbour flushing	19
Effluent dilution	19
Environmental concerns	20
1970s	20
1980s	20
1990s to present	21
LITERATURE REVIEW	22
IMPORTANCE OF ESTUARIES TO THE SURVIVAL OF SALMON	23
Estuarine diversity and benefits	23
Habitat sufficiency, quality and linkage to survival	24
PORT ALBERNI PULP AND PAPER MILL	25
Acute toxicity of pulp mill effluent	25
Laboratory tests	25
Mill effluent toxicity and hypoxic conditions	25
Toxicity compliance monitoring and environmental relevance	26
Sub-lethal bioassays	27
PME zone of influence	27
Deductions regarding the impact of pulp mill operations	28

TABLE OF CONTENTS (contd.)

	Page
DISSOLVED OXYGEN	29
Effluent colour, photosynthesis and dissolved oxygen	29
General and specific considerations	31
What is an appropriate level of dissolved oxygen to safeguard aquatic resources, and especially salmon?	31
Effects of hypoxic conditions on the breathing rate of adult sockeye salmon	31
Effect of hypoxic conditions on the swim speed of salmon	32
Behavioural response of adult sockeye salmon to hypoxic conditions	32
Growth impairment of juvenile Chinook salmon due to hypoxic conditions	32
The dissolved oxygen level that does not impair function	33
Criteria for dissolved oxygen and the protection of fish	34
The adequacy of DO criteria for application in Alberni Inlet	34
Dissolved oxygen monitoring reports and their assessment	35
Halocline	37
Surface waters	37
Upper water layer	38
Lower water layer	38
Historical comparisons	39
Outfall area	40
Fibre mat	40
ADULT SALMON	41
Adult sockeye salmon migration and aquatic conditions in the Somass River estuary	41
Fisheries and Oceans (DFO) study	42
Hatfield Consultant's study	42
Migration rates	44
Thermal history and exposure to hypoxic waters	44
Adult sockeye salmon migration and dissolved oxygen in Alberni Inlet	44
Continuing concern for migrating adult salmon	46
Laboratory studies	46
Exposure to hypoxic conditions	47
Laboratory derived results and their relevance to field studies	47
Performance of adult sockeye salmon under hypoxic and normoxic conditions and sub-lethal exposure to contaminants	47
Deductions	48
JUVENILE SALMON	48
Juvenile salmon movement into estuarine habitat	48
Willapa Bay, Washington	49

TABLE OF CONTENTS (contd.)

	Page
Dungeness River, Washington	49
Water velocity	50
Cowichan River and estuary (water velocity and depth)	50
Water velocity, depth, and habitat	51
Campbell River and estuary	51
Reduced value of some habitats and their use	52
Water velocity and prey	52
Tidal factor and habitats occupied	53
Habitat Type and Connectivity	54
Skagit River, Washington	54
Importance of the vegetated riparian zone	55
Food production	55
Cover	55
Movement of juvenile salmonids in the Somass River estuary	56
Dispersion, displacement and carrying capacity	57
Displacement and dispersion	58
Skagit River estuary	58
Sarita River estuary Barkley Sound	58
Somass River and estuary	59
Carrying capacity	61
Skagit River and estuary	62
Fish densities and habitat type	62
Somass River and estuary	62
Investigations of juvenile salmon ecology in the Somass estuary	63
Survival and behaviour experiments	63
<i>In-situ</i> survival bioassays	63
<i>In-situ</i> behaviour experiments	65
Laboratory studies (behaviour of juvenile Chinook salmon and hypoxic conditions)	66
Fish capture in vertically-stratified near-shore habitat and water quality	67
Fish capture in the intertidal zone and water quality	68
Fish capture 1970/71	68
Fish capture 1975/76	69
Study design	69
“Wild” juvenile Chinook salmon	70
Length and weight	71
Growth	71
Duration of juvenile Chinook presence and residence in the Somass River estuary	71
Residency	72
Hatchery-reared juvenile Chinook salmon	72
“Wild” juvenile Chinook salmon	74
Examples of the duration of use of estuaries by salmonids	74

TABLE OF CONTENTS (contd.)

	Page
Salmon River, Oregon	74
Campbell River, BC	75
Dungeness River estuary, Washington	75
Fraser River estuary, BC	75
Juvenile Chinook salmon captured in differing habitat in the Somass estuary (1975)	75
Habitat groups A-D	75
Zone 1 vs. 2	76
High vs. low tide	76
Recent observations of juvenile Chinook salmon in the Somass River and estuary	76
Observations after the hatchery release of juvenile Chinook salmon	77
Access to habitat and estuarine use	77
Juvenile Chinook salmon and water quality	78
Temperature	78
Influence of water quality on juvenile Chinook salmon in the Somass River estuary	80
Comparisons of water quality among habitat groups A-D	80
Comparisons of water quality between Zones 1 and 2	81
Range in water quality variables (0.5 m depth) when juvenile Chinook were captured	81
Thermal stress, temperature preference and optimal levels	82
General deductions regarding water quality implications to juvenile salmon in intertidal habitats of the Somass River estuary	83
Relevant complimentary studies in the Fraser River estuary	83
Depth and the size (length) of juvenile Chinook salmon	84
Temperature effects on juvenile Chinook presence and size	84
Dissolved oxygen influence on behaviour and occurrence	85
Salinity	85
Interaction of temperature and dissolved oxygen	85
BENTHIC ORGANISMS, DIET, FEEDING AND GROWTH	86
Habitat and the availability of prey in the pelagic and intertidal zone	86
Pelagic zone of the Somass River estuary	86
Benthic organisms in the Somass River estuary	87
Diet of juvenile Chinook salmon	89
Studies in the Somass River estuary (1970 – 1975)	89
Potential competition for prey	90
Site fidelity and opportunistic feeding	91
Examples of juvenile Chinook diet from other locations	91
Sarita River estuary, Barkley Sound	91
Campbell River estuary	92
Willapa Bay, Washington	92

TABLE OF CONTENTS (contd.)

	Page
Smith River estuary, California	92
Salmon River estuary, Oregon	92
Fraser River estuary, BC	92
Coastal Washington and Oregon	94
Feeding and growth rate	94
Implications of reduced size and growth rate	94
Somass River estuary	96
Examples of feeding and growth from other locations	97
Campbell River estuary	97
Skagit River, Washington	97
SURVIVAL AND FITNESS OF HATCHERY-REARED VERSUS WILD JUVENILE CHINOOK SALMON AND THEIR INTERACTIONS	98
Genetic factors	99
Hatchery-reared fish “success” following release	99
Importance of behaviour	99
An example of differences in feeding behaviour	100
Hatchery-reared and wild juvenile Chinook salmon interactions	101
Release strategies	102
Relative “fitness” of hatchery-reared naturally-spawning adults	102
Somass River Chinook salmon populations, hatchery production and questions	104
PREDATION	105
Predation of juvenile salmonids in estuaries	106
Value of vegetative cover	106
Influence of turbidity on predation	106
Predation by fish	107
Pacific Staghorn sculpin	107
Spiny dogfish	107
Primary fish predators in the Strait of Georgia	108
Avian and other predators	108
Big Qualicum River estuary	108
Campbell River estuary	108
Somass River estuary	108
Consumption of fish by mergansers	109
Predation by otters	109
Deductions	109
Predation and early marine survival	110
Barkley Sound	110
Skagit River estuary and marine survival	111
Columbia River estuary and early marine survival	111
Competition for prey and linkage to growth and survival	112

TABLE OF CONTENTS (contd.)

	Page
RESTORATION OF ESTUARINE HABITAT	112
General considerations	113
Meaning of recovery, restoration and rehabilitation	113
Habitat degradation and rehabilitation	114
Restoration “success”	115
DEDUCTIONS AND CONCLUSIONS	116
Concerns and historical assumptions	117
Wild versus hatchery-reared Chinook salmon	119
Interactions of river-origin and hatchery-origin juvenile Chinook salmon	120
Competition for space	120
Competition for food and dietary overlap	121
Growth rate	121
Ecological aspects	121
Chinook salmon and degradation of estuarine habitat	122
Predation and survival	124
Port Alberni mill	125
Monitoring and inferences	125
Complimentary laboratory and field studies	126
Habitat features, water quality, restoration and rehabilitation	127
Adult salmon returns; “pristine” and “contaminated” estuaries	128
Conclusions	129
ACKNOWLEDGMENTS	130
REFERENCES	131

LIST OF TABLES

	Page
Table 1. Dissolved oxygen, temperature and salinity data determined at two locations in the Somass River estuary April 24 2014. The data reveal dissolved oxygen supersaturation to a depth of 7 m (Courtesy of A. Popovich, Catalyst Paper).	30
Table 2. Catches of juvenile Chinook salmon by beach and purse seine at Polly Point in 2000 and 2001 (from Tanasichuk; DFO unpublished data).	60
Table 3. Catches of juvenile Chinook taken by dip net from the water surface in Alberni Harbour during 1971 (from Kask and Parker 1972).	69
Table 4. The range in water quality variables at the time of fish capture by beach seine in the estuary of the Somass River, 1975 (* denotes marginally stressful levels).	81
Table 5. The level of dissolved oxygen and temperature when juvenile Chinook salmon were captured in the estuary of the Somass River during the Robertson Creek Hatchery's sampling program. (* potentially stressful; ** potentially lethal with prolonged exposure).	82
Table 6. Primary prey groups and dietary overlap for fish captured in the Somass River estuary 1975 (Birtwell 1978; DFO unpublished data).	90
Table 7. Items in the diet of juvenile Chinook salmon of river- ("wild") and hatchery-origin (semi-natural, small and large) captured in the estuary of the Sarita River, Barkley Sound (from Ochman 2014).	100

LIST OF FIGURES

Figure 1. Influence of temperature on growth of Chinook salmon at various oxygen levels (from US EPA data (1986), original research in Warren et al., 1973; BCMELP 1997).	33
Figure 2. "Upper" water column dissolved oxygen (% air saturation) values determined in 2001 compared with data for the previous 14 years (deemed historical). Data averaged for water depths <5 m and salinity <15‰ (from Seaconsult Marine Research Ltd. 2002).	35
Figure 3. "Deeper" water column dissolved oxygen (% air saturation) values determined in 2001 compared with data for the previous 14 years (deemed historical). Data averaged for water depths >5 m and salinity >25‰ (from Seaconsult Marine Research Ltd. 2002).	36
Figure 4. Sites at which sampling and <i>in-situ</i> experimentation occurred in 1975 in the estuary of the Somass River (from Birtwell 1978).	64
Figure 5. Average catch of juvenile Chinook salmon per beach seine (20 sets per date) within the Somass River estuary in 1975 (April 4 data from 1976), (from Birtwell 1978).	72
Figure 6. Length, weight and stomach fullness of juvenile Chinook salmon captured in the Sarita River estuary in 2013 (from Ochman 2014).	101

Birtwell, I.K., M.E. Wright, and P. Edgell. 2014. Aquatic habitat in the Somass River estuary: a selective review and implications to Chinook salmon. Fisheries and Oceans Canada, Nanaimo; Alberni Valley Enhancement Association, BC. DFO CATNO 352934. 151p.

SUMMARY

This report reviews information relating to the quality of habitat in the estuary of the Somass River, and implications to Chinook salmon. It draws on literature specific to Alberni Inlet and the Somass River and other publications to help understand the effects of habitat change and the benefits to salmon. In the context of this report the use of “habitat” is encompassing and refers to the integration of biological, chemical, and physical aspects; it therefore includes water.

Assumptions of differential survival of hatchery-reared and river-originating juvenile Chinook salmon (designated “wild” - a river-origin mix of progeny from wild and previously hatchery-reared individuals) to adulthood, focussed attention on estuarine habitat sufficiency and quality, and other factors that could affect their wellbeing. Accordingly, this review addresses potential constraints to the survival of juvenile Chinook salmon during their early life. It includes the quality of estuarine waters and the impacts of industrial wastes from the Port Alberni pulp mill; the distribution, estuarine residency and site fidelity of juveniles; interactions and differences between hatchery-reared and wild-origin juveniles; their relationships with habitat quality and type, food availability, diet and growth, and their behaviour; predation in river, estuary and ocean; survival to adulthood related to the quality of estuarine habitat; habitat conditions in the estuary during adult migrations; the value of estuarine habitat and its’ rehabilitation.

The vertically-stratified estuary of the Somass River has been degraded due to industrial and urban developments over almost 70 years since the Port Alberni pulp mill commenced operations; about 66.5% of estuarine habitat is considered to be either lost or degraded (Catherine Berris Associates Inc. 2010). Because of concern for the wellbeing of salmon and the need to rapidly dilute and disperse pulp mill effluent (PME) research findings dictated that “effluent *must* enter the Inlet at the surface, with a minimum of turbulence, and no vertical component of flow” (Tully 1948), and “to dump it into the deepest water would be even worse, because in the deep layers there is so little oxygen that the sewage would not be neutralized, and eventually would diffuse into upper layers, without warning, and create a state of pollution which could not be controlled”. Thus the toxic effluent was discharged into the freshwater lens of the Somass River estuary thereby facilitating dilution and seaward dispersion within waters that were relatively high in dissolved oxygen. These oxygen-saturated waters were used to “accommodate” the effluents’ biochemical oxygen demand (BOD) and result in a depression of dissolved oxygen (DO) towards a limit of 5 mg/L which was assumed to be an appropriate concentration of DO to protect salmon (in the 1940s knowledge of salmon ecology, behaviour and physiology was less than now and some assumptions have been refuted or found inaccurate).

The assimilative capacity of receiving waters of Alberni Inlet has been exceeded due to waste materials and significant depressions of DO (i.e. hypoxic conditions) have occurred, especially at depth in the upper Inlet. In 1948 the statement was made that “the presence and accumulation of pulp fibre in the anticipated amounts is not considered deleterious since there are no anadromous fish or sessile bottom forms in the part of the Inlet likely to be affected” (Tully 1949). Tully, unfortunately, was not able to predict the cumulative effects of the pulp fibre and the potential of harm to salmon at that time and a legacy from the decay of this material remains.

The level of 5 mg/L DO has proven inadequate to protect salmon; levels >7.5 mg/L would confer greater protection. Research revealed the exacerbating effects of toxicants combined with hypoxic conditions and forecast acutely lethal limits regarding dilutions of PME (Alderdice and Brett 1957): “Coincident high effluent levels and low oxygen saturation values occur only in the immediate vicinity of the mill outfall” that under present conditions, interference with seaward-migrating salmon might only be anticipated from the effluent “slug” in the immediate vicinity of the outfall if such migrants were to remain in this restricted area for a period in excess of about two days. But, “such behaviour is considered to be improbable.” However, we now know that salmon will not always avoid waters of sub-optimal quality and accordingly in polluted environments there is heightened concern for their wellbeing.

In the 1970s research in the Somass River estuary provided evidence of adverse effects on fish and their habitat attributable to PME, and industrial and urban developments. Inhibition of marine phytoplankton photosynthesis at the lower boundary of the halocline and below due to coloured PME limiting autotrophic and heterotrophic productivity had implications to salmon for not only would food be impoverished in the water column, replenishment of dissolved oxygen would be limited and hypoxic conditions prevail. Studies of benthic organisms revealed a complex interaction of PME and fresh waters resulting in changes in community structure. The availability of prey and the diet of the juvenile Chinook salmon reflected degrees of habitat quality and habitat fidelity, but growth rate of combined initially-larger hatchery-reared and smaller “wild” juvenile groups was similar to that in other estuaries. Studies on vertical and horizontal fish distribution in near shore intertidal regions of the estuary, examinations of the diet of fish related to benthic organisms, results from *in-situ* studies coupled to confirmatory results from laboratory toxicity and behaviour experiments, led to the conclusion that certain estuarine habitat conditions effectively constrained the living space for juvenile salmon laterally and vertically. Habitat conditions were potentially lethal to fish in some locations. Not all these studies were thorough but collectively they revealed a need for improved environmental conditions to safeguard aquatic organisms.

In more recent years DO conditions have shown improvement in the Somass River estuary but remain depressed at depth. In very shallow waters dissolved oxygen and temperature are not likely to stress juvenile salmon until later in the summer, unless food is limiting and necessitates movement to cooler waters to lower metabolic demands. However, hypoxic conditions at and below the very shallow halocline will likely continue to restrict the vertical living space of juvenile salmon during the late spring and summer.

Currently (May 2014) conditions in these waters reflect photosynthetic activity reminiscent of pre-mill times, and if persistent they will greatly benefit aquatic organisms in the surface waters.

Morris and Leaney (1980) commented that even though greater dissolved oxygen depression had occurred since the pulp mill started operating; it was “not considered to hinder adult salmon migration”. However, concern for safeguarding the health of adult salmon was emphasized in 1990 during a climate-induced 48-day migration delay (and 40-d in 2004, 8-d in 2012; K. Hyatt, Research Scientist, DFO *pers. comm.* 2014). Adult sockeye salmon occupied deeper cooler waters with low levels of DO resulting in the loss and debilitation of about 200,000 fish in the Inlet, and others died before spawning in fresh water. Temperature appeared to be the controlling and overriding directive factor, rather than dissolved oxygen, resulting in the occupation of deeper but debilitating hypoxic 9°C - 12°C waters, and increased infestation by sea lice ensued (Johnson et al. 1996).

It is expected that hypoxic waters at depth will continue to pose a threat to adult salmon, and especially when migration is delayed and these non-feeding adults reduce metabolic demands by behavioural thermoregulation which, unfortunately, results in movement to deeper waters containing very low and potentially stressful to lethal levels of dissolved oxygen. Such behavioural (survival) traits are adaptive and it is speculated that in less polluted environments such equivalent deeper and cooler waters may be of higher dissolved oxygen and therefore potentially less harmful.

Based on studies of adult salmon migration in 2012 (an “abnormal” year regarding oceanographic conditions and “an extended cool spring”), and in reference to results of monitoring water quality and effluent toxicity it was stated that “Overall, results indicate that historical impacts of paper mill effluent in Alberni Inlet no longer pose a risk to migrating sockeye salmon and that current Pulp and Paper Effluent Regulations effluent quality standards are protective of fish” (Hatfield 2013b). We consider that support for such a definitive statement is not currently available; the latter part of this statement has not been proven specifically, and the former part is questionable. A precautionary approach would be appropriate in view of environmental uncertainty and the warming climate which is considered to impact marine survival of Chinook salmon.

The efforts of the Port Alberni mill owners, their compliance with operating conditions, modifications to effluent treatment, and environmental and toxicity monitoring, has provided information relating to aquatic conditions at the head of Alberni Inlet over more than 20 years. Data generated by consultants have permitted changes and trends to be identified. Under the current operating conditions, improvements in water quality have been revealed from that which existed more than 2 decades ago.

Monitoring studies carried out for the mill have not always been of direct importance to understanding how environmental conditions in the estuary may constrain or facilitate use by juvenile Chinook salmon. Laboratory determinations of acute toxicity of mill effluent in which a “pass” or “fail” relates to whether $>$ or $\leq 50\%$ of test fish survive in a

96-h exposure have little relevance to fish inhabiting the Somass River estuary. The results have significant value in comparative assessments of effluent toxicity by using a standard protocol. The assumption of “no toxicity” is erroneous when <50% of test fish may be killed (and without regard to the debilitating effects at the sub-lethal level) yet the effluent would be considered as not toxic. Other results of effluent “toxicity” have been provided, especially through the Environmental Effects Monitoring (EEM) program. Some of the tests were more sensitive and appropriate, but also lack relevance to the estuary. Comments about this topic have been elaborated upon in the report; no criticism is implied of those who must perform such tests to comply with regulatory requirements.

That laboratory bioassay results have been used to infer or conclude circumstances in the estuary of the Somass River is a concern. A number of reports have deduced the zone of influence of the mill’s effluent and related this to laboratory-derived results (we are not aware of recent *in-situ* studies that would help define the influence of PME on organisms in the estuary). Furthermore, there is no guarantee that results determined in the laboratory will be mirrored in the environment, and vice versa. Accordingly it seems most logical that a combination of laboratory and field tests should be carried out; the latter present a greater logistical and statistical challenge. Such integrated studies will provide for more meaningful assessments and lessen reliance on inferences from laboratory tests alone.

Few studies have examined the relationship between habitat quantity, quality and function in the estuary of the Somass River (studies in other locations provide some relevant information). Studies of fish distribution within the last 17 years have revealed the presence of fish in differing habitats but these studies were not always standardized to sampling location nor did they always account for, or examine, factors influencing fish presence and use. Most recently, observers recorded fish in a variety of habitats. The program has been limited and provided information on fish presence and distribution, but not reasons for the occupancy of these habitats and the function they provide. All studies have deficiencies and are usually carried out under limitations in design and scope (such studies are not inexpensive). They have added to knowledge of the Somass River estuary and its use by juvenile salmon but it will only be through a more thorough co-ordinated approach that many of the concerns associated with benefits of estuarine residence to the health and survival of juvenile Chinook salmon will be possible. Some need not be of a large scale but they must strive for statistical rigour.

The inability to always differentiate juvenile Chinook salmon of river-origin from all hatchery-reared individuals prevents establishing differences and similarities between them and, accordingly, respective use of habitats and benefits that may accrue. Hatchery and “wild” juveniles have been present in the estuary until August; from late May to early June and from March respectively. The majority of hatchery-reared juveniles were estimated to reside in the estuary between 10 and 31 days, and residence of “wild” individuals >4 weeks. The peak abundance of “wild” juveniles in the estuary varied between April and June but may have been obscured by releases from the hatchery. Displacement of “wild” juveniles from riverine and estuarine habitat has been inferred

due to the influx of large numbers of juveniles released from the hatchery, sometimes in numbers exceeding those (estimated) of progeny from river spawning adults.

It is not known whether adverse water quality in shallow surface waters will restrict the vertical and horizontal living space of these fish at the present time. Seasonal changes will result in elevated temperature in the tidal waters flooding the intertidal zone and eventually they attain levels stressful to fish. It may not, however, deter fish from temporary excursions into potentially lethal waters to feed. On the other hand, lower levels of dissolved oxygen occur at elevated water temperature and together these factors have been determined to influence and limit the occupation of habitats for feeding.

Juvenile Chinook salmon have been shown to use many habitats in the Somass River estuary. They have been constrained or limited by adverse water quality yet have successfully obtained food in a variety of contrasting situations wherein preferred prey were not always present. Fidelity to such sites, and feeding in such “poor” conditions was unexpected, however, the facultative opportunistic behaviour of these fish is well known. Potential competition for food between juvenile Chinook salmon and other fish was indicated from analyses of stomach contents that revealed dietary overlap. Reduced growth rate has been attributed to density related competition for food in other locations and potentially reduce survival. However, predation has been suggested as the primary factor affecting survival of juvenile salmon.

Predation of juvenile salmonids by birds, fish and mammals has not been quantified in the Somass River estuary. These predators reside there and they have been documented to consume significant quantities of hatchery and wild juvenile salmon; predation in marine waters is a significant source of mortality, and field studies have deduced the greater vulnerability of hatchery-origin fish versus their wild counterparts.

Survival of juvenile Chinook salmon from the Robertson Creek Hatchery was related to growth rate in Barkley Sound which led to variable adult returns (<5% each year; ten-year period). Reduced fitness, performance and sensory deficits, and changed survival behaviours in hatchery-reared juvenile salmonids have adverse implications to long-term survival; hatchery fish typically have a lower survival to adulthood than their wild counterparts. Evidence that adults of “wild” Chinook salmon in the Somass River system were returning in fewer numbers than hatchery-raised fish was not found; the number of progeny from river-spawning adults is not known. One may also question the assumption that all river spawning individuals produce truly wild progeny in the Somass River system. The inevitable spawning of hatchery-reared individuals in this system for about 40 years has likely reduced the numbers of what were pre-hatchery, truly wild fish.

An extensive review of hatchery and wild fish interactions has raised concern regarding the productivity of such mixed-origin stocks in the same river system; as occurs in the Somass River. Chilcote et al. (2011) evaluated populations containing different proportions of hatchery-reared fish admixed with those of wild-origin. They determined that the reproductive performance of Chinook salmon, and other salmonids, declined as the fraction of hatchery-reared spawning adults increased in the natural population. It was

found that the productivity of a population will likely be reduced if significant numbers of hatchery reared fish are allowed to spawn naturally; recruitment performance for a population of entirely of hatchery fish was predicted to be about 13% of that for an equivalent population of wild fish.

Information is presented on the positive value of estuarine habitat and its contribution to the survival of Chinook salmon. The more the habitat becomes, or is in, a “pristine” state, with increasing complexity and meeting the functional rearing requirements of quality, space, food and protection, the greater is the promotion of diversity of life history strategies and resilience in populations which, in turn, are linked to greater survival (Magnusson and Hilborn 2003). Juvenile hatchery-reared Chinook salmon transiting contaminated estuaries have been determined to have poorer (45% lower) survival to adulthood and consequently fewer individuals returning to natal waters (Meador 2014).

Opportunities exist in the Somass River estuary to improve and diversify habitat for the benefit of all organisms. However, rehabilitation must consider the need for the prudent discharge and treatment of domestic sewage and other wastes to avoid compounding hypoxic conditions in deep upper-Inlet waters and potentially hindering natural recovery; notwithstanding other potential problems associated with increased organic pollution and contaminants and their effects on the wellbeing of organisms.

Sewage from the city of Port Alberni is discharged into surface waters near the middle of the upper estuary. The contribution of this material to the BOD load of the estuary is significant and accordingly the organic input and its distribution into tidal channels and other important nursery and rearing areas for many organisms is a concern. It is speculated that if dissolved oxygen depression occurred it would deter fish use and also have a negative impact on food production for them and others. The impact of this discharge requires study as it could influence and possibly complicate efforts to rehabilitate the estuary. Studies have documented the impacts of discharging sewage onto an intertidal region and the ensuing stressful and lethal conditions to fish.

There is a paucity of studies that address the ecology of Chinook salmon in the Somass River estuary. Many speculations made on impacts due to the Port Alberni mill, based on laboratory tests and limited field study, appear inappropriate and lacking environmental specificity and verification. Accordingly, important relationships between fish and their environment, and especially constraints due to human activities, are ill-defined or unknown, yet these aspects are within our control and may be changed for an environmental benefit.

Evidence and compelling inferences from other studies, which include analyses encompassing many years, have added knowledge on the importance of estuaries and also provide guidance for their rehabilitation. In recognition of this information it may be safely inferred that improvements to the complexity, quality, and sufficiency of estuarine habitat will benefit Chinook salmon and potentially increase population resilience and survival. But, validation of these actions will only be possible through co-ordinated programs, aspects of which have been exemplified in this review.

INTRODUCTION

Concern has been expressed over the lower survival of “wild” juvenile Chinook salmon (*Oncorhynchus tshawytscha*) to adulthood relative to the corresponding survival of juveniles released from the Robertson Creek Hatchery and this seems contrary to expectations (“wild” designates a river-origin mix of progeny from wild and hatchery-reared individuals). The reasons for such apparent differential survival are likely many but in the industrialized estuary of the Somass River a number of specific factors have been considered to negatively affect the rearing habitat of juveniles and potentially affect survival, directly and indirectly.

The suitability of water quality and other habitat features upon which aquatic organisms depend are of critical importance to their wellbeing in estuaries and elsewhere. However, because of the temporary residence in estuaries by rearing juvenile Chinook salmon it may be expected that habitat degradation and loss could have a negative impact on their survival. In the context of this report the use of “habitat” is encompassing and refers to the integration of biological, chemical, and physical aspects; it therefore includes water. It is understood that habitat (and related intrinsic factors such as predation) along the length of Alberni Inlet, in Barkley Sound and in the Pacific Ocean play a significant role in the survival of juvenile salmonids to adulthood. However, the primary focus of this review relates to upper Alberni Inlet and the Somass River estuary where much habitat change has occurred over more than 60 years.

A number of studies identified potential constraints to the use of the Somass River estuary by juvenile salmonids and other fish due to impoverished/alienated habitat caused by, for example, industrial and urban developments along the shoreline, degradation of tidal flats used for log storage, the discharge of sewage and other wastewaters including effluent from the pulp and paper mill, and exacerbated hypoxic conditions in sub halocline waters. (“PME” is used to categorize pulp and paper mill effluents which have varied in constituents and volume over time).

Depressed levels of dissolved oxygen (DO) have been a concern for many decades because of the requirements of Inlet waters to accommodate oxygen-consuming wastes, and the naturally-slow flushing rate of Alberni Inlet waters. Decomposition of organic matter, primarily from the Port Alberni mill was the prime cause of subsequent serious depressions in dissolved oxygen at the head of the Inlet. For many years the oxygen demand of PME, which is discharged into the freshwater lens of the highly stratified Somass River estuary, contributed to a decline in the dissolved oxygen concentration of these surface waters such that by the late 1980s the general decline was about 1 mg/L from pre-discharge conditions. Over the same period the corresponding decline in the deeper sub-halocline waters had been about 4 mg/L; a reduction of almost 60% (Stucchi et al. 1990).

Studies carried out in the 1970’s revealed that the waters at, and below, the shallow halocline were sub-optimal to acutely lethal to juvenile salmon, and that the distribution and the diet of juvenile Chinook salmon changed with proximity to industrialized areas of

the estuary. It was deduced that the habitat for juvenile salmonids in the estuary was restricted both laterally and vertically. Forty years later there continues to be concern over the quality of habitat, despite significant positive changes such as improved treatment of wastes discharged into estuary, reduced input of organic material and effluent from the pulp mill, and reduced intertidal shallow-water log storage.

Monitoring has identified improving trends in water quality but there remains a need to understand whether this is sufficient, how the habitat has improved, what habitat is being utilized by juvenile Chinook salmon (and other species) and for how long, and whether food, feeding and rearing areas have changed to benefit or constrain the use by aquatic organisms. Opportunities for improvement of habitat have been, and are being, assessed to aid rehabilitation of the estuary.

This report is one component of projects that attempt to address some of the concerns over the environmental status of the Somass River estuary and Alberni Inlet. Specifically, the tasks reported here have included:

1. A review of recent water quality data provided by Catalyst to determine whether juvenile salmon are being vertically and/or horizontally restricted in the estuary and upper Inlet by changes in water quality.
2. A review of previous research conducted in Alberni Inlet to inform the Department of Fisheries and Oceans (DFO) about the rearing behaviour, habitat use and preference, of rearing wild and hatchery-reared juvenile Chinook salmon.

BRIEF PERSPECTIVE

A brief synopsis of industrial development and consequential effects on the aquatic environment is provided to place the current circumstances in the Somass River estuary into the context for this review.

Pulp mill location, effluent discharge, water quality and concern for salmon

The pulp mill in Port Alberni began operation in 1947 and was expanded in 1954. It was located at the mouth of the Somass River to take advantage of the strong and consistent vertical stratification of estuarine waters that prevented rapid mixing between water layers above and below the pycnocline, and the seaward impetus provided by the Somass River for effluent dispersion and dilution in the fresh to brackish waters (refer to Parker and Sibert 1972).

Effluent discharge and dissolved oxygen (DO)

After much analysis, it was concluded that the effluent *must* “enter the Inlet at the surface, with a minimum of turbulence, and no vertical component of flow” (Tully 1948). “to dump it into the deepest water would be even worse, because in the deep layers there

is so little oxygen that the sewage would not be neutralized, and eventually would diffuse into upper layers, without warning, and create a state of pollution which could not be controlled”.

Thus the effluent was discharged into the freshwater lens of the Somass estuary. In this way dilution of toxic effluent in the fresh water lens would be assisted and dispersed seaward within waters that were, at that time, relatively high in dissolved oxygen. The oxygen-saturated waters would be used to “accommodate” the effluent biochemical oxygen demand (BOD) and result in acceptable reduced levels of DO. Keeling (2007) reported that “fisheries scientists framed the physical characteristics of Alberni Inlet in terms of its ‘assimilative capacity,’ or the ability of ocean waters to absorb, dilute and disperse industrial wastes without harm to valuable fish species”. In 1948 Tully concluded that his research had “established a workable measure of pollution, defined the tolerable limits, and shown how they can be determined, either before or after pollution occurs, in Inlets and rivers”.

The naturally-poor flushing, relatively lower DO in deeper sub-halocline waters with up-Inlet currents at the head of the Inlet/Harbour area was considered to negate the option to discharge wastes from the pulp mill at depth into these waters. According to Tully (1949) “the oxygen content of the water entering the Inlet would be a seasonal function varying from a minimum (in the summer during the prevalence of westerly winds along the ocean coast) of the order of 70% of saturation, to a maximum during the seasons of variable or south-westerly winds, when it would be 90% to 95%”. “The oxygen content of the upper zone would vary from saturation at the surface to this value at the inter-zone boundary. June 15 to September 15: 85% ± 5%; October 15 to May 15: 95% ± 5%”.

Oceanographic data for 1941 are cited (Fisheries Research Branch) in the report by Hatfield Consultants (2013a). It is of interest that before the mill, at Hohm Island (a reference location that is still utilized for oceanographic measurements) in Alberni Harbour, DO levels were typically close to, or above, air saturation levels at all water depths except those at the bottom.

Dissolved oxygen super-saturation occurred on numerous occasions in 1941 and especially so just below the halocline (considered a function of phytoplankton photosynthesis - refer to Parker and Sibert 1972) and on May 8, 1941 the water column at Hohm Island was supersaturated with dissolved oxygen. Only in the coolest (typically 10°C - 11°C) and deepest (10 m or 8 m depth) waters at the Hohm Island monitoring site did particularly hypoxic waters usually exist (but ranged from 20% to 104% air saturation) between April and August. Above these bottom waters dissolved oxygen was substantially elevated and, in the waters above the halocline, they were typically saturated with respect to DO (refer to data cited by Hatfield Consultants (2013a)).

Consideration for the wellbeing of salmon

Tully (1948) commented that industry had been constrained/directed in the type of mill that could operated because of the need to protect salmon resources (adults?) in Alberni

Inlet. In 1938, the Bloedel, Stewart and Welch lumber company proposed to construct a sulphite pulp mill at the head of Alberni Inlet (Keeling 2007). Tully concluded that oceanographic conditions precluded the establishment of a sulphite mill at the head of the Inlet, due to the extreme biochemical oxygen demand of the effluent.

It is recorded that the Federal Minister of Fisheries mandated that the process be “kraft” rather than “sulphite”, because of the potential for greater impacts due to the latter process. The construction of the pulp mill was in 1947. Tully stated that in 1948 “no pollution” was “expected from the existing pulp mill”.

A dissolved oxygen concentration of 5 mg/L was considered to be appropriate for the well-being of fish and not be harmful to them (refer to Tully 1948, 1949; Waldichuk 1954, 1987; Keeling 2007). Thus, it was expected that the usually high DO levels in waters receiving the PME would be lowered as the BOD of the wastes was “assimilated” (*the inadequacy of this DO criterion is commented upon in more detail later*).

Tully (1949) commented that “the presence and accumulation of pulp fibre in the anticipated amounts is not considered deleterious since there are no anadromous fish or sessile bottom forms in the part of the Inlet likely to be affected.” (*Information on salmon migration behaviour in the Inlet was not known at this time. We now know that adult salmon do use such waters at depth and sometimes to their detriment; Birtwell and Korstrom 2002*).

Keeling (2007) reported that “Ongoing monitoring of the Inlet revealed that the goal of forecasting pollution had proven elusive, as already by the mid-1950s, water quality problems emerged. Initially, mill waste was discharged via an open channel across the swampy tidal flats at the mouth of the Somass River, a situation which threatened to create intermittent toxic concentrations of effluent, particularly during periods of low river flow” “Twice the company was prevailed upon to relocate the outfall to where the effluent would mix more effectively with receiving waters”.

Although annual follow-up surveys of Alberni Inlet found ample dissolved oxygen levels in the water, a proposed mill expansion in the mid-1950s that would double pulp production and add a newsprint mill raised concerns about the dilution and dispersion of increased volumes of effluent, particularly during periods of low river discharge (Waldichuk 1956 cited by Keeling 2007).

For the protection of juvenile salmonids and the maintenance of an oxygenated surface layer for adult salmon migration it was considered necessary to maintain a minimum flow into the river through an upstream dam. This, it was thought, would provide sufficient fresh water for effluent dilution to levels that were not expected to cause acute stress.

Effluent dispersion and the settlement of particulate matter

Modelling and oceanographic data for the Inlet by Tully (1948, 1949) provided much certainty in regard to the above-halocline dispersion and dilution of dissolved

components of effluent. However, these actions and predictions did not alleviate concern for deeper waters due to effluent disposal and other practices (e.g. such as log booming and storage, ocean disposal), to adversely affect salmonids that utilized these waters during rearing and seaward migration.

Particulate organic material (fibre) from the pulp mill became deposited in the upper Harbour. The deposition and subsequent decay of this material was found to be extensive (Stucchi et al. 1990). Webb and McCullough (1992) recorded a “black visible layer” in sediment cores, and characterized them as having a “lack of macroscopic organisms and a strong smell of hydrogen sulphide”; typical of anoxic conditions.

The volume of impacted sediments was calculated to be 231,000 m³ and it extended from the mouth of the Somass River primarily along the eastern shoreline to a location opposite Hohm Island (Seaconsult Marine Research Ltd. (1992). This finding indicated that the deposition, at that time, was along the expected net seaward effluent dispersion path caused by flows from the Somass River and tidal currents, thus conforming to the findings and predictions of Tully (1948, 1949).

Upper Alberni Inlet and Harbour flushing

Prior to the Environmental Effects Monitoring (EEM) program, Seaconsult Marine Research Ltd. (1994) reviewed baseline information and referred to the effluent plume delineation studies of Hodgins et al. (1993). These studies confirmed the restriction of *the dissolved effluent components* to the brackish upper water layers of Alberni Harbour and seaward along Alberni Inlet as predicted by Tully (1948, 1949).

The flushing time for the “harbour” under low-flow conditions was 2-3 days according to Seaconsult Marine Research Ltd. (1994), but Tully (1949), cited by Morris and Leaney (1980) reported that it could be up to 11 days.

Seaconsult Marine Research Ltd. (1994) did not comment on the flushing of shallow waters in the north-western area of the estuary where waters were predicted by Tully (1948, 1949) to accumulate and also take longer to exit the harbour.

Effluent dilution

It is generally accepted that effluents entrained in fresh surface waters of the Somass River will be dispersed laterally and across the Inlet by Polly Point.

Effluent dilution at Polly Point, the entrance to Alberni Harbour (essentially Alberni Inlet north of Polly Point) was calculated to range from >1% to 10% at the “log pond” (Seaconsult Marine Research Ltd. 1994). Furthermore, Seaconsult Marine Research Ltd. (1994) reported that between Polly Point and Hocking Point (approx. 15 km down the Inlet from the mouth of the Somass River) effluent dilution is rarely greater than 1% and usually ranges of 1 to 0.1%, thus, they concluded that organisms “south of Hocking Point will never be exposed to effluent at concentrations exceeding 1%”.

Environmental concerns

1970s

At the time the pulp mill started operations, studies focussed mostly on potential changes to water quality due to effluent discharge and, in a very preliminary but understandable way, the potential toxic effects on salmonids. At that time there had been little emphasis placed on understanding salmonid ecology, the use of the Somass estuary for other industrial activities and their potential to affect aquatic production and use.

In the early 1970's DFO staff at Port Alberni requested an assessment of the habitat and fish use as they recognized the changes that had occurred, and were occurring, could have a detrimental impact on the salmonid resources in particular. (*It was expected that the studies would be replicated and expanded upon at some later date but, this has not occurred to any significant extent*). The findings of earlier studies will be expanded upon later. They include those by Kask and Parker (1972), Sibert and Parker (1973) and Parker and Sibert (1973) who carried out investigations relating to the impact of coloured PME on the production of organisms and of juvenile salmonid in the Somass River estuary. Harger et al. (1973a, b; Ketcham 1977) examined the effects of ambient conditions and PME on benthic invertebrates along the eastern shoreline of Alberni Harbour.

Birtwell and colleagues undertook some baseline studies of the habitat and its use by fish in 1975/1976 (e.g. refer to Birtwell 1978; Birtwell and Harbo 1980; Birtwell et al. 1984; Birtwell and Korstrom 2002; Birtwell, DFO unpublished data). It was concluded from this research that the habitat for juvenile salmon in the Somass River estuary was restricted laterally and vertically. The waters at depth below the shallow halocline were potentially lethal to juvenile Chinook salmon, and the waters were sub-optimal close to the discharge location of effluent from the pulp mill.

Also, the diet of the fish shifted in relation to the availability of prey which was less abundant and impoverished on the eastern side of the estuary proximal to the industrialized shore and dilutions of effluent from the pulp mill. These authors considered that the aquatic environment in Alberni Inlet had been seriously affected by industrial activities, and specifically through the discharge of effluent from the Port Alberni pulp mill.

1980s

The status of the Somass estuary almost 30 years after the mill had been operating was reported by Waldichuk and others (refer to e.g. Morris and Leaney 1980). Based upon their review of the status of the Somass River estuary, Morris and Leaney (1980) commented that even though greater dissolved oxygen depression had occurred since the pulp mill started operating; *it was "not considered to hinder adult salmon migration"*.

This, and similar statements were made without specific knowledge of the behaviour of adult salmon migration and it was later determined that such fish (i.e. sockeye) preferred the lower temperature, sub-halocline, oxygen deficient waters to much warmer, very shallow surface waters containing more oxygen.

Subsequent research provided an insight into the behaviour of the adult sockeye salmon, the conditions experienced by them during migration and the consequences to their fitness and performance. It was apparent that the choices that we deemed appropriate for the fish to make in the face of recently deteriorated aquatic conditions were not those chosen by the fish whose behavioural repertoires had previously facilitated survival.

1990s to present

By 1990, it was obvious that the deep-water conditions of upper Alberni Inlet were potentially hazardous and lethal to salmon and that their occupancy would be detrimental to their wellbeing (Stucchi et al. 1990); as deduced from studies undertaken two decades earlier. In 1990 there was a delay to the migration of adult sockeye salmon through Alberni Inlet and the Somass River estuary due to warm climatic conditions. This 48-d delay resulted in an estimated loss and debilitation of about 200,000 migrating sockeye salmon (refer to Spohn et al. 1996; Johnson et al. 1996; Birtwell and Korstrom 2002). Migration delays have occurred since that time with consequent mortality (e.g. 2004, 40-d delay, K. Hyatt, Research Scientist DFO *pers. comm.*, 2014). Adult salmon were found to utilize cool hypoxic seawater rather than use warmer normoxic less saline waters (*in marked contrast to expectations stated decades earlier*). In addition, the combined effects of sub-lethal exposure to contaminants and hypoxic waters were found to reduce their performance. Subsequent actions taken by governments and the forest products industry limited the discharge of solids to Alberni Inlet, material which previously had contributed to a reduction in dissolved oxygen in the waters at the head of the Inlet.

Numerous studies monitored changes in water quality in these years and especially in the deeper waters of the Harbour area. Studies were also initiated as part of environmental effects monitoring programs (EEM) primarily concerned with the aquatic condition at the head of Alberni Inlet in relation to the pulp mill's effluent discharge within the context of a national monitoring framework. Very few studies have addressed the distribution of fish within the Somass River and estuary, and we are not aware of any current *in-situ* or laboratory studies that specifically address causative factors related to the wellbeing of fish within the Somass River estuary.

Since the special regulation (under the Pulp and Paper Effluent Regulations of the *Fisheries Act*) came into effect in 1992, and changes to pulp mill processes and effluent treatment, a general continuing overall improvement in the levels of dissolved oxygen in the waters at the head of Alberni Inlet has been reported. It is expected that over time the sediment oxygen demand in the deepest waters at the head of the Inlet will diminish and dissolved oxygen levels will improve, with consequential benefits to the aquatic organisms using the waters at and below the halocline in upper Alberni Inlet.

At the time of this report, some improvements to the aquatic environment have occurred but questions remain. One such question is whether the changes to fish habitat that have occurred have been sufficient, and furthermore, whether or not there remains a constraint to the occupancy and use of habitat that is required by salmonids to facilitate their survival to adulthood.

Planning is currently underway to relocate the discharge of sewage effluent in the Somass River estuary; an issue that requires attention because of the potential for such wastes with high BOD and contaminants to degrade fish habitat and potentially hinder rehabilitation of water quality in deeper waters of the upper Inlet.

Of specific concern in this review is the sufficiency and quality of habitat in the Somass River estuary and its capacity to enable Chinook salmon (and other organisms) to carry out all critical life-supporting activities.

LITERATURE REVIEW

Comments are provided that highlight important topics and findings as a pathway towards an assessment of current circumstances in the Somass estuary; there is a large data base regarding Alberni Inlet and a voluminous one on the ecology of salmonids.

There has been much reiteration in many of the reports that have addressed Alberni Inlet and particularly monitoring documents provided for EEM and for other requirements regarding the Port Alberni mill and the receiving waters of the Somass River estuary.

Documents that were used in this review are referenced. Numerous quotes from the scientific literature have been used and attributed to the authors however, where these authors also cite the publications of others, these additional documents have not always been read; they are included for completeness. We considered that this process of identifying documents referenced and used by others and abstracting from them where appropriate was probably one of the more efficient ways to report the information, rather than attempt to summarize and assess all the voluminous pertinent documents in the various disciplines which this review covers.

The opinions presented in the report are a function of the references supplied to us from DFO, others which have been obtained recently, and those of personal publications and related cited literature. The material that has been reviewed is not exhaustive but hopefully it is appropriate to satisfy the objectives of this review and assessment. In some instances information has been added to help understand the importance of certain habitat features that have significant effects on aquatic organisms, such as temperature and dissolved oxygen. Some information from studies undertaken outside the Somass River estuary have been used to identify areas of concern and provide information relating to the ecology of juvenile Chinook salmon. Comments are also provided on habitat restoration and rehabilitation. It is hoped that by providing this information it will

facilitate decisions that will, in the future, benefit the Chinook salmon populations of the Somass River system and other organisms.

IMPORTANCE OF ESTUARIES TO THE SURVIVAL OF SALMON

The return of adult Chinook salmon to natal streams (and hatcheries) is, intuitively, a function of the fitness and fortunes of individuals and the inherent limitations and constraints of various habitats, which include risks posed by predators. Assessing which components control and influence survival of individual fish to adulthood and spawning is a formidable task given the enormity and complexity of the habitats experienced throughout their life. That said, some studies have related the return of adult Chinook salmon to the diversity in, and sufficiency of, the quality of estuarine habitat (e.g. Magnusson and Hilborn 2003; Beamer et al. 2005).

Weitkamp (2010) provides an annotated bibliography on estuarine use by young salmon. He partitions the report to cover the time period when the fish are found in estuarine areas, characteristics of habitats used by the young salmon, behavioural characteristics during estuarine rearing, food sources consumed by the juveniles, salinity tolerance of young salmon, duration of residence in the estuary, growth during estuarine rearing, and information on predation. Reference should be made to this document for additional information.

Aquatic habitats have the potential to influence the fish that occupy them in numerous ways but the realized function of habitat is ultimately associated with the opportunity (i.e. water depth, velocity, quality) as well as capacity (e.g. prey availability, structure) to support the life history patterns of a salmonid that depends upon it (Simenstad and Cordell 2000, cited by Sather 2008). It is apparent that fish from different river systems and with differing life history strategies use estuaries over differing time periods and in this way demonstrate the value of innate behaviours and requirements that have facilitated survival and their species/stock. The role that estuaries play in the life of Chinook salmon is complex and related to life history variants as well as the availability of habitat and their temporary dependency upon it for acclimation to salt water, refuge from predators, food production and feeding (Levings et al. 1989). Semmens (2008) stated that the interface between fresh and salt water aids in the physiological changes of smoltification (Simenstad et al. 1982; MacDonald et al. 1987; Thorpe 1994), the abundance of food in the near shore environment allows for rapid growth (Congleton et al. 1982), and the habitat components of the estuarine environment provide ample cover from a potentially large predator base (Wood 1987). Macdonald and Levings (1988) also reported the positive relationship between extended estuarine rearing and survival of returning adults (Sather 2008).

Estuarine diversity and benefits

In general, and often despite specific conclusive evidence, it has been accepted through compelling inferences that the temporary estuarine residency of juvenile salmonids

confers benefits which accrue and facilitate ocean survival to adulthood. In this regard, life history diversity has been closely linked to the estuarine rearing opportunities afforded by various habitats such as, for example, tidal channels, marshes, mud flats, eelgrass meadows, sloughs and embayments (refer to Sather 2008).

Sather (2008) stated that increasing life history diversity is important to consider as it increases resilience to natural and anthropogenic changes. It has been documented, that the restoration of estuarine habitat complexity in Oregon has resulted in an increase in life history strategies by Chinook salmon and that there has been a corresponding increase in residency and a shift for smaller size classes of individuals to migrate to the estuary earlier. While Quiñones and Mulligan (2005) reported that once juvenile salmonids reach the estuary, high mortality rates can decrease the seasonal abundance of juveniles rearing in unsuitable habitats, other studies of yearling spring Chinook salmon have demonstrated a faster estuarine growth prior to seawater entry in the spring and improved smolt physiology (seawater adaptability) and smolt-to-adult survival (Wagner et al. 1969; Beckman et al. 1999). The complexity of the issue is indicated by Beamer et al. (2005) who considered that whereas “this linkage has been demonstrated for both yearling and sub-yearling salmon, high survival rates have not been conclusively linked to high growth rates in young juvenile salmon (<110mm fork-length)”. Notwithstanding the lack of definitive cause and effect data, these authors provide the case for increasing tidal delta habitat capacity and quality in order to increase fish residence and especially in locations where density dependent factors may influence survival. By doing so, they considered that it should be possible for fish to benefit from faster growth and increased time of estuarine residence translating into a larger size of individuals and potentially better survival. Conner et al. (2011) stated that “On average a Skagit ocean type juvenile Chinook salmon will rear in the estuary approximately 35 days (Beamer et al. 2005). The results of an ongoing otolith study links juvenile Chinook salmon survival potential in Skagit Bay to rearing time in the Skagit tidal delta (Beamer, E., pers. comm., SRSC, 2010)”.

Habitat sufficiency, quality and linkage to survival

The sufficiency and quality of habitat has been shown to influence survival of juvenile Chinook salmon to adults (Magnusson and Hilborn 2003). These authors commented that “while it has long been known that Pacific salmon use estuarine habitat, it has proven much harder to establish that the loss of estuarine habitat results in reduced survival”. They used coded-wire tagging of hatchery fish to estimate the survival from release until maturity and related this survival to several indicators of estuarine condition.

A significant relationship was determined between the survival of Chinook salmon and the percentage of the estuary that is in pristine condition (but no significant relationship for coho salmon (*Oncorhynchus kisutch*)). The findings of Magnusson and Hilborn (2003) therefore support field observations that Chinook salmon use estuarine habitat much more than coho salmon and confirmed that the loss of estuarine habitat results in lower survival of Chinook salmon.

“Marine production processes linked to salmon survival (e.g. wind-driven upwelling, time of spring transition, and the Pacific Decadal Oscillation) are quite variable along the Oregon coast (e.g. Huyer 1983; Landry et al. 1989; Mantua et al. 1997); and marine mortality of juvenile salmon may be greatest soon after ocean entry (Nickelson, 1986; Percy, 1992; Logerwell et al. 2003)” (Bottom et al. 2005a). Magnusson and Hilborn (2003) concluded that Chinook salmon from relatively unaltered estuaries (as indicated by the proportion of intact salt marsh, eelgrass, and other shallow rearing habitat) “have higher average survival rates than those from severely altered estuaries” (refer to Bottom et al. 2005a). From their study, the average survival rate of fall Chinook was 1.1%, ranging from 0.2% to 2.3% by hatchery, and the average survival rate in coastal Washington was 0.7%, somewhat lower than 1.2% in Oregon. Similarly, Meador (2014) reported that juvenile Chinook salmon “transiting contaminated estuaries exhibited an overall rate of survival that was 45% lower than that for Chinook moving through uncontaminated estuaries”.

Magnusson and Hilborn (2003) demonstrated “for the first time a direct link between estuarine condition and survival of salmon through their entire life history, suggesting that sub yearling Chinook salmon are dependent on estuarine habitat for growth and transition from fresh to salt water”, and, therefore, “adds considerable strength to the arguments for preservation and restoration of estuarine habitat as a component of salmon recovery plans by showing that pristine estuaries have much higher Chinook salmon survivals than degraded estuaries”. These comments are supportive of those of Meador (2014) and germane to the Somass River estuary and the survival of salmon.

PORT ALBERNI PULP AND PAPER MILL

Acute toxicity of pulp mill effluent

Laboratory tests

The toxicity of effluent from the Port Alberni pulp mill has been assessed over many years through the application of standard laboratory-based methods in order to fulfill the obligations specified in permits under which the mill has operated. One such method tests for lethality using fish survival over 96 hours in PME and the effluent is considered to be “non-toxic” if 50% of test subjects are surviving at the end of the exposure period. The test (96-h LC50) is a very coarse standard for effluent monitoring but does permit comparative assessments over time and among other effluents and mills etc.

Mill effluent toxicity and hypoxic conditions

Laboratory bioassays were used to examine the interaction of PME and hypoxic conditions such as may be experienced by fish in the Somass estuary. In this context Brett (1958) commented upon the need to understand indiscriminate stressors whose potential cumulative effect on all members of populations may be increased when they exert their effect singly or in combination (for example, in the Somass estuary with hypoxic waters

and toxic PME). Because of the long-standing concern for the protection of salmon in the Somass estuary and in recognition of the potential for hypoxic waters to constrain these fish, the interaction between hypoxic waters and PME was examined by Alderdice and Brett (1957).

The survival of juvenile sockeye salmon was examined in bioassays (Alderdice and Brett 1957). A lethal effect due to the exposure to PME was determined however it was progressively diminished with effluent dilution. Lethal conditions were exacerbated in hypoxic waters. The experiments did not replicate the temperature conditions found in the Inlet in summer which could have resulted in greater adverse effects on survival. It was concluded that 2.5% effluent was the limiting concentration for effluent in Alberni Inlet at that time (Alderdice and Brett 1957) and that “Coincident high effluent levels and low oxygen saturation values occur only in the immediate vicinity of the mill outfall” (Waldichuk 1954), and then only in the very shallow surface-water layer.

It was estimated in the late 1950s “that under present conditions, interference with seaward-migrating salmon might only be anticipated from the effluent “slug” in the immediate vicinity of the outfall if such migrants were to remain in this restricted area for a period in excess of about two days. But, “such behaviour is considered to be improbable” (Alderdice and Brett 1957). Earlier studies suggested the DO level of 5 mg/L as one that would be adequate for protecting the wellbeing of salmon in Alberni Inlet (Tully 1948, 1949; Waldichuk 1987). Current information on the behaviour of salmonids and particularly that of juvenile Chinook salmon, degradation of the Inlet through deposits of organic matter, and reductions in water quality above and below the halocline cast doubt on the validity of this generalised assumption.

Toxicity compliance monitoring and environmental relevance

Hatfield Consultants (2013b) reported “that to remain in compliance with the Pulp and Paper Effluent Regulations, mills are required to demonstrate no acute toxicity of effluent to rainbow trout (i.e., all LC50s – effluent concentrations that kill 50% of trout – must be greater than 100% v/v effluent)” (an impractical result, theoretically-derived).

It has been shown that such tests can be more informative if the test subjects are from the receiving waters and test conditions (different to those of the standardized laboratory compliance tests) mimic receiving water ambient conditions and exposure scenarios (Birtwell 1978). The results of bioassays with Rainbow Trout only reveal “compliance” through the use of standard laboratory-based protocols.

In 1975 the surface waters of the Somass estuary proximal to the pulp mill were found to kill a number of caged juvenile Chinook salmon (Birtwell 1978; Birtwell and Harbo 1980). These findings of acute toxicity were in contrast to the results that the pulp mill operators had obtained using standard laboratory bioassays with rainbow trout where no mortality was observed. To resolve this apparent discrepancy, parallel laboratory bioassays were run over 4 days using juvenile Chinook salmon (Robertson Creek Hatchery stock), and it was revealed that at the temperature similar to that of the surface

waters of the Somass River estuary (20°C) some of the test fish died. Thus, although the results of the regulatory bioassay at 11°C revealed no acute toxicity, the results from *in-situ* bioassays and also those at elevated and realistic receiving water temperature were lethal to a number of fish (15% to 25% died in 90% and 100% effluent respectively in laboratory bioassays).

Hatfield Consultants (2013b) reported that there has been “no acute toxicity reported during any of the EEM cycles at the Port Alberni mill. In Cycle Six, there was no acute toxicity of effluent to either rainbow trout or *Daphnia magna*; 100% of all tests passed”. Similarly, the results of bioassays to determine effects of effluent on the survival (LC50) and growth (using the incipient concentration causing a 25% response – “IC25”) of the larval topsmelt in the Cycle 3 of the EEM program revealed “no effect at the highest concentration tested” (Hatfield Consultants 2004).

The results of all laboratory-based acute lethality tests have very little application to forecasting effects in the effluent receiving waters, primarily because of their inability to replicate environmental conditions and exposures.

Sub-lethal bioassays

It is apparent that the prediction of effects of effluent in the natural environment cannot be accomplished through laboratory-based bioassays where lethality is an end point. Many effects on organisms occur at much lower concentrations of wastewaters that have been described as non-lethal or lethal through standard bioassays. These deficiencies have been recognized and although the coarse 96-h LC50 tests are still used, techniques employing appropriate sub-lethal endpoints have been developed. However, extrapolating the laboratory derived results to field situations also has limitations.

The use of more sensitive and appropriate tests such as the invertebrate fertilization tests and the reproduction of algae are good methods to use to test for toxicity in other species (refer to Hatfield Consultants (2013b)). They do not, however, replace the need for more detailed examinations of sub-lethal effects on fish that are needed to more fully understand the ramifications to fish health and performance; notwithstanding the need for assessing effects on other aquatic organisms in receiving waters.

To place some of the above-mentioned information into perspective, Hatfield Consultants (2013b) reported the results of sub-lethal toxicity testing using Port Alberni pulp mill effluent and related their findings to define a zone of influence based on previous effluent dilution determinations.

PME zone of influence

Hatfield Consultants (2013b) commented that “Effects on echinoderm fertilization were observed at a mean effluent concentration of 30.0% (IC25); and algal reproduction was affected at a mean effluent concentration of 1.0% (IC25). The sub-lethal toxicity of effluent discharged from the Port Alberni paper mill was similar to or slightly greater

than that observed in recent EEM cycles”. These studies were undertaken six times from 2010 to 2012 for the Port Alberni paper mill, at different times of the year and yielded variable results based on 95% confidence intervals.

Hatfield Consultants (2013b) concluded that “based on a 1% effluent concentration zone of 3,000 m from the outfall, maximum potential zones of sub-lethal effect from the effluent discharge point were up to 100 m for invertebrate fertilization, and 2,888 m for algal reproduction”. This prediction was qualified and considered to be conservative because “the estimate of the 1% effluent zone was completed in 1993 when effluent discharge rates were approximately 2x the current rate ... As such, the current 1% effluent zone for the Port Alberni paper mill is likely considerably less than the 3,000 m determined by Hodgins et al. (1993)”.

However, using the dilution data previously reported by Seaconsult Marine Research Ltd. (1994) and relying on the data of Hodgins et al. (1993) the zone of influence could be much larger, and/or especially so if one were to use a different sub-lethal IC point (such as, for example, 10%). Under such a scenario the extent of sub-lethal effects as defined by these tests and related to dilution models could extend over a larger area more than 3 km down Alberni Inlet, and possibly as far as Hocking Point, 15 km away.

Clearly there are many factors that must be considered when attempting to define a zone of influence and among the foremost are the nature and volume of the discharge, hydrographical conditions in the estuary and Inlet, fresh water flow of the Somass River, and climate. Aside from the inappropriateness of using the results of the laboratory test, one would assume that there is much variability in such assessments and consequently only very approximate and imprecise predictions or inferences are possible. It would be most prudent and relevant to assess the zone of influence of the pulp mill’s effluent under a range of conditions and, most importantly for relevance to the protection of aquatic resources, to use both *in-situ* and controlled experimentation that mimics the receiving water conditions.

We are not aware of current studies that specifically assess the effects on fish under realistic conditions found in receiving waters.

Deductions regarding the impact of pulp mill operations

Consultants for the current operators of the Port Alberni mill have assessed the results of monitoring and other studies over a number of years. This has led to recent deductions by Hatfield Consultants (2013b) that “Overall, results indicate that historical impacts of paper mill effluent in Alberni Inlet *no longer pose a risk* to migrating sockeye salmon and that current *Pulp and Paper Effluent Regulations effluent quality standards are protective of fish*”. I think this is too strong a statement and it is overly simplistic.

The statement is, in part, based on salmon migration studies carried out in 2012; a year which was considered by the authors to be “abnormal” regarding oceanographic conditions and “an extended cool spring”. These conditions facilitated sockeye migration

and >75% had entered the Somass River by June 25; there was no obvious delay in their migration because of poor water quality and parasitisation previously documented in 1990 (Johnson et al. 1996; Birtwell and Korstrom 2002). These aspects will be dealt with in more detail later in this report. Hatfield Consultants (2013b) drew their conclusions based on results of laboratory experiments, monitoring data and the reduced size of the benthic fibre mat which continues to degrade waters at the head of the Inlet and, therefore, creates a potential concern for migrating adult salmon.

Water quality in the Somass River estuary has varied over many decades and dissolved oxygen conditions have generally improved, especially since pulp mill effluent flows and BOD have been reduced, the quality improved, solids retained, and activities impacting the estuary reduced. However, it is probably most appropriate to state that the current *Pulp and Paper Effluent Regulations* effluent quality standards *have contributed to the improvements in aquatic habitats that safeguard fish*. Some important questions remain however.

DISSOLVED OXYGEN

Variation in dissolved oxygen (DO) has been used as an indicator of aquatic pollution in the Somass estuary and Alberni Inlet over many years, and specific attention and emphasis is given here because of the significant influence that it has on organism function and survival. The following comments provide information that hopefully will aid comprehension of the effects that this variable may have on salmon.

The amount and quality of estuarine and other habitats requires protection so that the respiratory function of salmonids is not compromised and they are able to carry out all critical life support activities. In natural environments fish must adjust their scope of activities in order to survive while, for example, carrying out such activities as foraging and consuming food, avoiding predators, defending territories, and successfully reproducing on a seasonal basis. Increases in metabolic requirements for one activity will likely have consequence to others to the extent that dissolved oxygen could act as a limiting factor even at high saturation levels. Brett (1979) showed how DO can be a limiting factor for food conversion and growth.

Historically, prior to the pulp mill, dissolved oxygen levels at the head of Alberni Inlet at Hohm Island were typically well saturated and even supersaturated with dissolved oxygen except in those waters closest to the bottom (Tully 1948, 1949; Tully et al. 1957; Hatfield Consultants 2013a). This situation changed over decades of waste discharge into Alberni Inlet and the Somass estuary and created conditions that were lethal and/or stressful to salmon juveniles and adults with protracted residency in such waters.

Effluent colour, photosynthesis and dissolved oxygen

The colour of pulp mill effluent was implicated as a reason for depressed levels of dissolved oxygen in and below the halocline of the Somass River estuary in the early

1970s. It was considered that effluent colour inhibited photosynthetic activity (Parker and Sibert 1973; Sibert and Parker 1973). This seemed to be a logical explanation because prior to the mill's operation waters immediately below and sometimes in and above, the halocline were supersaturated with respect to dissolved oxygen.

Parker and Sibert (1973) deduced that the colour in PME discharged into Alberni Inlet had a detrimental effect on photosynthesis of autotrophic organisms resulting in reduced levels of dissolved oxygen. They commented that under the halocline there exists a mechanism for concentrating algae and also that the halocline traps organic matter from above. Zooplankters (prey for other organisms) and other organisms were found to move to density boundaries within the water column. Parker and Sibert (1973) speculated that prior to the pulp mill's operation the concentration of animal and plant material immediately beneath the halocline "must have been an attractive feeding area for the heterotrophic populations of several trophic levels, including fish".

At the present time (2014) the colour in surface waters has visibly decreased compared with that which existed in the early 1970s when Parker and Sibert (1973) carried out their research. However, effluent is still discharged and except for tests carried out by the pulp mill to discern toxicity through laboratory testing we are unaware of recent *in-situ* studies that would assist understanding the potential for adverse effects on dissolved oxygen production and prey for juvenile salmonids in the waters at and below the halocline. That said, dissolved oxygen levels above 100% air saturation were determined in the estuary on April 24 2014, and were indicative of photosynthetic activity just at and below the halocline (see Table 1; determinations at 2 locations at the mouth of the Somass River where fish were being temporarily reared in "net pens"). The low colour of effluent from the Port Alberni mill and high fresh water flow at this time were likely contributors to this circumstance. Persistence of these high dissolved oxygen levels throughout the late spring and summer should be of significant benefit to those salmon that use the estuary and to other organisms similarly dependent on high levels of dissolved oxygen.

Table 1. Dissolved oxygen, temperature and salinity data determined at two locations in the Somass River estuary April 24 2014. The data reveal dissolved oxygen supersaturation to a depth of 7 m (Courtesy of A. Popovich, Catalyst Paper).

Site 1, Net Pen	Temp. (°C)	Salinity (‰)	Dissolved oxygen (mg/L) (% satn.)	
Surface	13.70	0.78	10.87	105.5
1 m	13.61	0.88	10.46	100.1
3 m	13.14	4.44	10.42	102.1
5 m	10.13	22.62	11.45	116.8
7 m	9.41	25.20	11.30	115.3
Site 2, Centennial Pier				
Surface	14.02	0.78	12.77	125.2
1 m	13.72	0.89	11.32	109.9
3 m	13.08	4.51	10.61	104.0
5 m	10.26	22.39	11.45	116.8
7 m	9.79	24.62	12.20	125.8

General and specific considerations

On a cautionary note, much of the water quality data presented in reports that were reviewed relate to average conditions and, therefore, could be misleading when attempting to assess specific impacts of, for example, hypoxic conditions on aquatic organisms. It is also noteworthy that fish often respond to extremes and not necessarily to average levels of stressors (depending on acclimation, adaptation and exposure conditions etc.). In estuaries where temperature and salinity vary and each affects solubility of oxygen, the use of values expressed as % of air saturation has much merit. Both concentration (mg/L) and partial pressure are considered important for dissolved gas exchange in fish. Furthermore, it is important to realize that fish do not always avoid low levels of dissolved oxygen if other factors are more influential (such as temperature); notwithstanding the motivation of organisms to temporarily occupy potentially lethal/stressful habitats for, for example, feeding (refer to Birtwell et al. 2001a, 2003). Reduced levels of DO inhibit activities such as swimming, feeding and predator avoidance through impacting physiological processes. For example, below about 7 mg/L - 8 mg/L significant bio-energetic impacts would begin to occur and be manifest in, for example, growth of Chinook salmon (refer to Birtwell and Kruzynski 1989; Evans 2006; BC Water Quality Guidelines 1997).

What is an appropriate level of dissolved oxygen to safeguard aquatic resources and especially salmon?

The government of British Columbia produced guidelines (BCMELP 1997) that stipulate the levels of dissolved oxygen which are considered to provide protection for aquatic organisms. A thorough review of pertinent literature comprises the technical component supporting the guidelines. Much information on DO in the Inlet has been generated since the Port Alberni pulp mill began operations almost 70 years ago.

Some examples are provided below that support the requirement of high levels of DO for maintaining the wellbeing of fish. These levels, without consideration of any exacerbating influences of toxicants, are generally higher than the 5mg/L level that was expected to safeguard salmon from the effects of pulp mill effluent in the late 1940s-1950s. Information generated since that time has enabled a better understanding of the influence dissolved oxygen has on aquatic organisms.

Effects of hypoxic conditions on the breathing rate of adult sockeye salmon

Birtwell et al. (1994) showed how the innate behaviour of adult sockeye salmon to occupy deeper cooler salt water, rather than move to shallower normoxic warmer conditions in fresh water, under simulated estuarine conditions that mimicked those of the Somass River estuary, resulted in a significant increase in breathing rate/respiration at DO levels at and below 5 mg/L - 6 mg/L. Elevations in ventilation rate (from about 40 to a maximum of 105 opercula openings·min⁻¹) began when dissolved oxygen concentrations dropped below 5 mg/L - 6 mg·L⁻¹ (85 - 104 mm Hg pO₂), and decreased

only slightly in response to brief excursions by the fish into normoxic fresh water or upon movement to the halocline during experiments.

Effect of hypoxic conditions on the swim speed of salmon

The need to capture prey and avoid being eaten requires that the behaviour, and especially the swimming ability of salmonids, is not compromised by ambient conditions. Salmonids are active predators and they too are prey for other species. Both aspects require salmon to have swimming abilities that are not compromised by reductions in DO.

The effects of hypoxic conditions on swim speed appears to be greater at maximum swimming speeds versus lower swimming speeds, but it is significant that the greater effect of hypoxic conditions occurred at lower temperature (refer to Davis et al. 1963; Jones, 1971; US EPA, 1986). Davis et al. (1963), for example, determined that the maximum sustained swim speed of juvenile coho salmon was reduced by 8.4%, 12.7%, and 19.9% at dissolved oxygen concentrations of 6 mg/L, 5 mg/L, and 4 mg/L, respectively; the effects being slightly more pronounced at lower temperature. Similarly, Jones (1971) reported maximum swim speed reductions of 43% and 30% in rainbow trout at dissolved oxygen levels of 5.1 mg/L (77.8 mm Hg PO₂; 14°C), and 3.8 mg/L (68.3 mm Hg PO₂; 22°C).

Behavioural response of adult sockeye salmon to hypoxic conditions

Birtwell and Kruzynski (1987, 1989) examined the behavioural responses of juvenile Chinook salmon exposed to progressively greater or lesser hypoxic conditions; 50% of test populations moved to avoid decreasing DO levels when they had decreased to 7 mg/L - 8 mg/L (about 76% air saturation levels). The choice of the 50% response level in these experiments was for relevance to typical threshold levels used in bioassays. However, the response of a lower percentage of individuals in the test population would have been more appropriate to define levels at which metabolic functions are unconstrained by hypoxic waters.

These comments are not intended to suggest that fish will always avoid hypoxic or other sub-optimal waters, for example, in order to feed, but they emphasize that optimal conditions should be higher than 7mg/L - 8 mg/L DO (>about 76% saturation), and this would be particularly important if other stressors such as PME were present in their habitat (refer to Alderdice and Brett 1957). Birtwell and Kruzynski (1989) cite Sprague (1985) who concluded from a review of toxicological information that, in general, a reduction in dissolved oxygen from 100% to 80% of air saturation will cause increased mortality of fish exposed to some contaminants.

Growth impairment of juvenile Chinook salmon due to hypoxic conditions

Studies of yearling spring Chinook salmon have demonstrated a faster estuarine growth prior to seawater entry in the spring, improved seawater adaptability, and greater smolt-

to-adult survival (Wagner et al. 1969; Beckman et al. 1999). Growth and survival are interrelated. Growth rate can affect survival as a result of how rapidly the fish can “outgrow” portions of their predator population (Tovey 1999; Beamer et al. 2005). Parker (1971) showed that smaller fish in juvenile salmon populations were eaten at a higher rate than larger fish. Accordingly conditions that constrain or limit the growth of fish potentially decrease their chances of survival due to predation.

Hypoxic conditions can have a significant effect on reducing the growth of fish. The greater effect has been shown to occur at higher temperature (conditions which may occur in polluted estuarine situations such as those of the Somass and Fraser River estuaries), and fluctuating dissolved oxygen levels are more detrimental than stable ones.

Numerous examples of the effects of hypoxic conditions on growth of fish are provided in British Columbia Ministry of Environment, Lands and Parks (BCMELP) (1997). Figure 1 depicts the influence of DO and temperature on the growth of juvenile Chinook salmon.

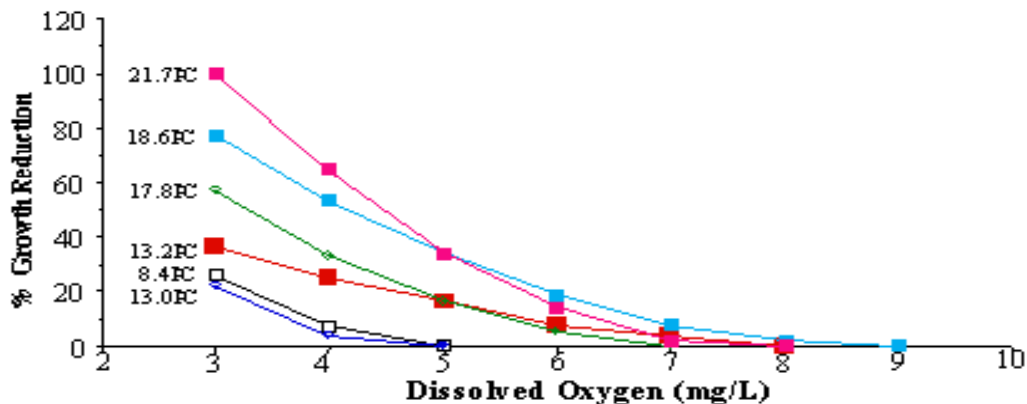


Figure 1. Influence of temperature on growth of Chinook salmon at various oxygen levels (from US EPA data (1986), original research in Warren et al., 1973; BCMELP 1997).

The dissolved oxygen level that does not impair function

A challenge in regions of competing resource conflict is to maintain and, if possible improve, the quality of habitat such that salmonids are not restricted and can complete all of the critical life-supporting activities. This challenge applies to the Somass River estuary because of the historic and current demands associated with urban and industrial developments. In setting criteria for DO, greater protection from the effects of hypoxia would most logically be afforded at higher levels of DO. This is particularly so if, as has been documented, the combination of hypoxic conditions and dilutions of, for example, PME are exacerbated (Alderdice and Brett 1957) and, similarly, compromise the swim performance of toxicant-exposed adult sockeye salmon (Birtwell et al. 1994).

Thus it is apparent that in order to safeguard fish there is a need for both high DO levels and reduced levels of toxicants.

Criteria for dissolved oxygen and the protection of fish

Davis (1975a, b) produced the following criteria after reviewing the responses of various fish to hypoxic conditions.

Level A: “represents more or less ideal conditions (i.e. little or no foreseeable harm) and permits little depression of oxygen from full saturation. It represents a level that assures a high degree of safeguard for many important stocks in prime areas”.

Level B: “some degree of risk (i.e. possibility of moderate harm) to a portion of a fish population exists if the oxygen minimum is prolonged beyond a few hours”. This level represents “the oxygen value where the average member of a species in a fish community starts to exhibit symptoms of oxygen distress”.

Level C: “a large portion of a given fish population or fish community may be affected by low oxygen. This deleterious effect may be severe (i.e. possibility of severe harm), especially if the oxygen minimum is prolonged beyond a few hours”.

In salt water, Davis (1975a, b) calculated limits for anadromous and non-marine species of fish to be 9.0 mg O₂/L for Level A and 6.5 mg/L for Level B; corresponding to 100% and 79-94% saturation over 0-25°C.

In fresh water Davis (1975a, b) stipulated 7.5 mg/L (76-93% saturation), and 6 mg/L (57-72 mg/L saturation) for Levels A and B respectively.

The adequacy of DO criteria for application in Alberni Inlet

The inadequacy of 5 mg/L dissolved oxygen as an appropriate level whereby protection would be afforded salmon in Alberni Inlet and the Somass River estuary in the 1940s and 1950s is revealed by the information supporting Davis’s (1975b) criteria and more recent information (BCMELP 1997).

It appears that although the importance of high levels of dissolved oxygen were required to support salmon and other organisms in the Somass River, its estuary and in Alberni Inlet little research was focussed upon this until the 1970’s. While comments were made in scientific documents about hypoxic conditions, *in-situ* impact studies were absent but water monitoring studies continued in relation to the operations of the Port Alberni pulp mill.

Concern for migrating salmon was expressed by Waldichuk (1987) who reported that in 1985, during summer dry conditions, the DO below 2m depth in Alberni Harbour dropped to <3 mg/L. He deduced that the 1985 DO data suggested that adult sockeye “can only migrate through the upper 2-m layer without severe low-oxygen impact”. He added that “even in this layer the dissolved oxygen concentration barely met the B level (6.5 mg/L) of protection at 20°C recommended by Davis (1975a, b),” and stressed that it

was “well below the 7.5 mg/L considered to be optimum for anadromous species at 20°C” (in fresh water?). However, despite these statements by Waldichuk which imply potential harm to these migrating fish and, without substantiation, Waldichuk (1987) documented that “low returns, below expectations, of sockeye salmon during 1985 and 1986 have been attributed to poor ocean survival.”

Dissolved oxygen monitoring reports and their assessment

A synopsis of the mill history and related aspects of dissolved oxygen changes in Alberni Inlet up to recent times has been provided by Seaconsult Marine Consultants Ltd. (e.g. 2001, 2002) and Hatfield Consultants (e.g. 2010b, 2013a, 2014). Although the data are valuable to understanding changes in Alberni Inlet in particular, we found the analyses and deductions confusing at times in relation to understanding potential impacts on aquatic organisms. However, both provide useful range and trend information for selected variables. A number of abstracted comments from these consultants’ reports are presented.

Seaconsult Marine Research Ltd (2002) provided information on DO (% saturation) levels determined in waters about 0.8 km away from the mill and in the effluent dispersal path. The following graphs show the data from 2001 for “upper” waters < 5 m depth and salinity < 15‰ (Figure 2), and those “deeper” waters >5 m depth and salinity >25‰ (Figure 3).

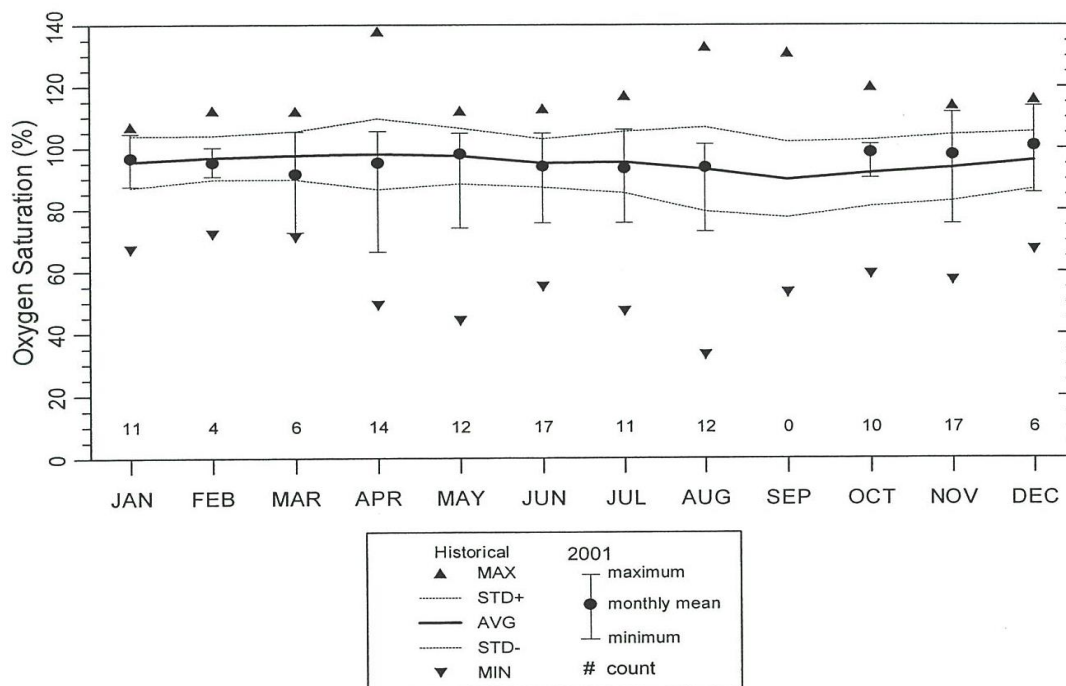


Figure 2. “Upper” water column dissolved oxygen (% air saturation) values determined in 2001 compared with data for the previous 14 years (deemed historical). Data averaged for water depths <5 m and salinity <15‰ (from Seaconsult Marine Research Ltd. 2002).

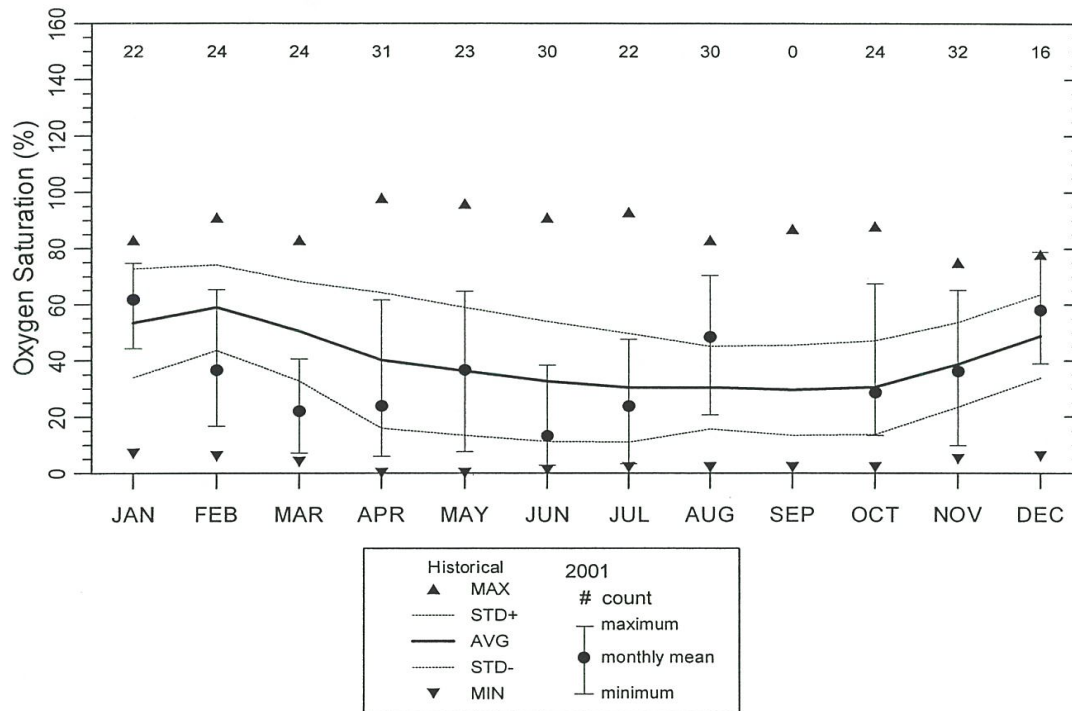


Figure 3. “Deeper” water column dissolved oxygen (% air saturation) values determined in 2001 compared with data for the previous 14 years (deemed historical). Data averaged for water depths >5 m and salinity >25‰ (from Seaconsult Marine Research Ltd. 2002).

These graphs reveal the substantial relative changes in DO expressed as a percentage of air saturation values, and the historical data relate to recent times when the mill has been operating, and not to pre-mill times. Nevertheless mean values *in the upper water* layers were very close to those of the “historical” levels. In the deeper waters, the results did not closely associate with the “historical” mean values. The authors consider that the “effects of extreme offshore oceanographic conditions” govern the DO in the deeper waters and are not linked to an increase in “the SOD” (sediment oxygen demand), because biological evidence suggests that re colonization of the fibre mat area is taking place and that sediment conditions are improving”. These deductions are not fully supported by the comments of Hatfield Consultants (2013a) who stated that “within this lower layer, the oxygen budget is also influenced by the oxygen demand from the historically-deposited wood-fibre mat closer to the mill outfall, as well as confounding BOD inputs from municipal sewage, wood processing, and log debris throughout the upper Inlet, natural organic matter in the water column and sediments, and to a lesser extent from current effluent biosolids”. One would assume that the opinions of both consultants have merit in explaining the low dissolved oxygen levels in the upper Alberni Inlet Harbour area.

The averaging of conditions over time and depth have provided for changes and trends to be identified but greater fine-scale analyses are required to understand how variation in measured variables may affect aquatic organisms, especially juvenile salmon.

Halocline

The fresh water of the Somass River overlies and progressively mixes with salt water of Alberni Inlet. The waters are separated by differences in density primarily due to temperature and salinity, and between them is, respectively, the thermocline and halocline within which variation in these factors rapidly change with depth.

Hatfield Consultants (2013a) commented that: “In an estuary, the halocline represents the layer demonstrating the most rapid salinity change over depth. The depth, thickness, and water quality of the halocline naturally varies from year to year, given variations in annual precipitation, river discharge, and to a lesser extent by mixing mechanisms (e.g. winds and tides)”.

The depth and definition of the thermocline and halocline varies seasonally and can be very close to the water surface, especially in periods of low freshwater flow. Often the depth profiles depicting the thermocline and halocline appear very similar; the halocline effectively separates deeper cooler salt waters from those, typically warmer fresh waters, above. This strong vertical stratification has been instrumental in how fish are able to use the estuary of the Somass River (refer to Birtwell 1978).

Hatfield Consultants (2013a) analysed data for Inlet waters in relation to depth of the halocline and described variation within using such qualifying words as “upper” and “lower” water layers which provides for only an approximate understanding: such terms are relative, somewhat subjective, and variable. Accordingly, it has sometimes been difficult to examine certain data regarding this aspect of study and their relationships to habitat use by fish - which is of importance in this review.

In 2002, the consultants defined the halocline “to be the layer bounded by the 15 and 25 ppt salinity contours” (Seaconsult Marine Research Ltd. 2002), but during the 2003 to 2004, and in 2005 monitoring programs the halocline was “defined by the 10 and 25 ppt salinity contours” (Hatfield 2005, 2006).

Beginning in 2006, the halocline was defined by the “10 and 20 ppt contours” (Hatfield 2007a, 2008, 2010b, 2011, 2012). In 2012 these same contours were used and “the thickness of the halocline was largely dependent on the season, with narrower (<2 m thick) haloclines present most of the year, and a thicker halocline developing when low precipitation and river flows allowed salinity gradients to breakdown” (*We do not fully understand what is meant by “breakdown” in this process*). “In 2012, the halocline was between 1-2 m thick and occurred between 1 and 5 m below the surface, depending on the distance from the river mouth, and the time of year”.

Surface waters

Hatfield Consultants (2013a) reported that “Towards the end of the drier summer months (June through August), precipitation and Somass River flows were lower, ... resulting in a decline in the levels of well-oxygenated freshwater into the estuary, and subsequently a

reduction in the thickness of the freshwater surface lens. Seawater inputs became more dominant, salinity throughout the water column increased and the thickness of the halocline increased (i.e., salinity changes more gradually with depth)". The authors concluded that "As in previous years, oxygen concentrations in the upper layer were similar between all monitoring stations in 2012, and did not vary considerably with distance from the outfall". Even if correct the imprecision of the statement detracts from an understanding what this really means.

Hatfield Consultants (2013a) reported that "since the introduction of enhanced secondary treatment in 1993, effluent quality and associated water quality has greatly improved, with upper layer oxygen reaching levels higher than those measured prior to mill start-up". However, a review of the data averaged over decades shows that this could be true for "non-summer" periods but that over summer periods the DO values were similar to those very few data recorded in 1941.

Upper water layer

Hatfield Consultants (2013a) stated that DO "in the upper layer during 2012 was similar to previous years, typically exceeding 10 to 12 mg/L in the winter through to late spring when precipitation and river discharge levels were high, and dropping to 8 to 9 mg/L during the drier summer months. In the drier months, oxygen concentrations in the lower layer throughout the harbour were marginally lower, ranging between 6 and 8 mg/L in the top portion of the lower layer, and between 2 and 4 mg/L near bottom".

These authors also mention that "mean concentrations in the upper layer during summer months were 8.7 mg/L in 1941, 7.7 mg/L between 1960 and 1993, and 8.9 mg/L between 2001 and 2012 (9.1 mg/L in 2012)".

Care is needed when assessing these data sets because, for example, the varying depths of what could be considered the "upper layer" and the factors that influence the data besides mill-related activities and, consequently may lead to different values being calculated. As mentioned previously, on May 8 1941 the whole water column at Hohm Island was supersaturated with dissolved oxygen.

Lower water layer

Hatfield Consultants (2013a) reported that "near the mill outfall, the influence of the mill-related oxygen demand appears overall to be diminishing, supporting conclusions made in the EEM Cycle Five study about reductions in the magnitude, extent, and oxygen demand of the historical fibre mat". However, the authors stated that "within this lower layer, the oxygen budget is also influenced by the oxygen demand from the historically-deposited wood-fibre mat closer to the mill outfall, as well as confounding BOD inputs from municipal sewage, wood processing, and log debris throughout the upper Inlet, natural organic matter in the water column and sediments, and to a lesser extent from current effluent biosolids".

Dissolved oxygen data for waters at Hohm Island were “standardized to the lower layer depth maximum of 10 metres used in 1941 (FRBC 1957), allowing oxygen values from 1941 and 2001 to 2011 to be directly comparable” Hatfield (2013a). “Using this method of standardization, mean concentrations in the lower layer during summer months were 7.2 mg/L in 1941, and 3.8 mg/L between 2001 and 2012 (5.2 mg/L in 2012)”.

Historical comparisons

Tully (1948, 1949) analyzed pre-mill oceanographic data and commented that “In the upper zone, the oxygen concentration increases with depth from saturation at the surface to a maximum at, or just below, the boundary. Immediately below the maximum there is an inflexion in the gradient marking the lower limit of oxygen enrichment. This maximum increases from about 90% saturation at the head to 120%” in Barkley Sound (Junction Passage). “The base oxygen content (*without plankton supply*) anywhere in the upper zone of the Inlet” is “85% to 95% depending on the prevailing coastal wind” (Tully 1949).

Hatfield Consultants (2013a) analyzed more recent data for Alberni Harbour, typically commenting on changes in DO concentration which are affected by salinity and temperature, and not % air saturation which is independent. They commented that “In the non-summer months, lower layer oxygen averaged 9.1 mg/L in 1941 and 4.5 mg/L between 2001 and 2012 (6.2 mg/L in 2012)” These are significant reductions in dissolved oxygen which occurred over almost 7 decades and most probably affected organism use of such waters. “Dissolved oxygen levels in the lower layer near Hohm Island were much higher in 1941, prior to the mill’s start-up, than during any other monitoring year since the mill’s opening... Although this was the only year of pre-mill oxygen data available, it provides a snapshot of conditions in the Inlet prior to the oxygen-reducing influence of settled fibre/biosolids from mill effluent and discharge from other local industries” Hatfield Consultants (2013a) (refer to Tully 1948, 1949).

Hatfield Consultants (2013a) stated that “Dissolved oxygen concentrations measured between 1960 and 1968 ranged between 2.5 and 4.1 mg/L in the summer months, and 2.9 and 5 mg/L in the non-summer months.... Oxygen began to decline in the 1970s, despite the introduction of effluent treatment, often dropping below 2 mg/L in the summer months from 1978 onward”. Thereafter, and after effluent treatment improvements at the pulp mill in 1993, “oxygen levels in the lower layer of the water column appear to have improved only slightly”. “As with the upper layer, the average of individual concentrations recorded between 1986 and 1993 (2.2 mg/L in summer months, 3.3 mg/L in non-summer months) were lower than the overall 1986 to 1999 average (2.8 mg/L summer, 4.2 mg/L non-summer), indicating that oxygen levels between 1994 and 1999 improved over time”.

“Average DO concentrations observed between 2001 and 2012 (3.2 mg/L in summer months, 4.1 mg/L in non-summer months) have fluctuated within a similar range to those observed in the earlier days of mill operations between 1960 and 1968 (average 3.1 mg/L in summer months, 4.1 mg/L in non-summer months)”.

“Since 2006, however, concentrations of dissolved oxygen have generally remained within the higher range of historical operational levels, a trend that partially corresponds to river discharge levels, but also may indicate further improvements to the reducing conditions in the historical fibre mat”. *We are not sure what this statement means.*

Outfall area

“Near-bottom oxygen concentrations near the outfall have fluctuated since 1992, but overall have remained relatively low in the drier summer months (July through October, ranging between 0.5 and 3.6 mg/L”. “Fluctuations over time have generally corresponded well with river flow rates and precipitation levels of the same time period” Hatfield (2013a).

“Near-bottom dissolved oxygen proximal to the outfall in 2012 (3.5 mg/L) was higher than the average since 1992 (2.2 mg/L), and increased relative to the previous year” Hatfield Consultants (2013a). Again, as mentioned above, this issue relates to how one determines which data to use in the calculations and whether or not they can be compared. That said, the data, as analyzed, reveal a small improvement in DO conditions at depth.

Fibre mat

Hatfield Consultants (2010a) also examined “the magnitude and geographical extent of effects associated with the historical fibre mat, comparisons with the extent of the historical fibre mat 20 years prior, the influence of sediments on overlying water quality in the upper Inlet, and the potential influence of water quality in the upper Inlet on migrating salmon”. The study concluded that “the current extent of the historical fibre mat is highly localized near the outfall (0.29 to 0.56 km²), has diminished by at least half its size in two decades, and only influences overlying water quality within a small area in the immediate vicinity of the outfall”. This deduction does not seem to match with their assessment in the report. In addition, Hatfield Consultants (2013a) concluded that “In particular, dissolved oxygen at the outfall station has recovered significantly, and in recent years concentrations have been similar to or even slightly higher than concentrations observed down-Inlet”.

We think it is important to recognize that such statements can be taken to mean that all the waters (surface to depth) within an ill-defined area around the outfall have recovered significantly. This would be an erroneous assumption for waters at depth continue to have depressed levels of dissolved oxygen and are at levels stressful and potentially lethal to, for example, salmonids.

Only when dissolved oxygen levels are at or above approximately 75% air saturation in the whole water column will such fish be adequately protected (without, of course, the imposition of contaminants and other stressors). Based on the data examined, DO in very shallow surface waters at most, but not all, locations was at an acceptable level for fish.

Depressed levels of DO have been recorded in shallow waters of the Somass River estuary in late spring and summer in other studies and will be presented elsewhere in relation to fish presence and use of such areas.

ADULT SALMON

The successful return of adult salmon to the Somass River system has been a concern for many decades due to deteriorated water quality in Alberni Inlet. Attention has focussed on the return of sockeye salmon when aquatic conditions in the upper Inlet/Somass River estuary could be stressful to them and especially so when thermal delays to migration result in prolonged occupation of deeper waters with potentially harmful DO levels at the head of the Inlet.

Adult Chinook salmon migration overlaps, and is also later than, that of sockeye salmon, typically commencing in August when temperature elevation and dissolved oxygen depression in the Somass River estuary are at potentially stressful levels; hence the merit of including the results of studies on sockeye salmon as it relates to water quality in upper Alberni Inlet. The significance of concern for the well-being of salmon is exemplified by events that occurred in 1990 (and subsequently) during the annual migration of sockeye salmon through Alberni Inlet and the Somass River to their spawning areas in Great Central and Sproat Lakes. During the summer in 1990, warm and stable climatic conditions elevated the temperature of surface waters in the Somass River and estuary to the extent that the migration of adult sockeye was delayed an estimated 48 days.

Sonar records revealed that the fish were holding at depth in the cooler (approximately 10 °C) hypoxic salt water, rather than continuing their migration through the warmer (>20 °C), less saline but more oxygenated surface waters. This holding pattern was not unusual, but because of the documented hypoxic conditions at depth we had concern over the likely loss of energy these non-feeding fish may incur and the consequence to reproduction. This concern was warranted, and about 200,000 adult salmon were estimated to have been lost in the Inlet. This loss was a significant proportion of those that were previously holding there. It was deduced that the cumulative effects of prolonged exposure to the adverse environmental conditions in sub-halocline waters at the head of Alberni Inlet, and increased infestation by saltwater parasitic copepods (*Lepeophtheirus salmonis*) with possible secondary bacterial infections, contributed to their demise (Johnson et al. 1996; Birtwell and Korstrom 2002).

Adult sockeye salmon migration and aquatic conditions in the Somass River estuary

Two studies have examined the migration and habitat used by sockeye salmon migrating through Alberni Inlet. Both suffer from inadequacies due to methodologies and the difficulty of the task. Specifically, the earlier studies reported by Spohn et al. (1996) utilized ultrasonic tags that recorded *in-situ* temperature or depth, the studies reported by Hatfield Consultants (2013b) employed temperature loggers attached to the fish.

The levels of DO in waters occupied by sockeye salmon at a recorded depth and temperature were inferred by reference to data from water quality profiles at the time of the study by Spohn et al. (1996). Similarly, both depth and DO conditions experienced by migrating sockeye were inferred from the *in situ* temperature recorded by data loggers on the fish in the studies of Hatfield Consultants (2013b).

Accordingly, both studies drew inferences on habitat quality and use from other sources and because of this specific deductions that were made require qualification if reliance is primarily through inference and not measurement. Both studies determined the temperature of waters occupied by the sockeye salmon that were tagged. Specific details are provided below.

Fisheries and Oceans (DFO) study

The movement and temperature/depth selection of adult sockeye in Alberni Inlet was examined using ultrasonic telemetry by Spohn et al. (1996). It was anticipated that these studies would provide an insight into the conditions experienced by these migrating fish and assist in the design of laboratory experiments that would more accurately reflect the natural conditions and hence permit accurate assessments of salmon behaviours.

Sockeye salmon for this study were captured and released within 10 km of the mouth of the Somass River (Spohn et al. 1996). These authors determined from few data that the mean temperature experienced by the adult sockeye salmon ranged from $9.7 \pm 0.6^\circ\text{C}$ to $9.9 \pm 0.3^\circ\text{C}$. The minimum recorded temperature the fish had experienced was 7.2°C and the maximum was 10.8°C . The mean depths the fish occupied ranged from 20.2 ± 0.9 m to 47.8 ± 38.2 m, however, fish were recorded to range between 1 m and 75 m depths). The fish chose to reside in waters beneath the halocline.

Based on depth and temperature recordings from the sonic tags, and on Inlet water quality data, these fish were in relatively cool hypoxic salt water ($3\text{-}4 \text{ mg}\cdot\text{L}^{-1}$ DO) but would also have experienced widely differing conditions during their vertical migrations.

Hatfield Consultant's study

A similar study which used more tagged individuals examined the migration of sockeye salmon in 2012. Hatfield Consultants (2013a) stated that “The effects of historical and current mill activities on Inlet DO and migrating salmon are now better understood, as a result of a fish tagging study undertaken in the Port Alberni EEM Cycle Six program, which determined that DO conditions in 2012 in the upper Inlet were unlikely to adversely affect migratory salmon”. The data supporting that statement are presented and commented on below. Its broad generalisation is, it seems, somewhat speculative and lacks specificity.

The aquatic conditions in Alberni Inlet when this study was carried out reveal a variance that, unfortunately, provides results which have less relevance to the more typical and

more stressful conditions that have tended to occur in late spring and summer during the migration of sockeye salmon.

Hatfield Consultants (2013b) stated that “Environmental conditions that prevailed prior to this work were deemed to be abnormal and accordingly deviate from the typical circumstance at that time of the year. An extended cool spring and unusually high discharge conditions in the Somass River favoured very rapid and early migration through Alberni Inlet and the Somass River, such that a relatively small proportion of returning sockeye were present in Alberni Inlet during July or August: an estimated >75% of the sockeye escapement entered the Somass River before June 25, 2012 (Hyatt and Dobson, DFO unpublished data)”.

The study reported by Hatfield Consultants (2013b) to determine how oxygen concentrations in the Inlet affect migrating salmon conducted in support of the Cycle Six EEM report (Hatfield 2013b) found that “during the migration period, salmon were typically found in the upper layer, where DO ranged from 3.5 mg/L to 9.5 mg/L”.

However, there is a lack of specific detail provided by the authors and some generalities are provided which appear to conflict with the data presented. In particular, their statement seemingly contradicts the generalizations that “Dissolved oxygen in the upper layer during 2012 was similar to previous years, typically exceeding 10 to 12 mg/L in the winter through to late spring when precipitation and river discharge levels were high, and dropping to 8 to 9 mg/L during the drier summer months. In the drier months, oxygen concentrations in the lower layer throughout the harbour were marginally lower, ranging between 6 and 8 mg/L in the top portion of the lower layer, and between 2 and 4 mg/L near bottom.” The use of relative terms only provide for general and subjective opinion.

The seemingly conflicting comments reflect the problems of obtaining synchronised data while conducting different activities. Unfortunately it is difficult to precisely relate conditions determined for one study (e.g. salmon movement) to another for a completely different aspect (e.g. water quality profiling at an unrelated location(s)). Thus, the comments of Hatfield (2013a) must be regarded as general comments and assumptions; they are not, however, without merit.

Hatfield Consultants (2013b) and “Fisheries and Oceans Canada (DFO) conducted an archival tagging program and hydro acoustic surveys of migrating adult sockeye to examine their potential exposure to low near-bottom DO in upper Alberni Inlet”. Adult sockeye salmon were tagged at eight specific locations in lower Alberni Inlet over three separate sampling events in July 2012 >10km from head. Data from the Port Alberni DO monitoring program were used to determine depth and DO concentrations associated with the tag temperature logs. Results presented are of the 33 fish that were recaptured in the Somass River. (Data from another 64 sockeye were not included in these analyses. Hatfield Consultants (2013b) stated “it could not be confirmed that these fish were exposed to the historical fibre mat and areas of low near-bottom dissolved oxygen”: a comment that one could probably also extend regarding the former group that was chosen?

Migration rates

Migration rates (i.e. average rate of movement from tagging location to the mouth of the Somass River) were similar for fish tagged on July 4 and July 10, 2012: 1.03 km/h (range 0.06 to 1.81 km/h) and 1.05 km/h (range 0.37 to 1.74 km/h), respectively, over 40 h. In contrast, fish tagged on July 17, 18, migrated at 0.60 km/h (range 0.13 to 1.58 km/h) and spent 69 h from the tagging location to the Somass River.

Thermal history and exposure to hypoxic waters

Sockeye tagged earlier in July occupied waters of warmer temperature (mean of 14.6°C and 14.3°C) and were exposed to lower maximum temperature during their migration (16.4°C and 18.5°C). They spent 75% of time between 14°C and 17°C corresponding to a depth range of 5 m to 15 m based on water quality monitoring information. But, those tagged in late July occupied a lower average temperature (mean of 13.6°C) and were exposed to higher maximum temperature (17.7°C). They spent 64% of time in waters of 9-12°C corresponding to a depth range north of Holm Island of 5 m - 9 m (DO 4.0 mg/L and 10.2 mg/L) and at the same depth range (DO 3.5 mg/L and 9.5 mg/L) seaward of this location.

However, many sockeye displayed frequent and short vertical migrations with no apparent diurnal pattern observed. As time progressed and surface temperature increased, the frequency and duration of vertical migrations decreased.

Sockeye tagged early July moved to warmer near-surface waters sooner, while fish tagged late July occupied cooler waters (~10°C), migrating to near surface only a few hours prior to river entry. In addition, many late-run sockeye exhibited holding behaviour and conducted several short vertical migrations just prior to river entry.

Adult sockeye salmon migration and dissolved oxygen in Alberni Inlet

The results of Hatfield Consultant's (2013b) study determined that while sockeye in Alberni Inlet continue to prefer water temperature in the range of 9.5°C to 12.0°C. DO "at the depths within this temperature range have greatly improved and remained above 5.0 mg/L". This comment is not fully supported by the statements made - that at these depths DO minima which fish were exposed to range between 3.5 mg/L and 4.0 mg/L, landward and seaward of Hohm Island respectively.

Hatfield Consultants (2013b) reported that "In addition, results of this study and the annual Port Alberni dissolved monitoring program have determined that low DO concentrations in the vicinity of the outfall are generally restricted to the lower 3 to 4 m in a cooler temperature range that is undesirable (<9.5°C) to migrating sockeye, based on 2012 results". We are not sure how to interpret this statement, especially in view of the previous statements about sockeye exposure and depths used, and the findings of Spohn et al. (1996) that revealed fish were recorded at the minimum temperature of 7.2°C in

1994. Similarly, Hatfield Consultant's (2013b) deduction that "current DO concentrations in the temperature range where sockeye were holding in 1990 and 1994 show that current concentrations would be >5 mg/L at nearly all locations and >7 mg/L in known holding areas" may be misleading as specific depth data were obtained for tagged fish by DFO (Spohn et al 1996) and not inferred from temperature recordings as was done in the studies by Hatfield Consultants (2013b).

Hatfield Consultants (2013b) stated "While results of this study show an overall improvement in the water quality conditions experienced by migrating sockeye in Alberni Inlet, the early migration timing observed 2012 was considered anomalous and in contrast to those observed in 1990 and 1994 (Hyatt and Dobson; DFO unpublished data). In 2012, higher than normal flows in the Somass River and relatively cool surface water temperature during most of the migration period resulted in almost no migration barriers and near optimal conditions for migrating sockeye". The authors expressed their opinions regarding future conditions and the potential delay to migrating adult sockeye salmon: "Although it may be considered that effects of the historical fibre-mat may still contribute to poor near-bottom DO conditions, and that this effect may be exacerbated in a year where migration timing and climatic conditions are similar to those observed in 1990 and 1994, this is considered unlikely given that current effects of the fibre-mat are small and localized." Unfortunately, delays have occurred in e.g. 2004 for 40 days and in 2012 for 8 days, with consequential losses of fish (K. Hyatt, Research Scientist, DFO *pers. comm.*, 2014), and such delays have extended through September.

The statement by Hatfield Consultants (2013b) is obviously speculative and could be misleading for even relatively small degraded areas can negatively impact fishery resources (Birtwell et al. 1983). However, one would expect that if progressive improvement to the DO content of deeper waters at the head of Alberni Inlet continue then any impediments to the migration and consequential impairments to the health of sockeye salmon will be understandably less over time, and perhaps similarly so for other returning adult salmon with similar behavioural repertoires and requirements. Hatfield Consultants (2013b) concluded that "Although low near-bottom DO concentrations persist in areas of Alberni Inlet, concentrations within the preferred temperature range of migrating sockeye are significantly greater than those experienced in the 1990s and no longer pose a risk to their survivability; and current DO concentrations in the temperature range where sockeye were holding in 1990 and 1994 surveys show that current concentrations are >5 mg/L at nearly all locations and >7 mg/L in known holding areas".

More recently in 2014 Hatfield Consultants (2014) reported that "The effects of historical and current mill activities on Inlet DO and migrating salmon are now better understood, as a result of a fish tagging study undertaken in the Port Alberni EEM Cycle Six program, which determined that DO conditions in 2012 in the upper Inlet were unlikely to adversely affect migratory salmon". These broad generalizations are subject to the same concerns expressed above regarding the details of their studies and deductions.

In the earlier studies by Spohn et al (1996) specific depths were recorded by transmitters attached to fish whereas in the studies by Hatfield Consultants (2013b) the depths which

fish used were inferred from temperature profile data. Both studies recorded temperature data and confirmed that sockeye salmon adults in the Inlet seemingly preferred waters in which temperature was between 9°C and 12°C in late July.

Continuing concern for migrating adult salmon

It was deduced that adult sockeye salmon experienced DO levels from 3.5 mg/L - 10.2 mg/L, and also down to low levels of 3 mg/L - 4 mg/L in the respective studies of Hatfield Consultants (2013b) and Spohn et al. (1996). Currently, exposure to hypoxic waters remains a concern for migrating and holding adult salmon that use the deeper waters of Alberni Inlet and particularly so through the summer and into the fall. Such delays continue to occur. It is the opinion of K. Hyatt (Research Scientist, DFO, *pers. comm.*, 2014) that the preference of the adult salmon for particular thermal conditions overrides the preferred oxygen range during times of migration delay (temperature range 9- 15°C; DO 1.2-4.6 mg/L) with potentially debilitating and even lethal consequences.

The behavioural trend for adult sockeye salmon to slow migration and/or hold at greater depth rather than migrate during conditions of rising river water temperature remains a concern for their wellbeing. This concern is, of course, also extended for other migrating salmon at this time and later in the summer before Somass River flows and temperature regimes are more conducive to unconstrained migration. In this context, Burt and Associates (1998) reported that adult Chinook salmon enter the Somass River system in August. Therefore, it is very likely that these fish could encounter water quality conditions that would be potentially harmful with prolonged residency (similar to sockeye) and especially so if migration was delayed and they responded by occupying hypoxic waters of their thermal preference at that time; around 10°C.

Laboratory studies

Behavioural responses to hypoxic waters under simulated vertically-stratified estuarine conditions

A continuous-flow Water Column Simulator (Birtwell and Kruzynski 1987) was used to mimic conditions that adult sockeye salmon experience during their spawning migration through the vertically stratified estuary of the Somass River. It was expected that the experimental conditions would elicit responses in the adult sockeye that would assist an understanding of their behaviour in Alberni Inlet.

An avoidance response to hypoxic salt water was expected and subsequent movement to overlying normoxic fresh water under isothermal conditions. Furthermore it was anticipated that the extent of this response would be diminished by the presence of warmer fresh water under the bi-thermal regime which typified conditions in the estuary of the Somass River at the time of salmon migration in late spring and summer (refer to Birtwell and Korstrom 2002). Under normoxic vertically stratified fresh and salt-water conditions during daytime, the fish (ages 4⁺ and 5⁺) remained in the deeper seawater, but moved upwards at night and made transient excursions into fresh water.

Exposure to hypoxic conditions

The imposition of short-term (6.5 h) hypoxic conditions in salt water during daytime did not elicit a definite avoidance response in adult sockeye salmon. The fish exhibited little displacement from their positions in salt water until the dissolved oxygen level decreased to about 3-4 mg·L⁻¹ (51-69 mm Hg pO₂).

The fish maximized gill ventilation rate (respiratory compensation) however, rather than directly avoiding the stressful conditions, they increased the frequency of movements (8 to 145 excursions) into the freshwater layer.

They continued to spend the majority of time (>90%) in hypoxic salt water. Elevations in ventilation rate (from about 40 to a maximum of 105 opercula openings·min⁻¹) began when dissolved oxygen concentrations dropped below 5-6 mg·L⁻¹ (85-104 mm Hg pO₂), and decreased only slightly in response to the brief excursions of the fish into normoxic fresh water or to the halocline (Birtwell et al. 1994; Spohn et al. 1996).

The behaviour displayed by the sockeye salmon in response to short- and long-term exposure to hypoxic conditions in seawater could result in additional energy expenditure for these non-feeding adult salmon. We speculated that prolonged exposure to hypoxic waters, in addition to contributing to mortalities, may also result in reduced spawning and production of progeny via depletion of energy reserves (Birtwell and Korstrom 2002).

Laboratory-derived results and their relevance to field studies

The laboratory experiments confirmed field observations of the behaviour of adult sockeye salmon which must reside or pass through regions of sub-optimal water quality in Alberni Inlet (Birtwell et al. 1994). We did not observe the expected avoidance responses to hypoxic conditions in salt water. It is possible that inherent behavioural traits may, in fact, be maladaptive at the head of Alberni Inlet which has experienced significant adverse changes to their habitat.

Perhaps the most significant finding was that temperature emerged as the primary environmental cue that overrode avoidance responses of these fish to hypoxic water. By choosing to remain in the cooler hypoxic deeper seawater rather than benefit from movement into the more oxygenated warmer and less saline surface waters, adult sockeye salmon potentially jeopardized their health and survival in Alberni Inlet.

Performance of adult sockeye salmon under hypoxic and normoxic conditions and sub-lethal exposure to contaminants

The interaction of hypoxic waters and the effects of contaminants on the ability of the sockeye salmon to migrate through warm (20°C) fresh water were studied in the laboratory. The contaminants were dehydroabietic acid (DHA) a persistent and toxic resin acid in pulp mill effluent (Oikari et al. 1983), and pentachlorophenol (a ubiquitous

wood preservative contaminant). It was anticipated that the performance of the adult sockeye might be compromised by exposure to the contaminants with or without the additional interaction with hypoxic waters and changing salinity and temperature regimes (Korstrom et al. 1996, 1997; Birtwell et al. 1997; Farrell et al. 1998; Jain et al. 1998).

Exposure to sub-lethal concentrations of DHA or the wood preservative pentachlorophenol under briefly hypoxic conditions reduced the ability of adult sockeye salmon to recover during repeated performance (swim) tests. The combined effects of pentachlorophenol and hypoxia were more debilitating than either the toxicant or hypoxic conditions. Thus, the potential exists for a combination of stressors to exert both direct and indirect effects on adult sockeye salmon. The applicability of these findings to the current conditions in Alberni Inlet is unknown with respect to any toxicant exposure due to the discharge of municipal and industrial wastes.

Deductions

It is deduced that temperature is the primary cue that adult sockeye salmon respond to when faced with choices to enter normoxic warm fresh/brackish waters overlying hypoxic salt water later in the summer when migration rates decrease, holding at depth in the Inlet increases, and river and upper Inlet water quality tends to decrease.

Laboratory and field experiments provide supporting information for these deductions and the potential exists therefore for exposure to sub-optimal hypoxic waters leading to metabolic demands that in turn may affect the performance and wellbeing. However, progressive improvements in the DO regime at the head of Alberni Inlet will continue to assist migrating and rearing fish and other organisms.

At the present time one may deduce that improvements have occurred but they remain a concern for migrating salmon especially under certain climatic and hydrological conditions that may hinder or delay migration (particularly in the late summer period).

JUVENILE SALMON

Juvenile salmon movement into estuarine habitat

Understanding what habitat features are important in the lives of juvenile salmon and what function they perform are fundamental requirements that will assist in assessing impacts and benefits from habitat degradation and rehabilitation respectively. Overall, studies emphasize the importance of maintaining diverse and complex macro and micro estuarine habitat for the benefit of juvenile salmonids.

Habitat use has been shown to relate to the size of under yearling Chinook salmon. Semmens (2008) reported individuals <135 mm tended to remain in the deeper waters. In other studies larger under-yearling individuals of similar size to those tracked by Semmens (2008) were caught in the deeper tidal channels of estuaries (Myers and Horton

1982; McCabe et al. 1986; MacDonald et al. 1987). Although “0-aged hatchery-reared fall Chinook smolts; <135 mm” are typically found in water shallower than 4 m (Dawley et al. 1981), they have a shorter estuarine residence than smaller sub-yearling migrants (Bottom et al. 2005a) and are less dependent on shallow rearing habitats such as emergent marsh, tidal creeks, and associated dendritic channel networks (Levy and Northcote 1981, 1982; Gray et al. 2002) Semmens (2008).

Hering et al. (2010) revealed the ways in which juvenile Chinook interact with, and exploit, intertidal wetland habitat. They affirmed “that a diversity of marsh rearing patterns exists in the present Chinook salmon population” and that “the behaviour of individuals on this finer scale is the mechanism that leads to the population-scale responses to restored habitat structure observed by Bottom et al. (2005a)”. In the Salmon River estuary Hering et al. (2010) suggested that the patterns of salmon residence in the Salmon River study channel may serve to maximize foraging success while limiting predation risks and the bio-energetic costs of increasing water temperature (Gray 2005). Tagged fish avoided shallow water where avian predation, potential for stranding, and elevated water temperature may pose increased risks of mortality during receding tides.

According to Hering et al. (2010), “ocean-type Chinook salmon (*Oncorhynchus tshawytscha*) may rear for prolonged periods in subsidiary and blind channel networks that connect main stem estuarine channels with peripheral wetlands (Congleton et al. 1981; Simenstad 1983; Healey 1991). Such channel networks are often intertidal, necessitating twice-daily evacuation of wetland areas and redistribution of nekton communities across hundreds of meters of habitat as channels flood and drain with the tide (Rozas 1995; Gibson 2003). Despite obligatory tidal emigrations, mark–recapture experiments indicate that individual Chinook salmon may return to particular wetland channels for days to months, moving into flooded channel networks during high tides and retreating to sub tidal habitats during low tides (Congleton et al. 1981; Levy and Northcote 1982; Shreffler et al. 1990)”. Some examples of these aspects are provided below.

Willapa Bay, Washington

Based on research in Willapa Bay, Washington, Semmens (2008) cautioned “from a management perspective, it may therefore be tempting to downplay the importance of fine-scale benthic habitats in favour of larger-scale estuarine features such as deep tidal channels and salinity gradients for smolt-sized fish. However, the strong influence of benthic habitat on the behaviours of larger Chinook salmon juveniles identified in this study suggests that the benthic habitat plays an important role in survival during outmigration and should not be discounted in preservation and restoration actions aimed at conserving and recovering Chinook salmon stocks”.

Dungeness River, Washington

Sather (2008) documented the movement of juvenile chinook in the estuary of the Dungeness River in Washington. She documented that the fish were continuously

redistributed due to the tidal regime, primarily because of the dewatering of channels and marshes at low tide, thus not leaving wetted areas as refuges at such times.

Sather (2008) considered that these hydro-geomorphic factors were responsible for fish not associating with a particular habitat; her results contrast with those of Levy and Northcote (1982) who recorded prolonged fidelity to channels in the estuary of the Fraser River that were tidally drained and flooded. Similarly, Hering et al. (2010) used PIT tag technology to examine the movements of under yearling Chinook salmon in the estuary of the Salmon River, Oregon and their studies revealed fidelity by individuals to a specific tidal channel and wide-ranging residency (hours to months) and use (both continuous and infrequent).

Sather (2008) did not capture large numbers of “*riverine Chinook*” migrating into the estuary when peak numbers of Chinook in the estuary were already present. She explains this in relation to different life history strategies however; there was a disproportionate distribution of wild under-yearling Chinook salmon within estuarine habitats of the Dungeness River estuary. Population abundance of all salmonid species captured over the migratory period was “disproportionately greater in the River Slough channel than at other sampling sites”.

Water velocity

Cowichan River and estuary (water velocity and depth)

The velocity of water due to river flow and/or tidal changes in estuaries can influence the occupation and use of habitats by juvenile salmonids. Pellett et al. (2013) observed the highest densities of Chinook in main stem river sites during their studies in the Cowichan River and estuary.

In side-channel habitats they observed that higher numbers were associated with higher velocities, contrasting with those locations with little or no velocity where few or no juveniles were seen. Concentrations of juvenile Chinook were observed close to the substrate in higher velocity locations > 4 m depth. It is unfortunate that no empirical data were provided by Pellett et al. (2013) for the actual water velocities corresponding to their observations.

Pellett et al. (2013) assessed Habitat Suitability Index (HSI) curves for summer Chinook rearing and commented that “habitat as shallow as 22 cm can support the highest probability of sub-yearling use”...and that water “velocities as low as 0.25 m/s are highly suitable for Chinook sub-yearlings”.

The authors caution about the application of relationships between probability of use and depth in the HSI used and considered that the “probability of use for 40-60 mm Chinook fry in shallow (< 20 cm) low velocity wetland or marsh habitats” is probably underestimated. Furthermore they stated that “perhaps more importantly, these shallow

wetland habitats may be responsible for the majority of invertebrate food production which is transported via tides and tidal currents to all parts of the estuary”.

Water velocity, depth, and habitat

Campbell River and estuary

During their estuarine residency, chum, Chinook, and coho salmon utilized regions of moderate current in the estuary of the Campbell River for feeding, sloughs, stream margin cover, and back eddies for refuge, and zones of increasing salinity which expose them to marine food and facilitate physiological adaptation to seawater (Macdonald et al. 1987).

Macdonald et al. (1987) commented that “Swimming ability is proportional to fish size (Brett and Glass 1973; Gray 1974), and therefore, larger fish are able to occupy deeper habitats further from shore where there is little protection from water currents (Everest and Chapman 1972; Bustard and Narver 1975; Symons and Heland 1978; Kennedy and Strange 1982) (Fig. 2 and 3). Occupying fast-flowing water may be a mechanism utilized by large fish to leave the river or estuary. However, knowing that many salmon feed within currents (Takahaski and Higashi 1984) and that faster currents present more food per unit time (Everest and Chapman 1972), it is not surprising that fish will move to areas with progressively stronger currents further from shore as they grow. For any salmonid, however, there exists a preferred upper flow rate above which energy expenditure to remain in the current out weighs the energy gain from food”.

While data from field studies did not allow Macdonald et al. (1987) “to obtain a direct estimate of this value, flows at sloughs during low and high tide appeared to be too strong to be favourable for wild and hatchery Chinook salmon ($46-60 \text{ cm}\cdot\text{s}^{-1}$)”. This comment is not supported by the HSI curves for summer Chinook rearing which reveal a >60% probability of use at such velocities (Pellett et al. 2013).

Flow rates of $8-35 \text{ cm}\cdot\text{s}^{-1}$, frequently recorded at high tide, coincided with large concentrations of wild salmonids - results that are supported by the HSI which predicts a >60% probability of use (Pellett et al. 2013). Interestingly, relatively large hatchery coho salmon were able to feed in areas with stronger currents at low tide, and yet maintain a speed approximating that of the wild chinook. The swimming abilities of hatchery fish in these instances perhaps indicate reduced performance relative to wild fish (a topic addressed elsewhere).

Macdonald et al. (1987) stated that “there is obvious adaptive value for smaller wild salmon to seek low current refuges along the marginal areas of rivers (Lister and Genoe 1970) and estuaries”. Furthermore, they considered that the use of outer estuary locations at low tide to avoid strong currents upstream may have less adaptive value in estuaries as large as Campbell River where tidal sloughs, marshes, and river margin cover are available as refugia from strong currents. “Back eddies created at the mouths of sloughs promote the mixing of deeper saline water with river water. The small amounts of marine

food eaten by wild salmon at high tide (Zoea, euphausiids) may enter the upper water column in this manner in addition to being present in the salt wedge. Accordingly, fish may obtain food of marine origin from both surface water and deeper, more saline water below the halocline”.

The “occupation of deeper, more saline environments by larger fish may reflect their readiness to move from the estuary” (McInerney 1964, cited by Macdonald et al. 1987). “Some fish may remain only briefly and therefore spend little time feeding in salt wedge and outer estuarine habitats” (Macdonald et al. 1987). This could explain why the diets of all salmon examined by these authors showed lower similarities with the food available in the salt wedge and at the outer estuary region than with food of the surface waters of the inner estuary. In addition, “deep-dwelling fish (coho, cutthroat, hatchery Chinook) augment planktonic food resources with benthic prey resulting in decreased similarities between their diets and the plankton samples from the salt wedge habitat”.

Reduced value of some habitats and their use

Inner regions of Campbell River sloughs may be of less value as refuge sites from high water velocity (Macdonald et al. 1987). Fewer food organisms were present there compared with other inner estuary sites. Additionally, certain Campbell River slough regions may be of less direct value as fish habitat because of low dissolved oxygen levels, a situation also commented on by Pellett et al. (2013) regarding the Cowichan River and estuary (this aspect emphasizes the need for water quality determinations at the time fish are captured and/or observed in these and other locations).

Macdonald et al. (1987) speculated that hatchery fish that frequent “suboptimal sloughs throughout the year may be disoriented and require a period of time after release to establish correct feeding locations and methods. Alternatively, they may lack stamina to remain in fast-flowing water and/or be attracted to the warmer water in the slough. However, estuarine sloughs may be valuable habitat for wild Chinook as winter refuge areas in the same manner as coho salmon and rainbow trout overwinter in freshwater sloughs”.

Water velocity and prey

The importance of a specific habitat type cannot always be measured by the amount of time occupied by the fish and this is exemplified in the studies reported by Macdonald et al. (1987). In the Campbell River estuary, and in high currents in regions where salmonids were rarely seen, these authors suggested that such water velocities may act to dislodge benthic animals, thus making this food available.

Macdonald et al. (1987) mentioned that although infrequently-used sloughs may not always have water of the quality required to support salmonids, they may support the marsh vegetation on which the salmonid detrital food chain is based (Sibert et al. 1977; Healey 1979; Wolf et al. 1983 cited by Macdonald et al. 1987). These authors considered

that maintenance of a large diversity of microhabitats within the estuary may be important for the perpetuation of salmon stocks.

Tidal factor and habitats occupied

Even though studies have documented “estuary-wide migrations, residence times, and habitat use by juvenile salmonids (e.g., Healey 1980; Kjelson et al. 1982; Miller and Sadro 2003), few have examined the fine-scale movement of individual salmon into and out of shallow marsh habitats as channels drain and fill with each tide (Levy and Northcote 1982)” Hering et al. (2010).

Levy and Northcote (1981) found juvenile Chinook in narrow (<1m wide) dendritic tidal channels in the marshes of the Fraser River estuary, up to 1 km from the main river channel, and in densely vegetated zones (Levings et al. 1991).

Similarly, Semmens (2008) commented that considerable research effort has focused on characterizing estuary-wide distribution patterns coincident with tidal cycles (Healey 1982; Levy and Northcote 1982; Moser et al. 1991) and salinity gradients (Simenstad et al. 2000). Conversely, relatively few studies have investigated the distributions and relative abundances of salmon in relation to near shore benthic–epibenthic estuarine habitats (an exception is Murphy et al. 2000). Benthic–epibenthic habitats in Pacific coast estuaries are important in the context of salmon management because they are a potentially productive source of prey (Bottom et al. 2005a) and a source of physical structure (Murphy et al. 2000; Shaffer 2004).

Using similar tag technology to that employed by Hering et al. (2010), Semmens (2008) implanted hydro acoustic tags to track the movements of larger under-yearling fall Chinook salmon (<135 mm) in Willapa Bay, WA, to link benthic habitats with near-continuous fine-scale observations on multiple individuals over multiple days. They commented that “most studies of juvenile salmon habitat use have focused on terrestrial–riparian habitats such as river mouth emergent marsh areas (e.g., Fresh et al. 1981; Healey 1982; Simenstad et al. 1982)”.

The investigations by Hering et al. (2010) revealed the fine-scale movement of juvenile Chinook salmon in relation to tides in the Salmon River estuary. They showed that the salmon used marsh channel habitat over a broad range of tidal conditions when water depth was greater than 0.4 m, that individual salmon remained in the intertidal channel for a median 4.9 h and as long as 8.9 h per tidal cycle, the timing of salmon movement into and out of intertidal habitat was not centered on high slack tide, and fish at times swam against tidal currents.

Hering et al. (2010) stated that “Although juvenile salmon usually entered and departed the Salmon River marsh channel in the direction of tidal currents, the asymmetry of salmon movement about high slack water and the high proportion of movements that occurred against ebbing tides indicate that Chinook salmon do not drift passively with the current, but rather enter and actively remain in intertidal habitat until late in the tidal

cycle. Peak salmon movement occurred during mid- to late flood tides (i.e., 1-2 h before high slack tide) and late during ebb tides (i.e., 3-4 h after high slack tide). Furthermore, 20% of individuals entered the channel against the ebbing tide, 8% exited against the flooding tide, and fish exited the channel at water depths that were, on average, 20 cm shallower than when they entered". The results are similar to those obtained by Mesa (1985) in the estuary of the Fraser River.

Hering et al. (2010) "did not observe a substantial difference in the number of tagged salmon detected between night and day, the longest tidal residence time of individuals within the marsh occurred during night time tides. Because the entire population of the intertidal channel network is concentrated within a limited number of sub tidal refuge habitats in the main stem estuary during low tide, some redistribution of individuals within the network likely occurs with each tidal cycle".

Individual salmon may exhibit fidelity at the scale of secondary marsh channels within an intertidal marsh-channel network despite having to vacate tidal channels with each ebb tide, and some individuals used a channel repeatedly on successive tides (Hering et al. 2010).

Habitat Type and Connectivity

Skagit River, Washington

Extensive research has been undertaken in the Skagit River and estuary to address ecological aspects of the system particularly associated with rehabilitation of estuarine function to assist survival of Chinook salmon. Comments are presented below from the reports of Connor et al. (2011), and Beamer et al. (2005).

The "Skagit Chinook Plan model assumes that juvenile Chinook densities increase with increasing connectivity (Beamer et al. 2005). The model predicts that Chinook juvenile densities would be highest in the upper freshwater areas of the delta and would progressively decline ... as the distance ... became greater and as delta channels become more and more branched". "Major habitat types found in the Skagit estuary include delta mudflats, lagoon pocket estuaries, near shore beaches, the offshore areas of Skagit Bay, and the vegetated delta. These areas can be further separated into blind channels, distributary channels, shallow intertidal habitats, sub tidal fringe habitats, and surface waters (Beamer et al. 2007)", cited by Conner et al. (2011). "These habitat areas provide a wide variety geo-morphological, substrate, current, salinity, temperature, food resource, and vegetation conditions that supports a diversity of fish including salmonids (salmon, cutthroat trout, and bull trout), small pelagic fishes (including Pacific herring, Pacific sand lance, and surf smelt), sculpin, flatfish, and other species such as three-spine sticklebacks and gunnels" (Beamer et al. 2007).

Conner et al. (2011) reported that restoration projects that restore natural tidal and channel processes to impaired habitats within the Skagit delta can "result in rapid improvements in juvenile Chinook numbers"; they found that "juvenile Chinook re-

colonized restored habitats the first year following construction, and that densities increased to over 10,000 fish per hectare (1.0 fish per sq-meter) three years following restoration (Beamer et al. 2006)".

Importance of the vegetated riparian zone

Food production

The vegetated riparian zone plays important functional roles in aquatic ecology such as the provision of organic matter, physical cover, and food – through the supply of invertebrates such as winged insects which colonize waters by aerial transport and movement of adults (Hunt 1975; Brennan and Culverwell. 2004).

According to Wallace (1990) re-colonization is dependent on the timing of disturbance and flight periods of various taxa. "Available evidence indicates that re-colonization by invertebrate taxa without an aerial adult stage requires longer periods of time than for those that possess winged, terrestrial adult stages (i.e., most insects)". Whitworth and Martin (1990) documented higher "taxa richness of macro-invertebrates", and "species richness, diversity, total density, and index of biological integrity (IBI) of fish" in waters with a vegetated riparian zone (Henley et al. 2000).

Fresh water, estuarine, and marine riparian vegetation is thought to provide key ecological functions such as supplying shade, nutrients, and prey items to near-shore environments (Brennan and Culverwell 2004). Levings and Jamieson (2001) suggested that the functional importance of marine riparian is likely to be related to food production, temperature regulation, wave energy absorption, and provision of structure as well as indirect ecological value. Mudflats have also been documented as productive habitats that support high densities of prey resources used by juvenile salmonids (Levings et al. 1991). Carbon from local sources of particular vegetation types has been shown to be routed to invertebrates in specific nearby habitats (Levings et al. 1991) thereby supporting its important role in the food chain leading to salmon growth and hence survival.

Cover

Both Chinook salmon and trout exhibited the highest densities in cover habitats regardless of the reach, and progressively diminishing densities in no-cover and mid-channel habitats in the Smith River estuary (Quiñones and Mulligan 2005). They found that the presence or absence of juvenile Chinook salmon was significantly influenced by year, cover habitat, and salinity. Salinity was the single most influential variable in determining the presence of Chinook salmon. Juvenile Chinook salmon preferred cover habitat over no-cover and mid-channel habitats to an equal degree.

Quiñones and Mulligan (2005) considered that the importance of riparian vegetation as cover was further accentuated in the Smith River estuary because of the virtual lack of tidal channels, in-stream structures, and its high water clarity which could make fish

more vulnerable to predation (Gregory 1993). These authors suggested that to enhance juvenile salmonid production, the protection and reestablishment of riparian vegetation must be an essential part of integrated watershed management, particularly in estuaries with little in-stream cover and few tidal channels, such as the Smith River estuary.

Movement of juvenile salmonids in the Somass River estuary

How and why juvenile salmonids use the estuary of the Somass River and waters of Alberni Inlet en route to the Pacific Ocean has not been determined. The motivation for seaward migration at a particular size/phase in their life is obviously innate and in general one would expect conformity among “races” of the same species as well as variations specific to them and the environment they occupy.

Juvenile Chinook salmon entering the estuary of the Somass River may be transported passively within the freshwater to brackish seaward moving waters along the Inlet. At the head of the Inlet studies have confirmed the use of estuarine marsh and intertidal habitat for periods of time beyond that which could be explained by local currents and water movements (refer to Tully 1948, 1949). Both “hatchery” and “wild” juveniles have been found in these locations in the spring and early summer but the majority of larger “hatchery”- reared individuals apparently move through and exit the upper harbour waters primarily along the eastern shore where stronger currents exist. The smaller “wild” fish use the upper estuary for a much longer period and based on the residency of fish and information from other locations it may be deduced that such occupancy has volitional components and it is not just passive movement with currents.

Research on the Fraser River estuary revealed the prolonged residency of juvenile Chinook salmon in tidal marshes and channels that were de-watered at low tide (Dunford, 1975; Levy and Northcote 1982; Northcote et al. 2007). Hering et al. (2010) determined that juvenile Chinook salmon do not drift passively with the current, but rather entered and actively remained in intertidal habitat until late in the tidal cycle.

It is speculated that both passive and direct volitional movements relate to fish use of the habitats. In the Somass estuary the studies and modelling of Tully (1948, 1949) show how waters on the north-western side of the Inlet to Johnston Slough accumulate there especially at high tides and provide a somewhat large body of brackish water that is not immediately flushed from the area on ebb tides. Tully (1949) stated “The western side of the harbour is occupied by mixed Inlet and river water, which is only displaced from the region by being drawn into the river stream. During the flood tide Inlet water enters the harbour, opposing the outflow of river water, which accumulates as a cloud. At the same time the mixed water on the western side is displaced onto the tide flats at the head. Boundary currents were observed along both eastern and western shores, in which the flood movement was very weak while the ebb movement was comparatively strong, and the water was conserved near the shore. From this it may be recognized that the western, and in particular the north-western part, of the harbour is a region of accumulation, where seaward displacement of the water is a minimum. The river stream is a region of displacement, and along both shores there is a region of restricted flow”. Lateral mixing

of waters occurs (refer to Tully 1948, 1949; Seaconsult Marine Research Ltd. 1994) and this relatively homogeneous body of water exits from the harbour after several (3-6) tidal movements into and out of the area.

If juvenile Chinook salmon (which are found to be behaviourally biased (Birtwell 1977; Birtwell and Kruzynski 1989) towards the water surface (<2 m depth, but with the majority at <1 m depth) were distributed passively with the currents one would expect a correspondingly short (4-11 days; refer to Morris and Leaney 1980) general period of utilization in estuarine habitats because of eventual seaward tidal flushing but, clearly this is not the case. While transport and dispersion of juveniles immediately entering the harbour area in the Somass River water will likely occur within the main water currents flowing initially along the eastern shore (Tully's region of "displacement" 1949), tidal movements provide the impetus for up-Inlet movement of waters and lateral dispersion. As Tully (1948, 1949) showed, these surface waters accumulate over a large area along the western shore and onto the tidal flats by Johnston Slough. Thus it may be expected, through currents alone, that transport and dispersion of some juvenile Chinook salmon will be towards the north-western part of the estuary.

Beamer et al. (2005) employed drift buoys to predict passive surface water dispersal of juvenile Chinook salmon. They deduced that the fish could, over a 6 hour period, move over 7 km during one ebb tide. Migration rates range from 4-14 km/day for marked chum salmon in Hood Canal of the same approximate size as Chinook fry (Bax and Whitmus 1981 cited by Beamer et al. 2005). Thus a combination of passive and volitional directed movements assists juvenile salmon as they dwell in, and move through, various estuarine habitats.

Dispersion, displacement and carrying capacity

It has been suggested that early fry swept into estuaries represent those that are surplus to the carrying capacity of riverine rearing habitats (Lister and Genoe, 1970). But Healey (1991) stated that the fry migrant pattern characteristic of many river basins is likely an adaptive response to productive estuarine nursery areas (Bottom et al. 2005a). However, if there were limitations to fresh water rearing capacity one cannot discount potential displacement of early fry migrants by later and larger individuals having reared for longer periods in fresh water (e.g. hatchery fish and/or those with a different life history strategy). The consequences of such movements could stimulate density-dependent interactions among differing size classes of individuals of the same species as well as inter-specific competition.

Not all downstream-migrating juveniles in the Salmon River in Oregon survive and "even though the largest proportion of fry migrants enter tidewater during April and early May, mark-recapture results indicated that few of these fish survived to the river mouth" (Bottom et al. 2005a, b). These authors considered that "The low survival of emergent-fry migrants may not be unusual. Studies in the Fraser (Levy and Northcote, 1981) and Nanaimo River estuaries (Healey 1980, 1982) similarly could not account for a large proportion of the downstream migrants to each estuary and suggested a high mortality

may have occurred soon after migration was completed. Most marked individuals that we later recaptured near the mouth of Salmon River (and presumably, were about to exit the estuary) had not entered the estuary before June. The causes of poor survival of emergent fry in the river and estuary are not known” (Bottom et al. 2005a, b).

Displacement and dispersion

Einum and Flemming (2001) concluded that “the performance of hatchery fish and their interactions with wild fish is of such a character that many of the current stocking practices may be detrimental to the recipient population”. Among the concerns was the influx of large numbers of hatchery-reared fish into limited habitat initially affecting population density, competitive interactions, food availability, a functional response to predators and the influence on growth and survival of wild individuals. The authors suggested that it was possible to speculate that “hatchery fish are to some degree able to displace naturally produced fish, but that they are unable to cope with the high cost associated with this behaviour in terms of risk of starvation or predation. If so, net fish production may actually decrease as a result of stocking (cf. Fleming et al. 2000).

Skagit River estuary

Beamer et al. (2005) found a density dependent response to fish abundance in tidal delta habitats of the Skagit River similar to that which appears to occur in freshwater. The implications of such density dependent movements have relevance to individual survival depending on the suitability and availability of habitats which displaced individuals then use.

In the estuarine regions of the Skagit River, Beamer et al. (2005) recorded that “as tidal delta habitat fills up, the excess fish respond by moving downstream into Skagit Bay” and “while we are fundamentally measuring this response at the population level, the density dependent processes that result in fry moving downstream into the bay likely occur at multiple scales. For example, different portions of the tidal delta will vary in their capacity to support fish based upon the habitat conditions that are present there. Similarly, within one tidal channel complex, the outcomes of the interactions of individual fish will determine what fish and how many move downstream. These processes are occurring continuously. We noted effects on size of tidal delta fry at varying densities but are unclear about the implications of these density dependent interactions to survival of the juvenile Chinook salmon”. Beamer et al. (2005) forecast that if fish size and survival are correlated as many studies have found (e.g., Healey 1991; Tovey 1999) “then survival could be negatively affected”.

Sarita River estuary Barkley Sound

The release of large numbers of different size categories of hatchery-reared juvenile Chinook salmon into the Sarita River and estuary was examined by Ochman (2014). Based on fish captures in the estuary, Ochman (2014) speculated that “semi-natural” smolts move out of the estuary quickly in a matter of days or that they are dying due to

predation, starvation or other reasons at a quicker rate than the two other hatchery groups (the reference to starvation is supported by analyses of fish captured; hatchery fish were significantly inferior to wild fish in capturing a wide variety of prey and many more had empty stomachs). “The number of hatchery smolts seemed to “overwhelm” the wild smolt population with only 5% of the smolts analyzed being wild”. “It seems that most Chinook smolts die, spread out or leave the Sarita estuary (in about 2 weeks) as evidenced by the low numbers of smolts captured during later sampling dates in June 2013” (Ochman 2014).

Somass River and estuary

There are inferences from the observations of Damborg and Wightman (2013) in the Somass River and estuary that downstream dispersion and/or displacement of “wild” juvenile Chinook salmon from riverine to estuarine locations could have occurred following the releases from the Robertson Creek Hatchery (May 21-27 2013) of 6 million larger hatchery-reared fish, and their rapid downstream movement; notwithstanding the natural progressive migration of these and other juveniles to the estuary and the Pacific Ocean.

From an estimated 11,507 adults Damborg and Wightman (2013) suggested that about 3.6 million “wild” fry would have been produced and they assumed that the majority would have migrated to the estuary where higher numbers would have been observed in their surveys. Damborg and Wightman (2013) stated that “Chinook fry use of surveyed estuary habitat was much lower than the surveyed reach of the lower river with fish densitiesbeing approximately 10% lower”. Such comparisons are difficult to interpret given greatly contrasting aspects of habitat complexity among sites, observation standardization, and other factors such tidal state and current, migration timing and the natural dispersion requirement of ocean-migrating salmonids to enter waters favourable for their transition to salt water. Nevertheless, Damborg and Wightman (2013) deduced from an estimation of production of “wild” Chinook juveniles that they “would have expected to see far greater numbers in estuarine habitats”. They also note that similar observations were recorded in the Cowichan River in spring 2013 (perhaps also related to artefacts of sampling and other unaccounted-for variables?).

While it is not possible to verify these findings and inferences, it is possible that the wild fish did not “migrate to the estuary soon after emergence” and that if they had done so the influx of more juvenile Chinook salmon into the Somass River and estuary may have resulted in untimely seaward displacement leading to fewer than expected individuals being seen in estuarine habitat. Or, natural dispersion into more and different habitats to those in riverine locations resulted in correspondingly fewer fish being observed than expected - a situation similar to that observed in the estuary of the Cowichan River by Pellett et al. (2013).

In 1999 15,300 adults were documented to have spawned in the Somass River system. It was calculated that this should have resulted in 39.9 million eggs. Considering survival at a level of 12% this would have resulted in 4.8 million fry in 2000. A further 7.6 million

juveniles were released for the Robertson Creek Hatchery on May 26-29 2000. Thus, in 2000 a total of 12.4 million juvenile Chinook salmon was expected to rear and/or migrate in the Somass River and estuary on their way to the Pacific Ocean.

In 2000, 3,500 adults spawned in the Somass River system and would have produced 1.1 million fry in 2001, using the same production and survival expectations as used for the previous data. The hatchery released 5 million juveniles May 30-June 7 therefore, in 2001 there were 6.1 million juvenile Chinook salmon in the river rearing and/or migrating. Thus, there was twice the number of juveniles in 2000 to that in 2001. The relative survival of these hatchery and wild fish is not known nor has any interaction been quantified; (0.03-4.4% fry to adult survival range for hatchery fish 1982-1992; Tovey 1999. Note - information from DFO reported occasionally different survival rates and in the late 1980s the rates averaged 9% and 2.5% in the 1990s).

The catches of juvenile Chinook salmon at Polly Point about 3 km from the mouth of the Somass River (Tanasichuk; DFO unpublished data, *pers. comm.*, 2014) revealed the presence of relatively larger numbers of “wild” juveniles immediately following releases from the Robertson Creek Hatchery in 2000 and 2001 (refer to Table 2).

Table 2. Catches of juvenile Chinook salmon by beach and purse seine at Polly Point in 2000 and 2001 (from Tanasichuk; DFO unpublished data).

Date			CPUE (no. fish per cubic meter x 100000)				Release
			Wild Chinook		Hatchery Chinook		
Day	Month	Year	BS	PS	BS	PS	
15	May	2000	.	0	.	0	May 26 - 29
29	May	2000	3853	0	0	1	7.6 million
13	Jun	2000	1966	0	546	425	
5	Jul	2000	419	19	0	10	
26	Jul	2000	84	4	0	8	
14	May	2001	0	0	0	0	May 30 - June 7
29	May	2001	0	5	0	14	5 million
12	June	2001	251	0	670	407	
29	Jun	2001	84	0	0	101	
24	Jul	2001	0	9	0	45	
28	Aug	2001	0	3	0	4	

The appearance of such large numbers of “wild” Chinook so soon after the release of hatchery-reared individuals may imply the displacement of “wild” fish from river and estuary habitats. The presence of hatchery-reared fish in both beach and purse seines after the times of release would be expected based on earlier studies (e.g. Birtwell 1978). It is of note that the ‘wild’ juvenile fish were captured in greater numbers in shoreline habitats by beach seine reflecting the expected use of the shallow water tidal habitat for feeding

(prey resources for these fish may well be inappropriate and/or impoverished in the off-beach areas of the Inlet (refer to Kask and Parker (1972) for historical information).

Irrespective of the validity of these assumptions and suggestions one might deduce that if estuarine habitat is limited and/or degraded in complexity, space, food production etc., and accordingly only able to support a certain number of downstream migrating juvenile salmon and other fish, that the imposition of larger numbers of fish from other sources, such as, for example, hatcheries, would increase interactions among the fish with potentially negative consequences mostly probably reflected in reduced growth rates (Weber and Fausch 2005) and associated increased risks from predators (Berejikian (1995).

Weber and Fausch (2005) conducted experiments to assess the effects of hatchery-reared juvenile Chinook salmon on the emigration, growth and survival of their wild counterparts. Their results indicated that hatchery-reared fish prompted few wild fish to emigrate during a period when food was not limiting and survival was similar between the groups.

Another example related to behavioural change is also provided by the research of Johnsson and Abrahams (1991). They determined different foraging behaviours between juvenile steelhead trout and hybrids leading them to conclude that interbreeding between escaped hatchery and wild fish may have a potentially damaging effect on the wild population. (Salmonids in estuaries do not typically show territoriality and therefore any density-dependent growth is most likely an expression based on competition for food resources and space).

In the Somass River estuary it has been reported that only 33.5% of the original estuary land base remains (Catherine Berris Associates Inc. 2010) and continuing impacts due to sewage and pulp mill effluents and log handling practices may further constrain estuarine habitat potentially resulting in density dependent interactions among juvenile Chinook salmon and other species.

Carrying capacity

If one considers survival to be linked to pristine habitats then degradation of them would have some proportional adverse consequence (Magnusson and Hilborn 2003; Meador 2014). It may be expected therefore that the reduction of estuarine habitat in the Somass River would lead to a reduction in carrying capacity directly or indirectly through density-dependent processes.

Determinations of the carrying capacity of an estuary will be constrained by information such as the establishment of what habitat types are used and fish residency therein, and the function they provide regarding the supply and availability of food and realized growth rates. An example of carrying capacity has been reported by Connor et al. (2011).

Skagit River and estuary

The carrying capacity of juvenile Chinook salmon was estimated for the freshwater tidal and estuary habitats found in the Skagit delta (Connor et al. 2011): “The carrying capacity value is an estimate of the maximum density of juveniles that could be attained *given that the number of fry entering the delta was not a limiting factor* (this would be expected in good spawning years)”. Competition for limited food resources was considered to be the most likely factor controlling the maximum density of juveniles in this area (Greene and Beamer 2005) and the maximum density of juvenile Chinook for both freshwater delta and estuary habitats was calculated to be 1.31 juvenile Chinook per cubic meter. Beamer et al. (2005) developed a simple reference site model for predicting the density of juvenile Chinook for natural and restored habitats in Skagit estuary habitat. The average density of juvenile Chinook measured in these areas was 1.1 fish per square meter (4,452 fish per acre).

Fish densities and habitat type

Among the habitat types identified in the Skagit estuary, it was determined that “the highest densities of juvenile Chinook salmon, with densities exceeding 15,000 fish per hectare (1.5 fish per sq-meter) occurred in vegetated blind channels along Skagit Bay”.

The second highest use by juvenile Chinook among estuary habitat types, occurred in the shallow vegetated “tributary channels of the lower north and south fork Skagit River”; “juvenile Chinook densities exceeding 7,000 fish per hectare (0.7 fish per sq-meter).”

By comparison, “non-vegetated intertidal flats and the sub-tidal fringe areas of near-shore beaches had much lower densities of juvenile Chinook, with densities within the intertidal flats of Skagit Bay exceeding 700 fish per hectare (0.07 fish per sq-meter), and densities within the sub-tidal fringe areas of near-shore beaches exceeding 300 fish per hectare (0.03 fish per sq-meter) (Beamer et al. 2007)”.

Densities of juvenile Chinook at sites in the *freshwater tidal areas* of the Skagit delta were found “to exceed 10,000 fish per hectare (1.0 fish per sq-meter) during the spring smolt outmigration period (Beamer et al. 2005), which is lower than densities observed in estuary blind-slough habitats, but similar to densities observed in shallow vegetated tributary habitats of the lower Skagit delta”. “Substantially lower densities of juvenile Chinook (approximately 3,000 to 5,400 fish per hectare) were measured at estuary and freshwater sites where tidal and riverine processes are constrained by dikes and tide gates (Beamer et al. 2005; Beamer et al. 2010)”.

Somass River and estuary

The carrying capacity of riverine areas within the Stamp-Somass River system was examined by Burt and Associates (1989). Unfortunately this study was carried out after the main downstream migration period of juvenile Chinook salmon. Hence, based on scarce data, the deduction that 31,738 individual Chinook juveniles (5.6 g) was the

carrying capacity for juvenile Chinook salmon was likely an underestimate. The availability of suitable habitat ranged from 5% (Somass River) to 16% (Ash River) for Chinook pre-smolts.

Damborg and Wightman (2013) observed the highest densities of juvenile Chinook salmon in the main stem of the river (31.6 individuals/m) on April 18 2013 and a secondary peak on June 3 2013 (21 individuals/m). At their “estuary index sites” densities did not exceed 6.7 individuals/m. However, not only were the linear observation distances different among grouped sites, the habitat type and availability (river edge versus tidal marsh/channel) varied, thereby confounding the reasons for such differences. Determining carrying capacity in an open system (versus a closed system such as a lake) within which fish immigrate and emigrate, and supporting habitat quality and resources vary is an extremely complex task. The carrying capacity of the Somass River estuary has not been determined and it is likely that only inferences regarding this aspect can be obtained from the sparse information that currently exists. Logically, there is large uncertainty in the results of the extrapolation of data obtained from an examination of small parts of a system to represent that of the whole.

To adequately reflect the numbers of fish using the estuary of the Somass River, extensive and appropriate surveys would be required, and even then, and without regard to other organisms whose presence and function interacts with those of the particular interest, there would be much uncertainty and ambiguity. Perhaps, in the simplest expression of density, its value may lie in the assessment of smaller, possibly “micro” habitats which may be much easier to define and examine from a comparative perspective. We think that determination of the carrying capacity of the Somass River estuary will be an elusive goal, but may be speculated upon, and inferred from other study results as mentioned above in the context of displacement and growth rate of fish.

Investigations of juvenile salmon ecology in the Somass estuary

Investigations undertaken in the 1970’s focused on the ecology of Chinook salmon and other fish species (e.g. Kask and Parker 1972; Birtwell 1978; Birtwell and Harbo 1980; Birtwell et al.1983a). Figure 4 shows the sites at which sampling and *in-situ* experimentation occurred in 1975 in the estuary of the Somass River (from Birtwell 1978).

Survival and behaviour experiments

In-situ survival bioassays

The survival of juvenile Chinook salmon held in cages was examined in 1975. Except for the control site the 5 other locations were along the effluent path along the eastern shore (see Figure 4). At the 0.5 m depth the highest mortality after 96-h exposure was 27.5% and after 14-d, 50% mortality approximately 450 m from the outfall from the mill. At the mid-Inlet “control” site 1400 m from the outfall the corresponding mortality was 2.5% and 6.6% over the same time periods.

Contrasting with these findings, the mortality of fish held at 4 m depth after 96-h was 20% at the site closest to the outfall (150 m) and no mortalities at the other locations. After a 14-d exposure all the fish had died within 450 m of the outfall and at the “control” site (re PME exposure, but likely not for dissolved oxygen depression). Only at sites 800 m and 1600 m from the outfall were 60% and 40% of fish alive respectively.

At 6.5 m depth all fish at all locations died within 24-h exposure (the first observation period). Based on discrete determinations at the time of observation dissolved oxygen levels ranged from 5% - 90%, 5% - 100% and 65% - 160% air saturation at 6.5 m, 4 m and 0.5 m respectively. The lower levels of dissolved oxygen would be lethal depending on duration of exposure.

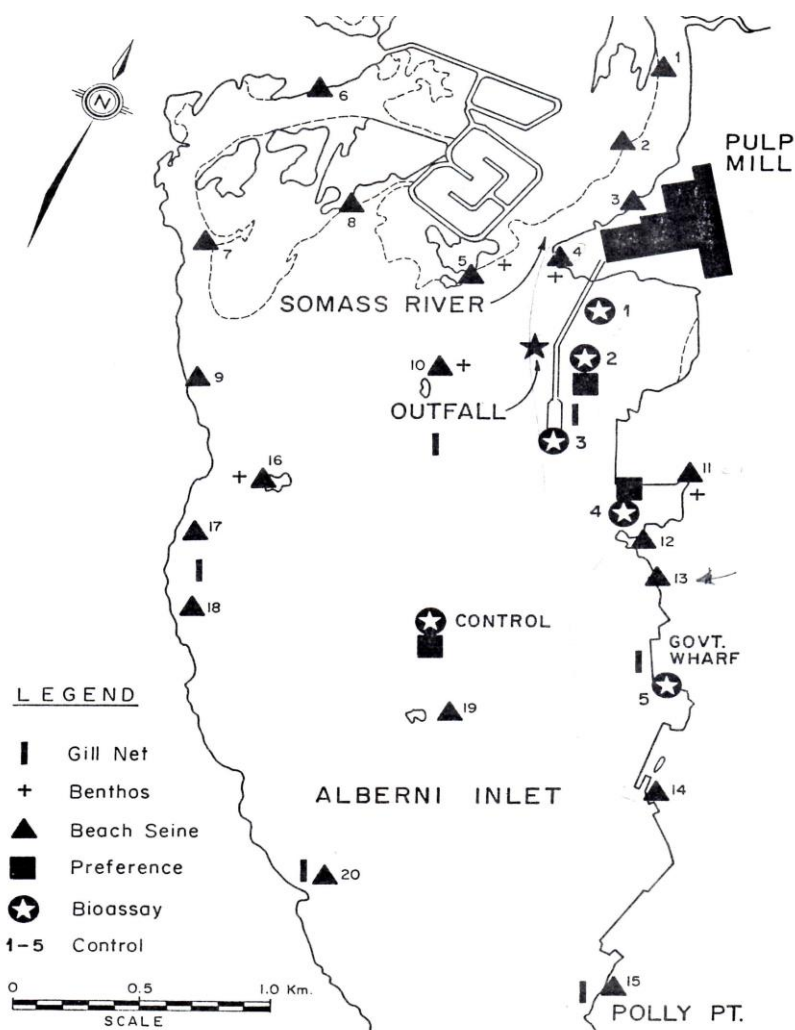


Figure 4. Sites at which sampling and *in-situ* experimentation occurred in 1975 in the estuary of the Somass River (from Birtwell 1978).

The results revealed that the waters of the freshwater lens in the Somass estuary were not, in general, rapidly lethal to juvenile Chinook salmon, despite the presence of dilutions of PME (Birtwell 1978; Birtwell and Kruzynski 1989). However, proximal to, and at distance from the effluent outfall some fish died within 96 h and more after 336-h exposure, but never more than 50% of the number of the caged fish.

It was deduced that the survival of juvenile Chinook salmon in the surface waters above the halocline were likely due to PME exposure whereas that at depth fluctuating acutely stressful and lethal hypoxic conditions were almost certainly contributed to the mortality of the test fish. Thus beneath the shallow freshwater lens in the upper Inlet water quality was potentially acutely lethal for juvenile Chinook salmon.

We are not aware of any similar *in-situ* experiments carried out to assess survival and/or debilitation of juvenile fish in similar locations and at the same time of year as in 1975. If water quality conditions have improved over the last 39 years, as suggested by the reports by Hatfield Consultants (2012, 2013a,b, 2014), one may expect conditions more favourable to the wellbeing of juvenile Chinook salmon and other species in surface fresh waters and those in and below the halocline in the estuary of the Somass River.

In-situ behaviour experiments

Experiments carried out in 1975 examined the behaviour of juvenile Chinook salmon in relation to vertical changes in the stratified waters of the estuary. The fish were permitted to volitionally-move within an enclosed 5-m long vertically-orientated cage subtended from the water surface (Birtwell 1977, 1978; McGreer and Vigers 1983). The netting of the cage permitted the experimental fish to be exposed to the prevailing and varying stratified waters.

Juvenile Chinook salmon chose to occupy the waters above the halocline and their vertical distribution was positively related to levels of dissolved oxygen (Birtwell and Kruzynski 1989). The fish were in the uppermost waters where dissolved oxygen levels were greater than about 60% air saturation. The fish would be found deeper in the water column when dissolved oxygen levels were higher at depth. Thus the fish chose to reside in warmer fresh surface waters containing dilutions of PME and higher levels of dissolved oxygen. Hypoxic waters influenced the behaviour of the fish in the Somass River estuary and restricted vertical movement and the occupation of deeper waters in 1975 (Birtwell and Harbo 1980; Birtwell and Kruzynski 1989).

In other experiments that similarly examined the behaviour of juvenile salmon in surface waters receiving toxic PME, the innate behaviour of these fish to occupy surface waters resulted in their death (Birtwell and Kruzynski 1989). In this instance, and in contrast to the water quality conditions in the Somass estuary in 1975 which were potentially lethal at depth, in this location the surface waters to 3-m depth were acutely lethal to juvenile Chinook salmon and other species with prolonged (minutes to hours) occupancy (a result confirmed through coincident *in-situ* bioassays). In these experiments fish moved volitionally in a 6-m water column and while many fish avoided the toxic surface waters

some did not and they perished. It was determined that fish deeper in the water column volitionally moved into the shallower waters which resulted in their death (Birtwell and Kruzynski (1989). In this location the health of juvenile salmon was compromised by poor (toxic) conditions in surface waters.

These two *in-situ* studies in different estuarine locations demonstrated that juvenile Chinook salmon have a very strong innate surface water bias that was potentially detrimental to them in conditions where water quality had deteriorated to stressful and lethal levels. The innate response of the fish to occupy surface waters jeopardized their survival. In addition, their use of deeper waters was influenced, and restricted by, dissolved oxygen levels < 60% saturation.

It was concluded that acutely lethal surface waters will not be continuously avoided by all fish; seemingly because of their innate behaviour. Accordingly it is speculated that juvenile salmon may occupy, and not consistently avoid, waters which are stressful to them.

In 1975 and since then, dissolved oxygen levels have been determined to decrease with depth in the Somass River estuary. They have attained levels that would be lethal to juvenile Chinook salmon with and without exposure to other contaminants. Dissolved oxygen levels at depth were a severe impediment to prolonged use of these more saline and cooler waters and as such would have constrained and limited estuarine use by juvenile Chinook salmon.

If improvement to effluent colour has occurred, as seems to be the case on visual inspection, it is possible that higher levels of dissolved oxygen should now occur at depths previously deemed and found to be harmful to juvenile Chinook salmon (e.g. refer to Table 1). However, the results of the mill's EEM studies reveal the existence of a zone of water within the upper estuary that is approximately 3 km from the outfall and in which algal growth is predicted to be impaired (Hatfield Consultants (2013b)). Whether this has relevance to phytoplankton photosynthesis and survival is unknown to us at this time. Concern would be warranted if autotrophic production is still inhibited as cascading effects on productivity may occur at different trophic levels and the lack of oxygen input at different depths would probably inhibit heterotrophic activity (Parker and Sibert 1973).

Laboratory studies (behaviour of juvenile Chinook salmon and hypoxic conditions)

Birtwell and Kruzynski (1987, 1989) carried out studies on the behaviour of juvenile Chinook salmon under conditions that mimicked the vertically-stratified waters in the Somass River estuary. It was shown that juvenile Chinook salmon primarily in the fresh water lens would choose to occupy deeper water at and below the halocline when subjected to progressively increasing hypoxic conditions. In these experiments the "threshold response" level for the population of experimental fish was 50%. As the fish were exposed to decreasing levels of dissolved oxygen from normoxic levels in surface fresh water, they moved, volitionally, to occupy deeper waters with higher dissolved oxygen concentration (i.e. to waters at 100% saturation in seawater below a well-defined

halocline). The 50% response level corresponded to 7 mg/L – 8 mg/L (just below the 76% air saturation level that results in the blood of salmonids becoming less saturated and measurable physiological effects occur – D. Randall, Professor, UBC *pers. comm.*). Had the test utilized the response of a lower percentage of the population of fish to move from hypoxic conditions, correspondingly higher DO values would have been identified as the threshold for effects.

Fish will use waters potentially detrimental to their survival in order to feed (Birtwell and Kruzynski 1989; Birtwell et al. 2001a, 2003). Juvenile salmon will volitionally move to feed in waters that are lethal to them with prolonged occupancy. Under these conditions the fish would move more rapidly to feed, in contrast to the circumstance when the stress (temperature, reduced dissolved oxygen) was absent (Birtwell et al. 2001a, 2003).

Thus the laboratory-derived data on fish behaviour were supportive of data gathered *in-situ* where conditions in stratified estuaries were found to influence and sometimes restrict or deny fish use of the whole water column due to industrial wastewater.

Dissolved oxygen levels > 7 mg/L - 8 mg/L were determined as the levels that did not compromise the behaviour of 50% of juvenile Chinook salmon in progressively increasing hypoxic conditions in waters without PME.

We are unaware of similar behavioural studies that have addressed this issue in relation to the Somass River estuary and the current conditions in the shallow vertically-stratified estuarine waters. It is probable that these findings could be related to ambient conditions in estuarine habitat and help understand what habitats are more likely to be used versus others in which hypoxic waters may temporarily or permanently restrict their occupation.

Fish capture in vertically-stratified near-shore habitat and water quality

Floating and sunken gill nets (mesh size 19-65 mm; surface to 2.5 m, 2.5-5 m depth; set over night for 12 h, high tide - high tide) were used in the upper Inlet waters to examine the vertical distribution (at 5 locations) of fish between May and July 1975 (Birtwell et al. 1983a; Birtwell and Kruzynski 1989). Sampling locations are shown in Figure 4.

Salmonids comprised 32% of fish captured in the 0 - 2.5 m depth stratum but only 1% in the deeper layer. The only time when juvenile Chinook and coho salmon were captured in the 2.5 m - 5 m depth stratum was in May when the level of dissolved oxygen was from 65% to 75% of air saturation: none were taken when dissolved oxygen levels were lower.

The level of dissolved oxygen in the waters fished by the gill nets was considered to have been a significant factor that influenced the catches of salmonids, especially in deeper waters as the lower net was within the halocline and below it at times when hypoxic waters existed.

Dissolved oxygen determinations ranged between 6.2 mg/L and 9.2 mg/L (65% - 95% air saturation) in the 0 - 2.5 m waters during the capture period and, in depths 2.5 m - 5 m the corresponding values were 2.4 mg/L - 9.1 mg/L (25% - 95% air saturation).

At the time of fish captures, the highest temperature and salinity recordings were in July when dissolved oxygen values were lowest. Temperature and salinity determinations ranged between 12°C - 19.3°C and 0.4‰ - 4.0‰ respectively, in the 0 - 2.5 m waters during the capture period, and in depths 2.5 m - 5 m the corresponding values were 10.4°C - 18.6°C and 1.5‰ - 25.6‰ salinity. All values were within optimal and/or tolerable ranges for the fish.

It was deduced that dissolved oxygen was the primary factor that influenced the vertical distribution of the salmonids that were caught. The study does not necessarily reveal the movements of fish between depths and locations sampled but provides inferences about the possible avoidance and/or influence of hypoxic waters; to this extent it is supportive of other findings in different studies carried out in the Somass estuary in 1975.

Collectively, this information indicates that hypoxic conditions in the shallow vertically-stratified waters of the Somass estuary may have been stressful at times (surface to 2.5 m) and even lethal (>2.5 m depth) to juvenile Chinook salmon and other organisms.

Fish capture in the intertidal zone and water quality

Fish capture 1970/71

Before the Robertson Creek Hatchery commenced its main production of Chinook salmon in 1972 and released juveniles in 1973, Kask and Parker (1972) undertook a brief survey in Alberni Harbour using deep and shallow purse seines and gill nets that fished specific depth strata. In 1970 and 1971, Kask and Parker (1972) observed loose schools/aggregations of small juvenile Chinook during early June and July at the surface along the wharves and beaches of the harbour. However, shoreline sampling by beach nets was not used to capture them. Catches with purse seine and beach seine by Tanasichuk (DFO unpublished data referred to later) reveal the innate shoreline shallow-water bias of these juvenile fish and their dependency on the intertidal zone for food during migration to the Pacific Ocean.

Kask and Parker (1972), using a large purse seine, recorded under-yearling wild Chinook salmon during May, June and July; highest numbers present June 10-24. The fish ranged in size from 43 mm to 90 mm and corresponding weight ranged from 0.9 g to 9.7 g.

Very few juvenile Chinook salmon were captured with the smaller purse seine (1 on May 26 1971 and 5 on May 28); their length ranged from 42 mm to 59 mm and weight from 0.9 g to 2.8 g. Catches from the small seine and the 2-boat trawl demonstrated the presence of juvenile Chinook in both the upper mixed zone and in the halocline.

Catches using the 2-boat trawl occurred from April 7, 1970 (7 fish, 43-46 mm; 0.8 g – 0.9 g), and in 1971 from June 2-16 when 30 fish were captured in 17 hauls. Fish length ranged from 42 mm - 72 mm, weight from 0.7 g - 4.6 g. Only 10 fish were caught in 7 sampling periods with the stratified gill nets; length ranged from 57 mm to 77 mm and weight from 2.3 g to 5.35 g, and only one fish (which was the largest) was caught below the halocline.

Kask and Parker (1972) cautioned that the fish may be quite transient, the sampling “reflecting the numbers entering rather than an accumulation”. Unfortunately, no determinations of water quality were made.

The scarcity and timing of peak numbers of fish in these studies is interesting as they were catches of wild fish unlike the mixture of fish that were perceived to be of wild and hatchery origin in some later studies (e.g. by Birtwell 1978; DFO unpublished data; Tanasichuk DFO unpublished data). They are also relatively small individuals. Kask and Parker (1972) recorded incidental captures of juvenile Chinook salmon taken by dip net from the surface waters (see Table 3).

Table 3. Catches of juvenile Chinook taken by dip net from the water surface in Alberni Harbour during 1971 (from Kask and Parker 1972).

DATE 1971	NUMBER	LENGTH (mm)	WEIGHT (g)
May 20	25	34-45	0.4 - 1.1
May 27	4	34-40	0.3 – 0.9
June 16	16	37-48	0.6 – 1.5
July 20	7	39-54	0.8 – 2.2

Consistent with the findings of Tanasichuk (DFO, unpublished data), peak numbers of wild fish occurred in June in 1971 but, contrasted with the peak numbers of “wild” fish in May that Birtwell (1978) recorded, and the observations of Damborg and Wightman (2013) (also refer to Table 2). However, it is possible that in the latter two studies any peak of “wild” juvenile fish in June could have been masked by the prior release of fish from the Robertson Creek Hatchery. It is also plausible that the period of peak use by wild fish could have been influenced and changed due to the influx of larger numbers of hatchery-reared juveniles.

Fish capture 1975/76

Beach seines were used to capture fish at 20 locations in the intertidal region of the Somass River estuary in 1975 (e.g. Birtwell 1977; DFO unpublished data). Figure 4 shows the location of these sampling sites. Mainly brief summary comments will be provided here.

Study design

This study was a preliminary investigation to assess fish utilisation of shallow estuarine waters and the influence on them of differing habitat conditions among the 20 sampling

sites. These sites were grouped into 4 within upper Alberni Harbour and also into 2 groups that encompassed sites based statistical analyses of colour values indicating the presence of PME. The four main groupings were designated: A - primarily riverine in nature (sites 1-5), B - marsh/intertidal (sites 6-10), C - urban/industrial shoreline seaward of A (sites 11-15) and D - lower estuary adjacent to log booming/storage and seaward of B (sites 16-20).

Zones based on the presence of PME (inferred from determinations of colour; assumed tracer) during the study were 1 (sites 4, 11-15, along the eastern side of the Inlet/Harbour) and 2 (sites 1-3, 5-10, and 16-20). It was hoped that such groupings may reveal differences among them and reflect conditions that may influence the presence of fish.

Bi-weekly sampling in 1975 was by beach seine (30.5x1.8 m, 6 mm mesh) at high tide (3 ± 0.4 m; ± 1 h) during daylight, and at selected sites (4, 5, 10, 11, and 16) sampling was also undertaken at night and also at low tides. At all locations and times sampled the weight, length and condition of captured fish were determined. A suite of water quality determinations was made that included dissolved oxygen, temperature, conductivity, salinity, pH, oxidation-reduction potential and colour.

Comments below relate to Chinook salmon even though a range of metrics and analyses were employed to examine the habitats used by, and influences on, other species of fish captured (Birtwell, DFO unpublished data). Statistical analyses were undertaken to determine if water quality, time of day, tide and "habitat" influenced fish presence/abundance, length, weight, condition, growth rate and diet.

"Wild" juvenile Chinook salmon

The number of age 0⁺ "wild" Chinook salmon in the estuary was estimated: *very* approximate estimates were made at the time of peak abundance in May. On this date it was estimated that about 146,000 fish could be present along the perimeter of shoreline areas based on an extrapolation from catches in shallow intertidal and riverine areas of the estuary (this crude extrapolation is only used to indicate that large numbers of fish were present – it is likely a very low estimate due to the inadequacy of sampling which did not cover all available habitats and depths).

Assuming an average escapement of 12,000 adults into the Somass River system (1971 to 1975) and the production of 5,000 eggs/female with a 3% - 5% survival, the total number of juveniles entering the river and estuary would have been between 915×10^3 and $1,525 \times 10^3$. (One could logically deduce that not all of these fish were in the areas sampled by beach seine and accordingly the crude estimates of individuals in May at the time of sampling probably represented <20% of the estimated production). This very approximate number was before the release of $1,731.8 \times 10^3$ juvenile Chinook salmon from the Robertson Creek Hatchery between May 31 and June 11 1975. The number of juvenile Chinook salmon using and/or migrating through the estuary in 1975 could have been in the range of 2.5-3.2 million individuals.

Length and weight

“Wild” juvenile Chinook salmon entering the Somass estuary had a respective mean length and weight of 42 ± 1.6 mm; 0.75 ± 0.09 g, and for the hatchery-reared fish the respective corresponding length and weight ranged between 62-84 mm and 2.7-6.7 g. The last fish captured in July were 64.1 mm in length and weighed 3.72 g; discernible hatchery-reared fish had a mean length of 59.8 mm and presumably they were the smallest of fish released 1.5 months earlier.

Growth

It was evident that the fish captured during the estuarine utilization period had increased in size but statistical analyses did not reveal significant differences among areas in the estuary. This finding could well be related to inadequacies of the study design, and especially an inability to distinguish captured fish as either “wild” or of hatchery-origin. At the time of their release the hatchery-reared juvenile Chinook salmon were generally larger and therefore distinguishable from “wild” individuals. But, over time, the size of fish captured increased and diminished the resolution among size categories of fish in contrasting habitats. In addition, only 8.6% of hatchery-reared fish were visibly identifiable (due to adipose fin clip).

Length-weight regression analyses revealed a growth rate of the fish captured over the study period to lie within the range of that reported for different river systems. However, data analyses have tended to focus on differences and similarities of mean values and their range in what is most likely a changing population base as fish immigrate and emigrate to and from the estuary. It was evident that some fish captured in mid July 1975 were of a size less than that of hatchery-reared individuals released 1.5 months earlier. The history of estuarine use for these, and for almost all the fish captured, is unknown.

Duration of juvenile Chinook presence and residence in the Somass River estuary

The estuarine utilisation period (i.e. the time over which fish were captured) of juvenile Chinook salmon was approximately 4 months, April to July (maximum in early May) in 1975. Figure 5 shows the average catch per seine over the study period in 1975. Hatchery-reared individuals were captured in the estuary over a shorter time period due to their release being later than the time at which “wild” fish entered the estuary. Juvenile Chinook salmon of the size released by the hatchery were captured as early as 1 day following release and as late as mid July when the last juveniles were caught. These larger individuals were captured in the estuary over a 6-week period. Hence the data imply that dependence on and/or, utilisation of, the estuary by these fish was generally shorter than that of the naturally-produced juvenile Chinook. The period of use by the juvenile Chinook salmon was shorter than that determined in some other estuaries such as, for example, the Nanaimo and Cowichan River estuaries where juvenile Chinook salmon were captured in September and October respectively (refer to Birtwell 1978), although much variability has been recorded, and the water quality of the Somass River

estuary was probably poorer than that of the Cowichan and the Nanaimo River estuaries, and morphologically and hydrographically different.

The reason for the relatively shorter utilisation period in the Somass estuary in 1975 is speculated to relate to the seasonal changes regarding increasing water temperature, the innate movement to marine waters, the adverse water quality that occurred in estuarine brackish and marine waters, impoverished food production due, for example, to PME, toxicity of surface waters proximal to the pulp mill and the influences of industrial and urban development on the availability of prey and habitat availability.

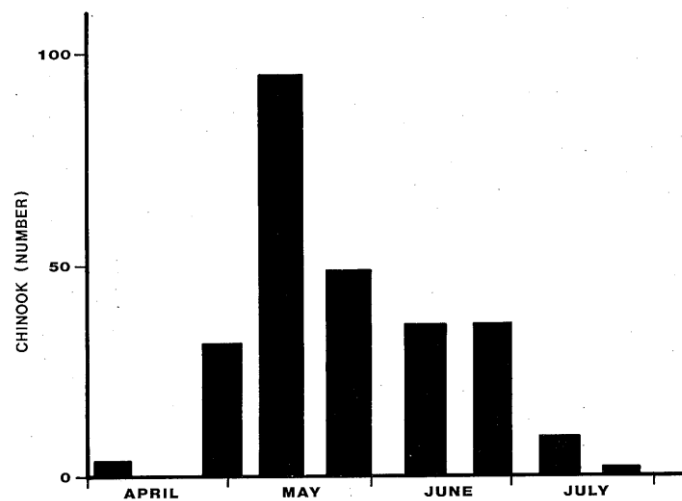


Figure 5. Average catch of juvenile Chinook salmon per beach seine (20 sets per date) within the Somass River estuary in 1975 (April 4 data from 1976), (from Birtwell 1978).

Residency

A residency study was carried out in June 1975 and 2,078 juvenile Chinook salmon were marked at sampling sites 1, 4, 5, 10, and 16 across the estuary. The study was limited and designed to examine fidelity to contrasting habitats within the estuary; seventy-two (3.5%) were recaptured, 18 were considered to be of “wild” origin and 54 hatchery-reared.

Recaptures between June 10 and 25 occurred at sites 2, 4, 5, 11, and 16 which implied a measure of fidelity to the place of marking (a finding also endorsed by studies of the benthic prey organisms of the fish and their diet at the location of capture – reported later).

Hatchery-reared juvenile Chinook salmon

Distinct (fin-clipped) hatchery-reared juvenile Chinook salmon were similarly widely dispersed in the estuary and between June 10 (maximum presence) and July 10 they were captured at sites 2, 4, 5, 10, 12, 16, 18, and 19.

The utilisation period of hatchery-reared fin-clipped fish in the estuary (assuming a rapid movement there from the date of release; approximately ≥ 1 day) was approximately 6 weeks. This finding is interesting and may not relate to the majority of hatchery-released Chinook salmon.

Tovey (1999) determined from scales taken from juvenile Chinook salmon of Robertson Creek Hatchery origin and captured in Barkley Sound in July and August, that the number of days taken for marine scale growth to begin following hatchery release was 34 days (the rate of deposition of marine circuli being 6.8 d per circulus).

Identifiable marine presence was confirmed just over 1 month following release of the fish. Tovey calculated that emigration from the estuary to their presence in Barkley Sound may occur on average between 21 to 34 days following release. If this was so, residence in the Somass estuary would be expected to be substantially shorter than the 6 week period of use based on their presence in estuarine waters at the head of Alberni Inlet. In Tovey's studies, the presence of the fish in Barkley Sound related to a transition to salt water between June 10 and 25; a result consistent with catch data showing that the number of Chinook which had emigrated to Barkley Sound began to increase by June 6 and peaked June 25 (Tovey 1999). Approximately 8 million juvenile Chinook salmon were released from the hatchery over a 2-week period between May and June during Tovey's (1999) studies. Based on these findings a relatively short residence time in the Somass estuary *per se* is implied, probably between <2 to 3 weeks when consideration is given to the time to migrate to Barkley Sound.

Knowing the speed at which these juvenile fish can migrate permits a refinement of the approximate residence period. According to Beamer et al. (2005) the migration rate ranged from 4-14 km/day for marked chum salmon in Hood Canal of the same approximate size as Chinook fry migrating from the Skagit River system (Bax and Whitmus 1981). It is possible, therefore, for juvenile Chinook salmon to reach Barkley Sound in approximately 3-11 days from the Somass estuary thus, when this time is considered in relation to the presence of the majority of fish arriving in Barkley Sound 21-34 days after release, perhaps a more realistic estuarine residence time for the majority of juvenile Chinook salmon of hatchery origin would range between 10 and 31 days.

In 1975 a few of the 1.7 million hatchery-reared fish that were released between May 31 and June 11 were captured in the estuary in mid -late July. Thus, in this instance, some individuals did not immediately migrate directly to the ocean. It is possible that these individuals were small at release because, in July, they were similar in size (approx. 64 mm) to those fish not identified as being of hatchery origin. It is possible that such fish could have been in fresh water/estuarine habitat for a maximum period of 6-7 weeks, but, consistent with the findings of Tovey (1999) the majority of hatchery-reared fish would be in marine waters of Barkley Sound before that time. (One cannot discount the potential for such migrations to be related to density-dependent factors due to the influx over a short time of such large numbers of fish into the Somass River system).

“Wild” juvenile Chinook salmon

The residency period of the “wild” juvenile Chinook, based on the recapture of marked fish, was between 2 and 4 weeks but that was almost certainly a minimum time and biased because of the lateness of the marking when numbers of fish were decreasing in fish catches, presumably related to seaward migration and/or predation. It would be expected that the residency of these fish was much longer when consideration is given to their arrival in the estuary in April (possibly March) and the results of studies in other estuaries. Kask and Parker (1972) captured small wild juvenile Chinook salmon at Polly Point in the Somass estuary in July and Tanasichuk (DFO unpublished data) also captured large numbers of juveniles considered to be of wild origin into August. Both studies revealed the prolonged use of the estuary by rearing juvenile Chinook salmon but did not determine residence *per se*.

Examples of the duration of use of estuaries by salmonids

“Sub-yearling fall Chinook smolts released during the summer and fall, around 0.5 - 1 year after the time of their parents’ spawning, reside in estuaries for a longer period than coho smolts, typically around 1 mo (Healey 1991; Thorpe 1994). In some estuaries the smolts stay for as long as 6 months, especially in larger systems such as Grays Harbour, Washington” (Simenstad et al. 1982).

Salmon River, Oregon

Bottom et al. (2005b) reported that in the Salmon River “the large proportion of fry that now enters the estuary soon after emergence may reflect changes in spawner distribution and abundance resulting from the large concentration of stray hatchery adults that spawn just above tide water. Nonetheless, we documented salmon survivors at the river mouth (i.e. ready to enter the ocean) for a wider range of time periods and sizes than in the 1970s. Most of these individuals had remained upriver to rear until June or later before entering the estuary and may have originated primarily from historical spawning areas in the upper basin, where relatively fewer hatchery strays occur. These results describe important linkages between the geographic structure of spawning populations and the patterns of estuarine habitat use by juveniles, underscoring the need for whole-basin approaches to salmon conservation and recovery (Nehlsen et al. 1991)”.

“Median estuarine residence time for individuals recaptured in the Lower Estuary zone was approximately five weeks. However, as many as 20% of the fish marked at Lower Salmon had resided in the estuary for nine weeks or more at the time of recapture in the Lower Estuary zone. A single individual marked the first week of May 2002 was recaptured 17 weeks later (28 August) in the Lower Estuary zone” (Bottom et al. 2005b).

More recently Hering et al. (2010) using (PIT) technology investigated the movement of individual Chinook >60 mm length into and out of tidally-flooded salt marsh habitat. Their studies in an Oregon salt marsh support the findings of Mesa (1985); the Chinook salmon were not passive but made directed movements. These fish occupied the intertidal

zone up to 8.9 h per tidal cycle. Similar to the findings of Levy and Northcote (1982), some individuals used the channel on multiple successive tidal cycles (over periods up to 109 days).

Campbell River, BC

Macdonald et al. (1988) documented prolonged use/residency of juvenile Chinook salmon that were released in the estuary of the Campbell River and estimates ranged from 25-50 days; comparable to findings in other estuaries such as those of the Fraser and Nanaimo Rivers (Healey 1980; Levy and Northcote 1982).

Korman et al. (1997) reported that hatchery Chinook had an estimated residency in the Campbell River estuary of 1.5 months (peak density May 17-19) and wild Chinook about 3 months (peak density May 25-26, constant June 1-July 15) based on captures from populations in the estuary. It may be important to consider that net capture methods may greatly *underestimate wetland residency* as they cannot measure variation in the frequencies of tidal excursions among individuals entering and leaving local habitats (Hering et al. 2010).

Dungeness River estuary, Washington

In the Dungeness River estuary, Washington, Sather (2008) documented the residence of wild under-yearling Chinook salmon to be up to 30 days. Also, Sather (2008) did not find a relationship between specific size classes of juvenile salmonids, and the larger fish did not necessarily associate with marshes further from the river mouth in the estuary. Hatchery-reared Chinook comprised 2% of the Chinook catch within tidal marshes of the river yet comprised a greater proportion within near-shore estuarine sites (24% - 31%).

Fraser River estuary, BC

In the estuary of the Fraser River juvenile Chinook were determined to use the inner marsh habitats for upwards of 4 weeks and even utilized the same tidally-drained channels over many tidal cycles (Levy and Northcote 1982).

Clearly there is much difference in behaviours among populations of Chinook and conditions in estuaries that favour residency. However, it is generally accepted that residency in such areas, natural or rehabilitated (Bottom et al. 2005a, b) has the potential to influence survival.

Juvenile Chinook salmon captured in differing habitat in the Somass estuary (1975)

Habitat groups A-D

There was no significant difference in the number of fish captured among the groups, despite greater numbers being captured in the upper estuarine locations comprising A (river influenced) and B (marsh/intertidal western side).

The length of fish was lowest at A (49 mm) and different than those at B and C (52-52.4 mm); weight and condition of fish was lowest at A (1.7 g, condition 1.17) and differed from those at D, B, and C (1.8, 1.9, 2.19 g; condition 1.18, 1.18, 2.19 respectively).

The data seemingly reflect the proximity to the river and the influx of smaller fish in lower condition, and the growth and condition of fish in more seaward locations (C, D) and marsh/intertidal habitat (B).

Zone 1 vs. 2

There was no significant difference in the number caught between zones influenced by PME (Zone 1), and those considered less influenced or outside of the main influence in Zone 2. The length of fish was higher in Zone 1 (52.4 mm) and differed from that at Zone 2 (50.6mm); weight was similarly different and higher in zone 1 (2.14 g) vs. Zone 2 (1.76 g); condition was also higher at zone 1 (1.21) vs. zone 2 (1.18).

It is speculated that the higher metrics for fish within the waters influenced by PME could be related to the stimulatory effect of PME on growth and metabolism and/or to the influx of larger hatchery fish captured at sites predominantly along the eastern shore. However, among the salmonids captured at these sites only juvenile Chinook salmon had a higher condition factor in zone 1 (refer to Birtwell 1978; DFO unpublished data).

High vs. low tide

None of the metrics for fish captured (length, weight, condition, number) were significantly different between high and low-tide.

Recent observations of juvenile Chinook salmon in the Somass River and estuary

Damborg and Wightman (2013) reported observations made in 2013 of juvenile salmon and other fish in the Somass River and estuary. It was interesting that there were relatively few species observed and of the non-salmonids only “Sculpin, stickleback and Shiner perch” were noted (Damborg and Wightman 2013). The results of their study provide useful preliminary information for an assessment of the presence of juvenile Chinook salmon in a variety of habitats. Observations were made at night in locations where habitats differed in biological and physical complexity. Surveyed sections were of 25 m or 50 m length in riverine and estuarine locations respectively. Only margins of habitat were surveyed in riverine locations. Surveys were selected to be “near high tide” but no specific details were provided on tidal height. Eleven sites were selected as “Index sites”. The authors designated sampling locations as main stem river (6), estuary (4) and marine (1) but do not provide reasons for their designation and delineation. The four estuary sites are in the NW part of the Somass estuary and less impacted by urban/industrial development. The “marine” site along the eastern shore lies along the main effluent dispersion path from the pulp mill, and is in an area of significant industrial and urban development.

The highest densities of juvenile Chinook salmon were observed in the main stem of the Somass River (31.6 individuals/m) on April 18 2013 and a secondary peak on June 3 2013 (21 individuals/m) Damborg and Wightman (2013). At the “estuary index sites” densities did not exceed 6.7 individuals/m. However, not only were the linear observation distances different among grouped sites, the habitat type and availability (river edge versus tidal marsh/channel) varied, thereby confounding the reasons for such differences.

The first observations of peak numbers of Chinook juveniles in April was prior to the release of larger individuals from the Robertson Creek Hatchery and most probably represented the downstream migration/rearing of “wild” individuals from river-spawning adults. The production of “wild” fry was calculated to be 3.6 million individuals (Damborg and Wightman 2013). The second peak was after the release of the hatchery-reared fish.

While it is difficult to draw strict comparisons among the different observation sites, the data reveal some general trends. Fewer “wild” individuals were observed in the estuary when highest numbers were in the river margins, but this changed by May 2 possibly reflecting dispersion and/or displacement of the “wild” fish within river and estuary habitats.

Observations after the hatchery release of juvenile Chinook salmon

On June 3 2013, after releases from the Robertson Creek Hatchery (May 21, 23 and 27) of 6.5 million under-yearlings, more fish were observed at estuarine locations, river sites and the first recording at the Harbour Quay “marine” site. Thus one may deduce that “wild” and “hatchery” juvenile Chinook were both using riverine and estuarine habitat; a situation similarly observed on June 19 and July 4. It is of interest that, no fish, and one fish, was sighted at the “marine” site on these dates respectively (the result may well reflect the relatively poor habitat conditions at the site, but nevertheless one may have expected more observations of individuals if they exited or were “shunted” along the eastern shoreline as suggested by the authors?). It must be noted that in a number of previous years the production of “wild” juvenile Chinook salmon fry would have exceeded the numbers released from the Robertson Creek Hatchery.

Access to habitat and estuarine use

Damborg and Wightman (2013) speculated that the fewer juvenile Chinook observed in estuarine habitats may be related to: “the lack of access to estuarine areas, lack of appropriate habitat due to impacts (68.5% lost) that have occurred through industrial and urban use, the shunting of most fish directly into the industrialized harbour and eastern end of Alberni Inlet”, the limited swimming ability of the fish “needing to access any area on the west estuary” and “the large number of predators along the route”.

Some of these deductions merit consideration and debate as the data provided in the report provide a basis for speculation and inference but not for conclusions. The observations of relative fish numbers and fish presence in the estuary provide new

information and pose questions related to the reasons why the fish occupy these habitats and if there are benefits to survival.

Damborg and Wightman (2013) stated that “In a more pristine state, with extensive vegetated channel connectivity, fish were more likely to be distributed downstream and laterally into widespread inter-tidal habitats, “filling” them to their natural capacity as the spring migration progressed. Now, the lower river may effectively isolate downstreaming fry from the adjacent estuary”. We are not aware of data that support these comments for the Somass estuary but studies carried out in other estuaries would lend credence to some of these aspects of estuarine use by juvenile salmonids and the benefits that accrue to them.

Juvenile Chinook salmon and water quality

The water quality of the Somass River estuary is influenced by natural factors and the input of waste waters and other materials. The importance of, and effects of, dissolved oxygen have been presented earlier in this report. Comments are provided in this section on the effects of temperature which has a significant controlling and sometimes limiting effect on the lives of aquatic organisms.

Either temperature or dissolved oxygen may facilitate or constrain the use of habitats by fish, but they may also act in combination. Juvenile Chinook salmon move to feed in the very shallow waters of tidally-flooding habitats. In late spring and summer such intertidal areas are heated when exposed and may, initially, constrain fish use on subsequent tidal immersion. These and other aspects related to temperature effects on the lives of fish are presented below to assist understanding results from fish capture studies in the Somass River estuary.

Temperature

Brett (1952) determined that the ultimate upper lethal temperature for Chinook salmon to be 25.1°C. During his experiments Brett did not find a relationship between mortality and size in the tolerance of higher temperature (in low temperature tolerance studies the smaller fish died first). Similarly, Bidgood and Berst (1969) found that size did not affect the tolerance of rainbow trout (*Oncorhynchus mykiss*) to upper lethal temperature. Contrasting with these findings, however, Beacham and Withler (1991) determined that heavier Chinook salmon survived better in thermal tolerance experiments in sea water than lighter individuals.

Juvenile Chinook salmon would be expected to die at, just below, and above the upper lethal temperature of 25.1°C with prolonged exposure. But brief excursions, such as to capture prey, would be possible (refer to Birtwell et al. 2001a, b, 2003). It is not known whether feeding in waters at a temperature that is just above lethal limits, or above that optimal for physiological and metabolic function, has a detrimental effect on survival. Understandably, if exposure to elevated temperature results in prolonged stress, inefficient utilization of energy, reductions in growth, increased risk of predation and

disease, then the advantages of obtaining food are minimal. Wissmar and Simenstad (1988) stated that the metabolic costs of maintenance are in a delicate balance with food intake and growth.

Neill and Magnuson (1974) in their comprehensive examination of the effects of thermal discharges on freshwater species of fish in the laboratory and in the field stated that thermoregulatory behaviour of fish was not permanently overridden by feeding behaviour. Even though planktonic food was more abundant in a thermal outfall area fish would only make brief feeding forays into these waters with extreme temperature. Thus the motivation to feed, even in potentially lethal waters, overrode the expected thermoregulatory response.

Brett et al. (1982) found that 19°C was the optimum temperature for the growth of juvenile Chinook salmon fed on maximum ration, but above this level feeding and growth decreased. They also stated that at 60% of maximum daily ration, the optimum temperature for growth decreased to 14.8°C. Their studies did not permit the opportunity for the fish to balance the thermoregulatory requirements against the energetic and metabolic demands of feeding and growth. Accordingly, perhaps feeding in higher temperature waters may not be as detrimental in thermally stratified environments that permit fish to behaviourally thermoregulate and maximize performance. In the circumstance of the Somass River estuary such downward movements to cooler waters could result in exposure to hypoxic conditions which would tend to increase metabolic costs. In such a circumstance the expected metabolic benefits from the cooler environment would likely not accrue to fish choosing such waters purely for thermal regulation.

The importance of increasing temperature on growth rate in salmonids has been well established (Weatherley and Gill 1995; Brett 1995). Provided food is not limiting, growth rate in many salmon species increases to a maximum between 15°C and 20°C, and then rapidly decreases as the incipient lethal limit is approached (Weatherly and Gill 1995). It follows that if food was impoverished in the preferred, yet thermally heated surface waters, the energetic costs of capturing food in high temperature waters could limit growth. For example, Donaldson and Foster (1941) found that juvenile sockeye salmon refused to feed when temperature increased from 17.2°C to 25.6°C but resumed feeding when temperature returned to 21.1°C. In this context, the movement of sockeye salmon into warmer surface waters to feed followed by a return to colder waters in lakes, is considered to be adaptive and energetically advantageous (Biette and Geen 1980). This apparent advantage is attributed to the lower maintenance requirements at colder temperature and a concomitantly greater proportion of food available for conversion to growth (Brett 1971a, b).

While the dispersion of food in the wild is unlikely to be available only in the surface waters (1 - 2 m) where the juvenile salmon prefer to reside, fish presence implies such. However, it has been suggested by Coutant (1987) that there may be marked differences in feeding behaviour in steep gradients and that fish may feed on uncharacteristic prey.

Research on the tolerance of Chinook and coho salmon to high temperature suggests that different results could be obtained through genetic (Beacham and Withler 1991), and phenotypic variation (Konecki et al. 1995), respectively. Although the latter authors state that their results of critical thermal maxima exceeded published data from some laboratory tests (of lethal limits), their methodology was different, and so was the result. They established a critical thermal maximum for different coho salmon removed from streams of differing temperature. While their results have relative value, and reveal the advantage of acclimation in the wild to the tolerance of elevated temperature, they also reflect the expected higher thermal end point determined by the critical thermal maximum test (over the upper lethal temperature determined via a different method and for a different purpose). To this extent, the results of Konecki et al. (1995) do not refute the earlier work of Brett (1952), DeHart (1975), and McGeer et al. (1991) but expand our knowledge of potential thermal tolerance in field situations (refer to Birtwell et al. 2001a). Beacham and Withler (1991), who speculate that the upper lethal temperature for a salmonid species may be more population-specific than previously realized, also share this opinion.

The significance of a preferred temperature range and behavioural thermoregulation lies in the potential exploitation of habitats and niche selection, and the maximizing of metabolic and physiological functions that have adaptive and survival value (Coutant 1975; Reynolds and Casterlin 1976, 1980; Coutant 1977a, b; Crawshaw 1977; Magnuson et al. 1979; Giattina and Garton 1982; Spigarelli et al. 1983). For example, chum salmon would be expected to occupy waters between 13.7°C and 17.9°C in marine waters (Birtwell et al. 2003). This selection would, of course, be subject to modification by other factors and because of this, Coutant (1977a) suggested that the temperature for optimum physiological and ecological performance would lie between the physiological optimum and the ultimate upper incipient limit (Birtwell et al. 2001a).

Influence of water quality on juvenile Chinook salmon in the Somass River estuary

Determinations of selected water quality variables were made at 0.5 m depth at the locations where fish were captured by beach seine (1975, 1976; DFO unpublished data; Birtwell 1978). The data were analysed to reveal similarities and differences among sampling sites grouped as per the fish capture data. Only significant results are presented for data collected over the whole sampling period.

Comparisons of water quality among habitat groups A-D

Temperature at A was lower (15.6°C) and significantly different than at B (17.3°C) (C/D were similar). Salinity was lowest at A (0.6‰) and different from B (1.6‰) and D/C (2.7-3.0‰). Dissolved oxygen concentrations (mg/L) at C, D, and B (8.5-8.8 mg/L) were similarly lower than that at A (9.9 mg/L). Dissolved oxygen (% air saturation) was similarly lower and different at C, D, B (92-95%) than at A (102%). pH at sites C, D, B (7.4) was lower and different from that at A (7.6). Colour was lower at A, B, D (7.1-7.3) and different than at C (12.1). Oxidation-reduction potential (mV) was lowest at A (244) and different to C (257) and D, B (263-270).

Collectively the results reveal the presence of PME along the eastern shoreline of the Harbour downstream from the pulp mill, slightly lower DO, and pH. Salinity and temperature were lowest at riverine sites comprising A, and dissolved oxygen highest. Temperature was highest at the upper estuary marsh habitat B; salinity was highest at the more seaward locations C and D on opposite sides of Alberni Harbour. None of these mean values are considered to be at stressful levels to the juvenile Chinook salmon but their importance lies in the identification of differing conditions among habitats in the estuary. Maximum and minimum values of certain variables may have influenced fish and this is commented upon later.

Comparisons of water quality between Zones 1 and 2

There was a significant difference between the two data sets for colour which was indicative of the presence of PME. Zone 1 had a significantly higher value (11.7) than zone 2 (6.7), the latter being considered to be less influenced by, or outside the main influence of, the discharge of PME at the time of fish sampling. Salinity was highest in zone 1 (2.4‰) and different than in zone 2 (1.6‰). Dissolved oxygen concentration (mg/L) was lower at 1 (8.8 mg/L) and differed from that at 2 (9.2 mg/L). Dissolved oxygen (% air saturation) was higher at 1 (97%) and differed from that at 2 (94%).

The water quality data grouped for these analyses inferred that the only likely stressful circumstance (based on mean values) to fish could come from the presence of PME at that time in the 1970s.

Range in water quality variables (0.5 m depth) when juvenile Chinook were captured

Juvenile Chinook salmon were captured in a variety of habitats where water quality varied over the utilisation period. The value of such data lies in identifying conditions which were not acutely lethal at the time fish were captured. They provide no insight into their appropriateness and/or potential to stress or otherwise influence the fish; it has been well-documented that fish will use sub-optimal waters (refer to Birtwell et al. 2001a) and the interpretation of these data should be made in reference to documented individual and combined effects. Table 4 shows the range in water quality variables when fish were captured in 1975 (Birtwell 1978).

Table 4. The range in water quality variables at the time of fish capture by beach seine in the estuary of the Somass River, 1975 (* denotes marginally stressful levels).

Temperature	9 - 22.5°C*
Salinity	0.01 - 8.1‰
Dissolved oxygen concentration	6.5* - 11.7 mg/L
Dissolved oxygen % air saturation	75* - 121%
pH	6.8 - 8.65
Colour	5 - 40
ORP	+150 - 320 (mV)

Robertson Creek Hatchery staff initiated a fish distribution study in the estuary of the Somass River and sampled by beach seine in 1986, 2001, and 2002 (unpublished data). The data in Table 5 relate to the upper marsh habitats on the western side of the estuary. They show the extreme determinations of temperature and dissolved oxygen that were made when fish were or were not captured during the sampling program.

The highest temperature and the lowest dissolved oxygen value were considered to be at levels that would lead to adverse effects with prolonged exposure: stressful and lethal levels (**) for temperature, stressful levels (*) for dissolved oxygen. At all other summer sampling times in 2001/2002 the recorded levels of dissolved oxygen and temperature were unlikely to be *acutely* stressful or lethal to juvenile Chinook salmon.

Table 5. The level of dissolved oxygen and temperature when juvenile Chinook salmon were captured in the estuary of the Somass River during the Robertson Creek Hatchery's sampling program (* potentially stressful; ** potentially lethal with prolonged exposure).

Site	Date		Catch	Temperature	Dissolved oxygen	
	2001	2002	(#)	(°C)	(mg/L)	(%)
4	June 21		1	19.9	8.5	
		June 5	1	17.7	2.8**	32
5	June 21		2	16.1	8.6	
		June 26	17	21.2	6.2*	73
6	June 21		3	20.6	7.9	
		June 26	0	23.6**	7.3	88

Unfortunately the data from the Robertson Creek Hatchery's sampling program have not been thoroughly analyzed and the use of different sampling sites among studies (1986 versus 2001/2002, and those in 1975) complicate comparisons. It was possible to abstract some data relevant to the examination of fish use and water quality by using the data for 2001/2002 as shown in Table 5.

Thermal stress, temperature preference and optimal levels

The maximum temperature when juvenile Chinook were captured in the Somass River estuary was 22.5°C, close to the upper lethal temperature of 25.1°C determined by Brett (1952). The upper temperature range when fish were caught in the estuary border on that which would be stressful (even under conditions of unlimited food) and, similarly, the lower concentration of dissolved oxygen was at a threshold level for invoking avoidance responses. It is important to note that combinations of temperature and dissolved oxygen can exert an influence on the physiology and metabolism of fish which can be reflected in growth, fitness and performance with implications for survival. It is likely that higher temperature in the estuary occurs in late summer to levels that exceed tolerable ranges, but juvenile Chinook were not captured after July in 1975.

In the outer tidal flats of the Fraser River estuary juvenile Chinook salmon were not captured in waters where the temperature exceeded 21.8°C (Mesa 1985). In the inner

Fraser River estuary sloughs, the corresponding maximum temperature at which juvenile Chinook salmon were captured was 19.4°C (Birtwell; DFO unpublished information regarding Deas Slough). Brett's work (e.g. 1995) has shown that Chinook, like other Pacific salmonids, prefer a temperature between 11°C and 14°C and that as temperature rises to stressful levels metabolism suffers; the severity of effect being greater if the food ration is less. The increasing metabolic demand caused by rising temperature is supported when food is unlimited until temperature becomes stressful and limiting.

Brett (1960) concluded that the upper lethal temperature for any species of fish should not exceed that which would curtail activity below 75% of optimum, and that a "freedom" of 3°C below the ultimate upper lethal temperature should be required. It is apparent that the Chinook captured in water with a temperature of 22.5°C in the Somass estuary may, accordingly, have been thermally stressed (Birtwell 1978; Robertson Creek Hatchery, unpublished data 2001).

General deductions regarding water quality implications to juvenile salmon in intertidal habitats of the Somass River estuary

Despite differences among sampling sites and their groupings in determinations of certain water quality variables there was little *significant* difference when the data were assessed over the whole study period in 1975. (*Not all potential fish habit was sampled and these deductions should recognize this limitation*).

The levels of DO in shallow waters (0.5 m depth) were high, and temperature similarly acceptable. The levels would not be expected to exert an adverse influence on fish at the sampling locations except in summer when the extreme values were recorded. (This comment presupposes an adequacy of food in these locations. If this was not the case the effects of these variables may be exacerbated and the thermal optimum for metabolic processes would be lower). The levels of other water quality variables measured in the surface waters was unlikely to result in harm to fish at most of the locations sampled in 1975, 1986, 2000, and 2001. Some potentially stressful to lethal conditions occurred towards the end of the estuarine utilisation period for the juvenile Chinook salmon. However, exposure to PME was a potential concern in 1975 based on results of *in-situ* experimentation which showed reduced survival with prolonged residency in waters proximal to the pulp mill. However, current conditions at the same locations studied in 1975 are unknown.

Relevant complimentary studies in the Fraser River estuary

The following abstracts from the studies reported by Mesa (1985) reveal the association of juvenile Chinook salmon with water quality and with depth in shallow estuarine waters of an intertidal zone. The results compliment and expand upon the findings of studies of juvenile Chinook salmon in the Somass River estuary.

Mesa (1985) examined the movement and presence of juvenile salmon in non-vegetated intertidal flats of the Fraser River estuary during different states of the tide. The results of

her studies have relevance to the Somass River estuary because of the presence of hypoxic conditions at some study locations and the general behaviour of juvenile salmon to utilize very shallow intertidal habitats during tidal immersion; a use that is presumably related to foraging opportunities but with risks due to the rapidly changing water quality at such times which may exceed adaptive and/or tolerable ranges.

Mesa's (1985) study locations encompassed sand/mud intertidal sites subject to anthropogenic changes due to waste disposal and the creation of hypoxic conditions, and others not so affected. Mesa examined the occupation of shallow waters at specific depth intervals (approximately 0-24 cm; 25-49 cm; 50-100 cm depth strata) by juvenile Chinook salmon and other salmonids in relation to ambient temperature, salinity, dissolved oxygen, water depth and their estuarine residency.

Depth and the size (length) of juvenile Chinook salmon

Mesa found that juvenile Chinook salmon of "increasing length" were captured at "increasing depth" (modified by seasonal and temperature changes). While juvenile salmonids were in as little as 5 cm water depth on flooding tides (e.g. in May) the greatest concentration of fish was in the 25 cm - 50 cm water depth stratum.

Fish with a fork length of <50 mm were found at all depth intervals sampled but most were in 25 cm - 49 cm depth range. Fish longer than 70 mm were in the deeper stratum (50 cm -100 cm depth). A significant correlation with depth and size was determined when the length of fish varied from 3.6 cm -11.4 cm in May, but not in June despite the range being between 4.8 cm and 10.2 cm, with the majority being in the 6 cm to 8 cm fork length range. Such relationships with depth have been recorded in fresh waters (refer to Mesa 1985).

Temperature effects on juvenile Chinook presence and size

Mesa (1985) found that temperature affected the presence of juvenile Chinook in the shallow waters on flood tides. The smallest fish (<5 cm length) were in the shallowest waters but when temperature dropped rapidly in late June and mean water temperature decreased to 16°C from average values of 18°C - 25°C, juvenile Chinook salmon <5 cm length once again were captured in the shallowest depth range <24 cm. Mesa (1985) considered that the shift of smaller Chinook salmon to deeper water corresponded to the onset of warmer and increasing temperature: a response consistent with behavioural thermoregulation and metabolic demands (Brett et al. 1982; Brett 1995).

During May Mesa's (1985) data revealed that there was a low probability of finding juvenile Chinook salmon in waters cooler than 14°C although DO levels exceeded 8 mg/L (not the period of maximum abundance though). However juvenile Chinook salmon were captured in waters with a temperature of 5°C and 9°C in the estuaries of the Somass River and Fraser River respectively (Birtwell et al.; DFO, unpublished data).

Temperature had a large effect on juvenile salmon distributions in the absence of low DO levels (Mesa 1985). Healey (1980) also considered that juvenile Chinook salmon in the Nanaimo estuary may have discontinued use of shallow waters to avoid high temperature.

Dissolved oxygen influence on behaviour and occurrence

Mesa (1985) stated that low dissolved oxygen conditions in deeper waters over the intertidal zone in the Fraser River estuary may have been responsible for the presence of larger, often sluggishly-swimming fish in higher oxygenated surface waters or those layers near the shore. On a flooding tide “the likelihood of capturing a Chinook salmon was reduced as temperature increased and oxygen levels decreased”.

Mesa (1985) commented that a combination of avoidance behaviour and a regularity in the movement patterns of juvenile Chinook salmon onto the intertidal area may account for their rare occurrence in waters of low oxygen concentration (<6 mg/L) and at a temperature above 20°C. Extremely low DO levels (<1 mg/L) were accompanied with sightings of debilitated juvenile Chinook at the water surface that could be captured by hand.

Salinity

Wide ranges in salinity were not strongly correlated with distributions of juvenile Chinook salmon (c.f. juvenile chum salmon with higher salinity waters); salinity had the weakest relationship with their presence (Mesa 1985). The fish utilised waters where the salinity ranged between 2.1‰ and 23.8‰, but had a weak and possibly co-incident relationship with low (<6‰) salinity in June. A positive correlation was found by Quiñones and Mulligan (2005). In their studies the presence of juvenile Chinook salmon was correlated with areas of low salinity (<5‰). Salinity was the single most influential variable in determining the presence of Chinook salmon, “regardless of the presence of cover habitat”.

Interaction of temperature and dissolved oxygen

Mesa (1985) found that the presence or absence of juvenile Chinook salmon in May and June was partially described by the interaction of temperature and dissolved oxygen. She described this interaction as particularly important for as “temperature increases the oxygen content of water drops owing to reduced solubility, and progressively higher percentage saturations of dissolved oxygen are required to fulfil the oxygen requirements of fish” (Davis 1975a, b; Evans 2006). “In May and June the probability of capturing a Chinook salmon occurred at similar temperature/oxygen combinations (16-17°C and 8-9 mg/L DO) and similar percentage saturation values (97%),” Mesa (1985). These levels for dissolved oxygen correspond to Davis’s (1975b) Criteria between Level A and Level B (see above).

In May and June combinations of oxygen and temperature associated with low probabilities for the occurrence of Chinook salmon ranged from 2-6 mg/L and 22°C -

28°C respectively. But, when temperature decreased to below 20°C and DO ranged between 2 mg/L and 8 mg/L the probabilities of Chinook being present increased.

Interestingly, in contrast to the usual capture of juvenile Chinook salmon at two sampling sites in mid-June, Mesa (1985) did not capture them when DO was below 6 mg/L at both sites. However, a rise in DO to 8 mg/L led to an “immediate” capture of juvenile Chinook salmon at one location but none were captured at the other where DO concentrations did not exceed 6.5 mg/L.

Mesa (1985) considered that “the daily timing of Chinook arrivals onto the intertidal zone” on flood tides “was not ultimately determined by water quality but represented a more predictable behaviour pattern synchronized by some other exogenous factor”. Only when low DO concentrations occurred and when warmer temperature prevailed did the first Chinook captures appear to be influenced by water quality.

BENTHIC ORGANISMS, DIET, FEEDING AND GROWTH

Benthic and other organisms in estuaries are preyed upon by juvenile Chinook salmon and numerous studies have identified that near shore habitats offer important foraging areas. For example, Semmens (2008) stated that “benthic habitat plays an important role in survival during outmigration and should not be discounted in preservation and restoration actions aimed at conserving and recovering Chinook salmon stocks”. Bottom et al. (2005b) cited by Semmens, identified “three general prey-production-foraging habitat types important for juvenile Chinook salmon in the estuary: terrestrial-riparian, shallow benthic-epibenthic, and pelagic.”

Habitat and the availability of prey in the pelagic and intertidal zone

Pelagic zone of the Somass River estuary

Prey for juvenile Chinook salmon in the pelagic zone of vertically stratified estuaries may be partitioned because of prevailing density differences in waters above and below the halocline. The depth and thickness of the halocline varies with numerous factors and in the Somass River estuary, river flow has a significant influence and in periods of low flow, the depth of the fresh water layer diminishes and the halocline is correspondingly closer to the surface. The availability of prey for fish in these stratified waters is variable because of these features. For example, in marine waters below the halocline various planktonic organisms including “protozoa, adults or larvae, or both of ctenophores, chaetognaths, cirripeds, amphipods, polychaetes, brachiopods, mysids, molluscs, appendicularians, and teleost eggs” were found to accumulate at the interface of waters of differing densities (Harder 1968; cited by Parker and Sibert 1973). Similarly, the vertical phototaxis and migration of a dinoflagellate “was observed in a high salinity bottom layer, but stopped at the interface with an overlying brackish layer” (Seliger et al. 1970; cited by Parker and Sibert 1973). Thus, fish feeding on these resources would need to penetrate into or beyond the halocline into deeper waters to capture such prey.

In the vertically-stratified estuary of the Somass River, Parker and Sibert (1973) stated that the upper waters above the halocline would be expected to be biologically productive because of shallow depth and high stability. Before the pulp mill, high levels of dissolved oxygen below the halocline provided evidence of benefits from primary productivity which would have contributed to opportunities for the development of heterotrophic communities which could be exploited by feeding juvenile salmon (cf. Webster et al. 2007) and other organisms.

One may surmise that for many years before and after these studies in the 1970s that such production in the pelagic zone would have been diminished and resulted in impoverished sources of prey because of the presence of coloured PME and sub-halocline hypoxic conditions. Parker and Sibert (1973) suggested that “reducing the BOD of the mill waste discharged into the estuary is not likely, by itself, to remedy this situation.”

The shallow benthic/epibenthic zones in the Somass River estuary have exhibited differences from the less industrialized western uppermost regions to those on the industrialised and urbanised eastern shore and, similarly, changes have occurred to the terrestrial-riparian areas, mostly along the eastern shore and to a lesser extent other areas of the estuary. This habitat change and alienation has occurred over many decades in the estuary and intuitively one would expect it to have imposed constraints on organisms that depend on this habitat. Furthermore, this dependence would be expected to increase competition for food and space when additional numbers of fish which also temporarily depend on the estuary, are released from the Robertson Creek Hatchery. The following comments address some of these aspects.

Benthic organisms in the Somass River estuary

Birtwell et al. (1983b, 1984) reported studies on benthic organisms that were collected by the use of a core sampler at 5 of the sites used to examine fish presence etc.; namely sites 4, 5, 10, 11, and 16 in 1975 (refer to Figure 4).

Site 16 was on Hoik Island on the western side of the estuary close to log storage areas. Site 10 was adjacent to islands in the tidal mud flat area and relatively undisturbed by industrial activity. Site 5 was in the fresh water marsh complex near the pulp mill. Site 4 was on the eastern side of the estuary adjacent to the pulp mill at Lupsi Cupsi Point. Site 11 was in the “developed” part of the estuary and most influenced by PME. Duplicate samples were taken at the upper, mid, lower and sub-tidal zones at each site.

The density and the presence of certain taxonomic groups of organisms were highly dependent on location. For example, amphipods were most numerous at site 10 in the relatively undisturbed habitat sampled. *Corophium* sp. were the most numerous amphipods. Oligochaetes, typically tolerant of hypoxic conditions and organic enrichment (Birtwell 1972; Birtwell and Arthur 1980) were recorded at all stations but in highest densities at sites 4 and 11 - the most disrupted habitats.

The greatest number of taxa was found in the western part of the estuary, at Hoik Island and in the undisturbed marsh/mud flats; there was a decreasing trend in the number of taxa and numbers of organisms at sampling sites west to east across the estuary.

Lower numbers of invertebrate taxa and individuals were recorded on the eastern shoreline and the most impoverished benthic community was at site 11 within a wharf complex that received wastewaters especially from the Port Alberni mill. Oligochaetes, nematodes and copepods predominated in samples from the eastern shore. Amphipods were particularly abundant on the western side of the estuary but were absent at site 11.

The trend of decreasing abundance and diversity of benthic organisms with proximity to the Somass River and the pulp mill and effluent dispersion path along the eastern shore support the findings of Harger et al. (1973a, b; Ketcham 1977). Harger deduced that hypoxic waters influenced the benthic organisms in the low tidal to sub-tidal zones whereas above, fresh waters influenced the organisms in the mid to higher zones on the shore. Harger stated that the benthic periphytic fauna of the Somass estuary was impoverished. Ketcham (1977) concluded that the PME adversely influenced benthic communities along the eastern shore and within 2 km of the pulp mill outfall.

We are not aware of similar studies that have been carried out at the same locations examined in 1975. However, the operators of the Port Alberni pulp and paper mill have investigated benthic organisms through different methods and, studies have examined the marine dumping in deep waters in the upper Inlet near Polly Point. These studies were different and not that relevant to the work carried out by DFO in 1975 that identified benthic organisms in the intertidal and shallow sub-tidal regions of the estuary and endeavoured to link them to consumption by fish.

It was suggested by Hatfield Consultants (2004) that because extensive development has occurred along the eastern shoreline of Alberni Harbour and impacted the aquatic environment it negated the use of benthic studies to assess the influence of the pulp mill alone. However, Hatfield Consultants (2007b) reported the examination of the benthos as part of the EEM program for the Port Alberni mill, and determined that within approximately 200 m of the outfall it was “moderate to grossly impacted, with high levels of terrestrially derived organic matter, anoxic sediments, and poorly developed benthic communities”. Further along the eastern shoreline of the Somass River estuary, about 300 m to 600 m from the outfall Hatfield Consultants (2007b) considered that there was “low to moderate impact, with moderate levels of terrestrial organic matter, reasonable oxidative state, and enriched benthic communities (i.e. higher densities and numbers of taxa than stations further down-Inlet”. In the log handling and booming area across the Inlet from Polly Point these authors also found a “low to moderate impact, with high terrestrial organic content, reasonable oxidative state, and enriched benthic communities”.

In general Hatfield Consultants (2007b) documented a response in the benthic communities along a gradient from the source of effluent discharged into the Somass River. They attributed some changes in the benthos to organic accumulation and

enrichment from the discharge of sewage and of woody debris from log handling and related activities. Benthic communities were considered to be showing some signs of recovery through colonisation (Hatfield Consultants 2007b). We are unaware of specific studies that relate the significance of these findings to the needs of fish in the Somass River estuary.

Diet of juvenile Chinook salmon

The diet of juvenile Chinook salmon reflects the facultative and opportunistic feeding of these fish in diverse habitats. Beamish et al. (2003) provided general comments regarding the diet of salmon and reported that “Chum and Chinook salmon coexist in estuaries and pink and chum salmon in high salinity nurseries. All three species are opportunistic feeders, and often have the same diet components when they coexist. However, when dominant food items are the same, they generally are found in different proportions in the diets and the choice of secondary items differs. Chinook, particularly, feed on different things than chum salmon during estuarine residence. Harpacticoid copepods and shrimp larvae are dominant items for chum feeding, but Chinook feed on harpacticoids for only a few days after migrating downstream, and after that concentrate on amphipods, insect larvae and adults, and mysids”.

Juvenile salmonids in north-eastern Pacific coast estuaries feed on a large variety of prey taxa and inter-specific differences in diets reflect prey items that are present in the microhabitats occupied by the fish. Macdonald et al. (1987) concluded that in the estuary of the Campbell River “differences in habitat utilization among the fish are supported by the results of diet analyses”; a deduction similar to those from earlier studies of prey availability and the diet of juvenile Chinook salmon in the Somass estuary (Kask and Parker 1972; Birtwell et al. 1984).

Studies in the Somass River estuary (1970 – 1975)

The diet of juvenile Chinook salmon was reported by Kask and Parker (1972) for sub-yearlings captured in 1970; amphipods formed about 46%, euphausiids about 20% and fish larvae about 22% of the total bulk ingested. The amphipod *Anisogammarus confervicolus* was common in periphyton on floating logs and other near-bank substrates in the upper Inlet and it was observed swimming up to 0.5 m from its cover; it was seldom in the open water plankton (Kask and Parker (1972). These authors considered that “this substrate-dwelling amphipod is available to the juvenile Chinook mainly from the practice of storing log rafts around the margins of the upper Inlet”. Small juvenile Chinook salmon fed more consistently on insects (especially chironomid larvae).

Feeding in waters in and below the halocline was inferred from the diverse prey captured by juvenile Chinook salmon close to shore (marine mud-dwelling cumaceans, copepods and cladocerans featured in their diet) and further from shore many marine planktonic organisms were captured (Kask and Parker 1972).

It was concluded by Kask and Parker (1972) that “these data, taken together, suggest that juvenile Chinook, while in the estuary, exploit food resources generated both in the upper mixed brackish water layer and in the underlying saline layer. Whether they penetrate the halocline and feed in the underlying saline layer or acquire the marine forms in the halocline cannot be determined from these data”.

In 1975 the diet of juvenile Chinook salmon and of other fish was also determined from analysis of stomach contents of fish captured at each of the locations (Figure 4) where benthic invertebrates had been sampled in the estuary (Birtwell et al. 1983b, 1984). A wide variety of invertebrate taxa were preyed upon by juvenile Chinook salmon.

At sites 16 and 10 on the western side and in the middle of the estuary respectively, juvenile Chinook salmon consumed primarily amphipods, while insects were the second most abundant prey. These results are consistent with the findings reported by Kask and Parker (1972). Conversely, in the eastern part of the Somass estuary at the riverine Sites 5 and 4 insects were eaten in the greatest numbers followed by amphipods. Oligochaetes were the most prevalent organisms in the diet of Chinook captured at the degraded habitat site 11 on the eastern shoreline, and insects the next most numerous prey items consumed. At this site foreign matter was also ingested, suggesting feeding at the sediment surface. In the absence of their seemingly “preferred” food items (amphipods) juvenile Chinook salmon preyed upon insects and oligochaetes. Low numbers of isopods were found in the stomachs of the juvenile Chinook taken from all sampling sites and, similarly, a small number of mysids at all sites except site 11.

Potential competition for prey

Amphipods and insects were the major prey groups for different species of juvenile fish in the intertidal area of the Somass estuary. However, the presence of similar prey groups in the stomachs of fish revealed an overlap in their diets inferring competition among species as well as that between hatchery-reared and “wild” juvenile Chinook salmon. Table 6 presents information on the major prey groups selected by species of fish captured in the Somass River estuary in 1975 (Birtwell 1978; Birtwell et al. 1984).

Table 6. Primary prey groups and dietary overlap for fish captured in the Somass River estuary 1975 (Birtwell 1978; DFO, unpublished data).

Species	Prey group
Chinook salmon	amphipods; insects; oligochaetes
Threespine stickleback	amphipods; insects; oligochaetes
Pacific Staghorn sculpin	amphipods; insects; oligochaetes
Chum salmon	copepods; insects; oligochaetes
Coho salmon	amphipods; insects
Rainbow trout	amphipods; insects
Starry flounder	amphipods; oligochaetes
Shiner perch	insects

Site fidelity and opportunistic feeding

While amphipods were the dominant prey consumed on the western parts of the Somass River estuary, it is plausible that the consumption of oligochaetes at site 11 reflected the opportunistic feeding behaviour of the fish and the absence of the “preferred” food (amphipods) captured at other less impacted locations. Tokar (1968) found that the consumption of oligochaetes previously immersed in 100% KME (kraft mill effluent) reduced the growth of Chinook salmon, but such a situation in the Somass estuary was not identified (Birtwell 1978; DFO unpublished data). Importantly, juvenile Chinook salmon did not avoid habitats immersed in dilutions of PME and were apparently quite resourceful when “preferred prey” were scarce or absent.

A strong relationship between the diet of juvenile Chinook salmon and the same benthic prey items found at particular sites within the estuary was identified thus inferring the temporary fidelity of fish to specific habitats, which was confirmed through mark-recapture studies; a finding also supported by other studies in different estuaries (Levy and Northcote 1982; Macdonald et al. 1987; Bottom et al. 2005a; Hering et al. 2010).

The release of juvenile Chinook salmon from the Robertson Creek Hatchery could increase competition for food in the river and the estuary. The “wild” juvenile Chinook salmon are present in the Somass River estuary for a longer time than hatchery-reared fish. Juvenile Chinook salmon in this estuary, perhaps unlike relatively unpolluted estuaries such as that of the Campbell River where fish can exploit food resources in oxygen-richer marine waters below the halocline or in surface waters, were found to be severely limited in their vertical movements due to hypoxic conditions and therefore would be expected to forage less in such waters - assuming that food was present (refer to Parker and Sibert 1973). If these conditions of adverse water quality and reduced availability of prey exist in the shallow estuary waters at present (i.e. in 2014) it is conceivable that competition for space and food between “wild” and hatchery-reared juvenile Chinook salmon would increase in the spring and early summer. The consequences of such could lead to reduced growth rates as found in other estuaries (e.g. Levings et al. 1989; see comments below).

Examples of juvenile Chinook diet from other locations

Sarita River estuary, Barkley Sound

Ochman (2014) examined the diet of river-origin “wild” and 3 size ranges (deemed to be semi-natural to large, hatchery-reared individuals) of juvenile Chinook salmon in the Sarita River estuary, Barkley Sound.

Although fish from each source consumed particles of wood at a low percentage, their diet comprised numerous prey types. Insects and amphipods were dominant food items (similar to findings in the Somass estuary and other estuaries) as well as harpacticoid copepods and cumaceans.

Campbell River estuary

In the Campbell River estuary the diets of wild and hatchery-reared juvenile Chinook salmon overlapped; insects (primarily larvae), harpacticoid copepods, calanoid copepods, amphipods, and freshwater cladocerans were common prey. But, wild juveniles consumed larger numbers of insects and harpacticoid copepods than hatchery fish whose diet was dominated by marine calanoid copepods (Levings et al. 1986).

Macdonald et al. (1987) were of the opinion that “as salmonids grow and move seaward, a decreased dependence on the surface layer for physiological adaptation and for food supply is reflected in a dietary shift to benthic and/or marine organisms. Daily shifts in the diets of fish captured at the inner estuary of the Campbell River “reflect the increased availability of marine prey at high tide and freshwater prey at low tide (e.g. *Neoclanus* sp. and Euphausiidae larvae eaten by chum, Chinook, and hatchery coho at high tide and *Bosmina* sp. eaten by wild chum and Chinook at low tide)”.

Willapa Bay, Washington

Semmens (2008) commented that juvenile Chinook salmon may “slow down in native eelgrass because the habitat affords better foraging opportunities, better cover from predators, or both”. Diet composition studies in both Willapa Bay (Dumbauld 2005) and Puget Sound (Brennan et al. 2004) suggest that Chinook salmon (<135mm) feed predominantly on terrestrial insects, a food source that likely is not mediated by benthic habitat (Semmens 2008). Restored estuarine habitat in Puget Sound was used by juvenile Chinook salmon which selected prey types that mimicked the detritus-based food web of natural estuarine marshes (Sather 2008).

Smith River estuary, California

Quiñones (2003) found that juvenile salmonids rearing in the Smith River estuary were predominately feeding on aquatic insects that were only found in the upper and middle reaches, supporting the idea that juvenile salmonids were actively choosing habitats that minimized the risk of predation and also provided foraging opportunities.

Salmon River estuary Oregon

Hering et al. (2010) documented that Chinook salmon feed actively in Salmon River marsh channels on invertebrate taxa produced within the marsh (Gray et al. 2002). The authors speculated that by remaining within the channel as the tide ebbs, individuals may maximize encounters with drifting invertebrate prey exported from the marsh channel network and concentrated during receding tides.

Fraser River estuary, BC

Levings et al. (1991) examined juvenile Chinook salmon and their invertebrate food in the North Arm of the Fraser River estuary in relation to habitat zones on “narrow

beaches”. Fish catches were highest on un-vegetated habitat in the low tide area. The weight of food items in stomachs was highest from fish in the mid intertidal area.

The distribution and abundance of ten common prey used by juvenile Chinook salmon were examined leading to the conclusion that emergent vegetation (sedges (*Carex lyngbyei*), rushes (*Scirpus* sp., *Typha* sp.) and riparian shrubs and trees in the middle and upper intertidal zones, respectively, were “vital components” providing detritus and habitat for their prey. Interestingly “the forage ratio data indicated that fish were feeding heavily in the mid-intertidal zone but not necessarily eating prey produced in the vegetated areas and not in proportion to their abundance”. However, Levings et al. (1991) considered that this was expected (a contrast to the Somass estuary where impoverished benthic communities appear to directly influence prey abundance and capture); vegetation was correlated with the abundance of chironomid adult prey emerging from this vegetation.

Levings et al. (1991) obtained greater catches of juvenile Chinook on shorelines than mid-channel habitats at lower intertidal areas suggesting that while the fish were concentrated there they were “subsequently dispersed” into shoreline habitats with tidal immersion. This speculative comment would be supported in part by the findings of Mesa (1985) who captured juvenile Chinook on shallow un-vegetated beaches in the outer estuary of the Fraser River. Although the un-vegetated habitats of sand and mud were likely not serving as a refuge (Levings et al. 1991) several prey species were “most abundant”, especially mysids and amphipods, were present there and in the low-tide channel.

More recently Northcote et al. (2007) and Magnhagen et al. (2007) reported the results of studies that examined the spatial distribution of juvenile salmonids in tidal channels in the Fraser River estuary and dietary overlap of these fish. They found spatial distribution within tidal channels to be species-specific. Mid-channel trawl catches of juvenile pink, chum and Chinook salmon were significantly lower near the bottom than near the surface and that chum and Chinook were most abundant within 1.5 m of the channel banks.

Diet of the three species differentially included elements of the benthic, planktonic, and surface prey that were present. Diet overlap by prey volume was highest between Chinook and chum salmon (90%) and low between pink and the other two species (chum 32%, Chinook 30%), (Northcote et al. 2007). These authors concluded that “Spatial, temporal, and diet overlap among the cohabiting species suggested segregation of resource use during their estuarine residency period”.

Difference in diet was recognized among these 3 species of salmonids. “Pink fed mainly on harpacticoid copepods. This was also the most common prey item for the other species, but chum also ate other benthic species and Chinook fed more on adult insects than did the others”. Magnhagen et al. (2007) concluded that “these three salmonids differ in their use of food resources in tidal channels, and that these species potentially can influence the diet of each other when co-existing”.

Coastal Washington and Oregon

Magnusson and Hilborn (2003) stated that “the fall Chinook diet is more diverse than that of coho, reflecting their extended estuarine residence, diversity of size classes, and different estuarine habitats used. In the inner estuary they feed on emergent insects and epibenthic crustaceans such as amphipods, mysids, and cumaceans, as well as algae, while in the outer estuary they feed on small nekton such as decapod larvae, fish larvae and juveniles, euphausiids, and neustonic drift insects (Healey 1982, 1991; Simenstad et al. 1982; McCabe et al. 1983; Bottom and Jones 1990; Fisher and Pearcy 1996; Miller and Simenstad 1997)”.

Feeding and growth rate

Information provided below indicates the linkage between feeding and growth and their impact on survival. For example, Connor et al. (2011) reported that declines in available prey in the Skagit River estuary have been shown to result in small juvenile salmonids migrating more quickly to other areas in search of prey (Simenstad et al. 1980) and that the corresponding extra expenditure of energy for this migration is thought to slow growth and lead to an increased risk of predation (Smith et al. 2005).

Survival to adult has been shown to be much lower for *non-estuary rearing* Chinook (Reimers 1973; Levings et al. 1989). A population and life history model completed for Skagit Chinook found that “estuary residency of out-migrating smolts results in higher ocean survival rates, thus improving adult return rates (Greene and Beechie 2004)” Connor et al. (2011). In the Skagit delta “the availability of food resources is considered to be the primary factor limiting the density and growth rates of juvenile Chinook (Greene and Beamer 2005)” (Connor et al. 2011).

Implications of reduced size and growth rate

Growth and survival are interrelated as growth rate can affect survival as a result of how rapidly the fish can “outgrow” their predators (Beamer et al. 2005). Parker (1971) showed that smaller fish in juvenile salmon populations were eaten at a higher rate than larger fish thereby emphasizing that not only does the size of individuals matter but that a more rapid growth rate is advantageous to survival; also concluded by Tovey (1999) for juvenile Chinook salmon from the Robertson Creek Hatchery, while present in Barkley Sound. Magnusson and Hilborn (2003) reported a high daily growth rate of sub-yearling fall Chinook salmon to be on the order of 4% of body weight (Healey 1982, 1991) but Neilson et al. (1985) found evidence of food-limited growth. Thus, it is possible that smaller sized individuals from the Somass River system, including those from the Robertson Creek Hatchery, with or without a slower growth rate, may be especially vulnerable to selective predation pressure (refer to Tovey (1999) re Barkley Sound and early marine life of Chinook salmon from the Robertson Creek Hatchery).

If competition for food and living conditions hinders occupancy of favourable waters that optimize health and performance, smaller fish could be under greater predation pressure

than larger individuals (e.g. those from the hatchery; notwithstanding the documented performance deficits of such fish). A fish that is less fit, and therefore less able to effectively compete for food and avoid predators is, potentially, likely to be selectively preyed upon (Bams 1967). In relation to this opinion Semmens (2008) commented that “wild Chinook smolts may not necessarily exhibit the same behavioural responses to habitat exhibited by the hatchery fish”. “Hatchery-reared salmonids tend to have a lower survivorship than wild salmonids”, it is considered to relate to the former having “less well developed predator avoidance behaviours”. Also, it has been found that there could be reduced fitness of fish from hatcheries (Bams 1967; Ginetz and Larkin 1976; Beall 1972), and reduced performance capabilities (Bams 1967; Beall 1972) - an interesting comment in light of the concern over the survival of “wild” Chinook in the Somass River system.

One may expect that a larger size alone would promote greater survival because of potentially greater swim speeds compared to smaller individuals. Birtwell et al. (2001b) commented on such aspects when examining the effects of sub-lethal stress due to temperature and total gas pressure on juvenile chum salmon. Furthermore, and in support of these comments Taylor and McPhail (1985) determined that the burst speed of juvenile coho salmon was determined to be greatest for the larger individuals and differences of up to 80% in swim performance were recorded within the first 0.03 s. This size-mediated difference in burst speed (approximately 19 body lengths·s⁻¹) was subsequently reflected in the predation of smaller rather than larger individuals of the test population, thus providing a causative factor for the differential mortality of juvenile salmon in the wild and the selection of smaller individuals (refer to Parker 1971). Bams (1967) also revealed a correlation between the swim performance of different sizes of sockeye salmon fry and the greater vulnerability to predation of the smaller fish which swam slower.

Brett (1971b) determined how the maximum sustained swim speed is affected by the growth of juvenile salmon and that burst speed, which is virtually independent of temperature, is primarily an anaerobic activity that will incur an oxygen debt and lead to fatigue in the fish (Brett 1964, 1965, 1967). Repeated bursts of speed to escape predation will lead to fatigue, and it is possible that fish whose swim performance is compromised by stressors will more readily succumb to predation than those individuals not so fatigued.

Despite any differences in growth and growth rates among locations and life history types of Chinook salmon there is a general understanding that “predation is believed to be a more important cause of smolt mortalities than food shortage (Fisher and Percy 1988; Mathews and Ishida 1989; Percy 1992)” (Magnusson and Hilborn 2003). One cannot however eliminate the possibility that both causes are linked and that in areas which are degraded due to water pollution and where habitat has also been lost or altered many factors will influence survival and their impact must be accounted for; such is the case for the Somass River estuary.

Somass River estuary

Growth rate analyses for juvenile Chinook salmon collected in 1975 (Birtwell, DFO unpublished data) revealed a similar slope for the length/weight regression lines for Chinook salmon captured at different locations in the estuary (a presumed changing mix of hatchery and “wild” fish over the study period). The slope was not significantly different for fish captured among the contrasting habitat groupings (A - riverine, B - upper estuarine marsh/tide flats west, C - urban/industrial lower estuary east, D - lower estuary west, and 1 >PME versus 2 <PME (page 71) and the common slope value was 3.36. This value was similar to those reported by Tanasichuk (Research Scientist, *pers. comm.*, 2014). Thus, it may be deduced that in 1975 the growth rate of juvenile Chinook salmon was similar to that recorded, at a later time, for juveniles in the Campbell River estuary. For additional comparisons, the slope values for juvenile Chinook from the Nanaimo, Squamish and Fraser River estuaries were reported to be 2.69, 2.96 and 3.43 respectively (Healey 1980; Levy and Levings 1978; Dunford 1975).

Had there been constraints to growth of juvenile Chinook salmon in the Somass River estuary in 1975 due, for example, to stressful conditions caused by adverse water quality or impoverished food and an inadequate diet, it was not reflected in the data used in analyses for fish captured during the estuarine utilization period. It is not known if growth rates are lower now due to the larger releases of juvenile Chinook salmon from the Robertson Creek Hatchery (e.g. 1.7 million in 1975 versus 7.6 million in 2000) causing density-dependent differential growth rates between “wild” and hatchery-reared fish.

In 1975, the length-weight regression analyses could not be carried out for strictly “wild” or “hatchery-raised” individuals over the study period because of the difficulty of identifying the origin of all fish (<10% of hatchery fish had been visibly marked). Consequently the results of length-weight regression analyses only provide a general indication of the rearing conditions as reflected by growth rate of mixed hatchery-reared and “wild” individuals. This finding was unexpected because of noticeable differences in water quality, prey resources among sampling sites, differences in the diet of juvenile Chinook salmon, documented short-term fidelity to certain locations and an estuarine utilisation period from weeks to months.

The study carried out in 1975 was of a general nature and as such only provided rudimentary information. It is probable that the analysis of weight-length data gathered over the entire study period and the biases created by the chosen, and also justified, grouping of information for all juvenile Chinook captured masked any differences that may have occurred (and relationship with site fidelity).

Resolution of growth rate between “wild” and hatchery-reared fish and among habitat types will only be possible when differences between these groups are obvious. Current technology should permit a refinement of such studies and permit similarities and differences to be determined (e.g. refer to the studies by Hering et al. 2010).

Examples of feeding and growth from other locations

Campbell River estuary

The occupation of habitats by juvenile salmonids in the Campbell River estuary was influenced by species-specific reactions to many physical and biological characteristics (Macdonald et al. 1987). This finding, according to Macdonald et al. (1987), is in accordance with the recorded reduction in inter-specific competition among some salmonid species (e.g. territoriality) during smoltification and seaward migration (Keenleyside 1962; Griffith 1972; Kwain 1983; Kennedy and Strange 1982; Moyle and Vondracek 1985).

Although juvenile Chinook salmon in the Campbell River estuary maintained residency despite strong river currents and the large tidal prism, Levings et al. (1989) commented that the availability of *preferred foods* may be less within the estuary. Evidence for the reduced growth rate of wild juvenile Chinook was presented by Levings et al. (1989) for the Campbell River estuary, and for the Sixes estuary, Oregon by Nielsen et al. (1985). Levings et al. (1986) also deduced that the reduced growth rate of wild juvenile Chinook salmon in the Campbell River estuary was due to food limitation, which contrasted with findings in the Nanaimo River estuary (Healey 1980).

It has been considered that the large release of hatchery-raised Chinook and of all salmonids released to the estuary of the Campbell River had the potential to influence wild Chinook growth (Korman et al. 1997). Because the peak of both hatchery and wild juvenile Chinook salmon occurred about the same time in the estuary this would likely have been a period of strong competitive interaction between individuals. Accordingly, it was speculated that growth could be density dependent, and reduced growth rate an indicator that the carrying capacity of the estuary has been exceeded (Korman et al. 1997); a situation also reflected by the reduced growth rates of juvenile Chinook salmon in the estuary of the Skagit River, mentioned by Conner et al. (2011).

Korman et al. (1997) documented the significantly greater growth rate of wild Chinook (0.49 - 0.55 mm per day) versus hatchery Chinook salmon (0.36 - 0.40 mm per day) in the Campbell River estuary. More recently, Tanasichuk (Research Scientist, *pers. comm.*, April 2014) provided information on length/weight regression analyses for Chinook salmon captured in the Campbell River estuary (the greater the slope of the regression line the higher the growth rate). The slope of the regression lines differed among years and ranged between approximately 2.9 and 3.55.

Skagit River Washington

The growth rates of juvenile Chinook salmon were found to be greater in the estuarine areas of the Skagit River compared to freshwater habitats (Beamer and Larsen 2004). According to Connor et al. (2011) the increased rearing time and faster growth rates in the estuary produces larger juvenile Chinook salmon entering Skagit Bay compared to Chinook life history types that do not have an extended rearing period (i.e., fry out-

migrants), or do not rear in the “high-productivity habitats found in the estuary”. The marine survival for larger juvenile Chinook salmon entering Skagit Bay was assumed to be greater than the survival for smaller juveniles, with delta tidal rearing juveniles having an average smolt-to-adult survival rate of 0.5% (Beamer et al. 2005).

It was reported by Conner et al. (2011) that marine survival rates of juvenile Chinook salmon in Puget Sound significantly increased as a function of out-migrant size (Duffy et al. 2005). Juvenile Chinook growth rates, in turn, were found to be dependent upon diet composition and food availability in the near-shore and estuarine areas, with “juvenile growth rates highest in areas where insects, gammarid amphipods, decapods (crab larvae), and forage fish are abundant (Duffy et al. 2010)”.

SURVIVAL AND FITNESS OF HATCHERY-REARED VERSUS WILD JUVENILE CHINOOK SALMON AND THEIR INTERACTIONS

The scientific literature provides information which indicates that hatchery-reared individuals do not survive to adulthood as well as their wild counterparts. For example, Beamish et al. (2012) provided evidence of reduced survival of juvenile Chinook salmon in marine waters. They reported the increased vulnerability to predation of hatchery-reared fish in contrast to “wild” fish: fall Chinook salmon of hatchery origin in the Cowichan River had an early (to September) marine survival of 1.3% in the southern Strait of Georgia, whereas the corresponding survival of “wild” Chinook juveniles ranged between 7.8% and 31.5%.

Meador (2014) provided much information on the survival of hatchery-reared juvenile Chinook salmon in the Pacific Northwest over 37 years. Based upon “the primary metric to assess life-cycle success” i.e. smolt-to-adult return rate, “the number of juvenile salmon released and the number of adults enumerated and estimated from fisheries and hatchery returns. Survival for first-year ocean-type Chinook in the Pacific Northwest has been estimated at 0.4% (compiled by Spromberg and Meador 2005). Rates of survival over successive years are considerably higher for 2-, 3-, 4-, and 5-year-old fish at 60%, 70%, 80%, and 90%, respectively (Pacific Salmon Commission Chinook Technical Committee 2002). Clearly, first-year survival is important for Chinook, and most of the mortality for first-year ocean type Chinook is attributed to predation, poor growth, pathogens, starvation, and toxicants”. Einum and Fleming (2001) undertook a review that addressed the concern regarding the releases of “artificially-produced” fish into wild populations. Their findings and deductions are also highly relevant to this review and are presented below.

These cautionary statements cannot be taken in isolation from concerns over other factors and the sufficiency and quality of habitat has been shown to influence survival of juvenile Chinook salmon to adults (Magnusson and Hilborn 2003). Most typically contaminated estuaries are also locations where industrial and urban development has occurred (Meador 2014). Hence the findings of Magnusson and Hilborn (2003) and Meador (2014)

are indicative of the integration of degrading effects within estuaries at the physical, chemical and biological level.

Genetic factors

The reasons for differences between hatchery and wild fish include genetic factors because, “fish are highly phenotypically plastic and therefore their phenotypes may be shaped considerably by the rearing environment” Einum and Fleming (2001). In this context the rearing of fish in hatcheries (i.e. high densities in flow-through tanks) shows little or no resemblance to natural rearing conditions, and “most environmental characteristics that may influence fish development differ. This includes feeding regimes, density, substrate, exposure to predators, and interactions with conspecifics. Therefore, it is not surprising that such differences can have substantial impacts on the resulting fish phenotype,” Einum and Fleming (2001). Another reason why hatchery fish may differ from wild fish is that the intensity and direction of selection differs between the two environments. “Perhaps most importantly, survival during egg and juvenile stages is substantially higher in the hatchery environment than in the wild” (reviewed by Jonsson and Fleming 1993, cited by Einum and Flemming 2001). Thus, genotypes that potentially are eradicated in the wild, by predation or starvation, are artificially brought through the vulnerable period of selection during early juvenile stages (Elliott 1989, Einum and Fleming 2000a, b). Einum and Flemming (2001) suggested that “such genetic changes (due to relaxed and/or altered selection) are likely to accumulate in stocks being cultured over multiple generations (e.g., when brood stock is consistently chosen from adults originating from hatchery-produced smolts). Multi-generation hatchery stocks are thus likely to differ more from wild fish than first generation stocks where most of the changes are likely to be of environmental origin”.

Hatchery-reared fish “success” following release

“The success of hatchery-produced fish after release appears to be constrained by phenotypic divergence from their wild conspecifics” Einum and Flemming (2001). Ecological interactions among fish are an outcome of their behavioural traits and it has been shown that hatchery-reared fish differ from wild fish in levels of anti-predator behaviour, feeding behaviour, and habitat use. These authors considered that the results regarding such effects are “more equivocal, potentially reflecting a time lag in adjustment to feeding on natural prey. Released fish may initially behave inappropriately after being introduced into a novel environment, but with time may acclimate to the local environment. Hatchery populations may also differ morphologically from wild fish” Furthermore, “any deviation in morphology from the local population may be expected to result in decreased fitness”.

Importance of behaviour

Numerous studies support the deductions of Einum and Flemming (2001) regarding the apparent differential survival of hatchery-reared and “wild” salmon in the same river system.

Semmens (2008) speculated that wild Chinook salmon smolts may not necessarily exhibit the same behavioural responses to habitat exhibited by the hatchery fish which tend to have lower survivorship than wild salmonids (Wales 1954; Kostow 2004). These differences have been primarily attributed to the fact that hatchery fish have less well developed predator avoidance behaviours (Dickson and MacCrimmon 1982; Johnsson and Abrahams 1991; Olla et al. 1998; Berejikian et al. 2003), tend to be more surface-oriented (Vincent 1960), have elevated stress levels owing to handling (Olla and Davis 1989) and poorer swimming performance and less stamina (Pederson et al. 2008; Bellinger et al. 2014).

Under yearling Chinook salmon (<135mm length) in a large enclosure in tidal waters were examined to establish their relationship to benthic cover, including eelgrass. Here, Semmens (2008) recorded an increased susceptibility of hatchery-reared fish to predation in contrast to wild fish.

Berejikian (1995) studying the vulnerability of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry to avoid predation by Prickly sculpin, showed how the innate predator avoidance ability was negatively altered through “domestication” (hatchery-rearing), that attempts to condition hatchery-reared steelhead to avoid predators may be limited for such fish, and increased risk-taking behaviour of predator-naïve individuals would likely increase vulnerability in the wild.

An example of differences in feeding behaviour

A brief study, in May 2013, examined the interaction between “wild” juvenile Chinook salmon and “three different kinds of Chinook smolts released from the Nitinat Hatchery” in the Sarita River estuary in Barkley Sound (Ochman 2014). A beach seine was used to capture fish in the estuary and especially in eelgrass beds during flooding and ebbing tides (Ochman 2014). Length, weight and stomach fullness data are provided in Figure 6 and Table 7. The size range of “wild” fish overlapped that of the hatchery-reared individuals although the smallest and largest individuals were of river origin.

Table 7. Items in the diet of juvenile Chinook salmon of river- (“wild”) and hatchery-origin (semi-natural, small and large) captured in the estuary of the Sarita River, Barkley Sound, (from Ochman 2014).

Diet and stomach fullness	Semi-natural	Large	Small	Wild
Total items collected	341	513	1243	3495
# fish	30	50	76	65
#empty fish	12	30	18	8
woody debris	3	8	13	7
only wood	2	2	1	0
average prey items per fish	11.4	10.3	16.4	53.8
Percentage empty	40	60	24	12

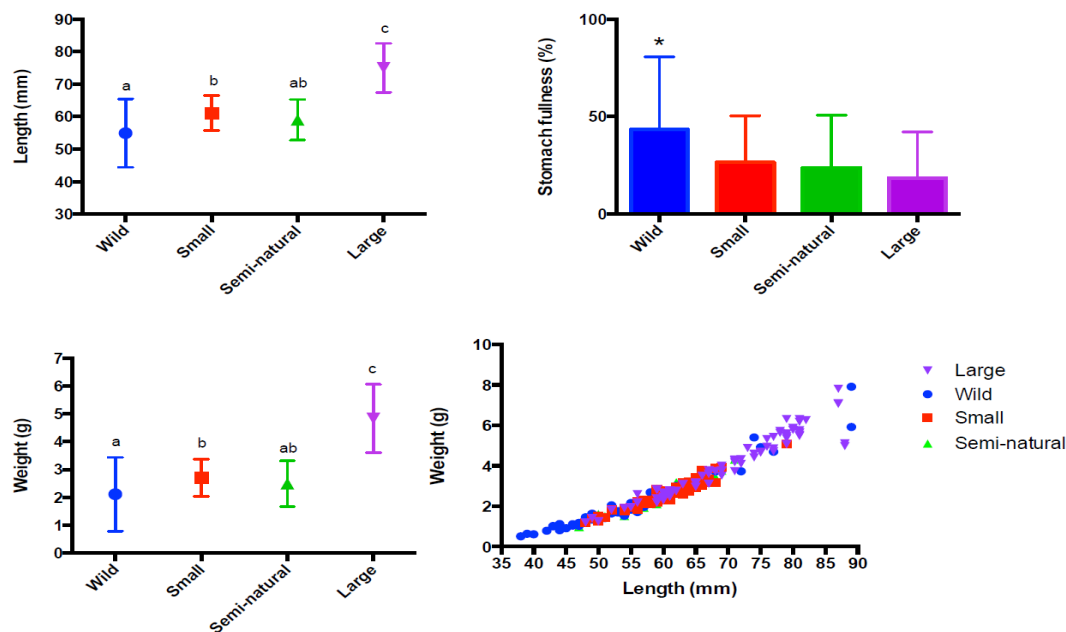


Figure 6. Length, weight and stomach fullness of juvenile Chinook salmon captured in the Sarita River estuary in 2013 (from Ochman 2014).

Ochman (2014) reported that “wild fish appear to be 5.2x more successful at capturing prey compared to the large size production fish, 4.7x more successful at capturing prey items compared to semi-naturals, and 3.3x more successful than the small production fish” from the hatchery”. Furthermore, it was found that while only 12% of wild juvenile Chinook salmon had empty stomachs those of the hatchery-reared fish had a greater percentage of individuals with empty stomachs (60% of the large size, 40% of semi-naturals, and 24% of small production fish). “Adjusting for the fish that actually had food in their stomachs of the fish that did capture prey, wild fish managed to eat roughly 3x more food per successful fish than any of their production counterparts” (Ochman 2014).

The consequences of these findings to growth and survival were not determined but one would logically forecast adverse effects if the prey capture performance of hatchery-reared fish continued to be inferior to that of their “wild” counterparts.

Hatchery-reared and wild juvenile Chinook salmon interactions

Weber and Fausch (2005) conducted experiments to assess the effects of hatchery-reared juvenile Chinook salmon on the emigration, growth and survival of their wild counterparts. Their results indicated that there was an effect of hatchery-reared fish on the growth of wild fish which provided “some evidence that hatchery fish had a greater negative effect on wild fish growth than an equal density of wild fish did”.

If the same findings were applied to the Somass River system one could expect that the release of hatchery-reared juvenile Chinook salmon at a larger size and in greater numbers than “wild” fish had the potential to have an even greater negative effect on the

growth of the latter individuals with potentially adverse size-related consequences to their survival.

According to Bottom et al. (2005a) “relatively few empirical studies have examined effects of hatchery programs on wild salmon populations (Brannon et al. 2004), particularly effects on patterns of juvenile migration and estuarine habitat use (e.g. Myers and Horton 1982; Unwin and Glova 1997). Many salmon life-history traits are under some degree of genetic control (e.g. Taylor 1990; Hankin et al. 1993), and hatchery programs can affect multiple traits, including age at maturity and juvenile age at migration (Unwin and Glova 1997). Moreover, variations in salmon life history, including duration of juvenile residency in the river and estuary, have been linked to geographically and genetically discrete subpopulations within a river basin (Carl and Healey 1984). Thus, changes in adult distribution or genetic structure from the many hatchery strays that now spawn in the Salmon River could alter estuarine life history traits in the population (Carl and Healey, 1984; Unwin and Glova, 1997)”.

These comments raise questions about the “wild” fish in the Somass River system and whether or not estuarine life history traits could have been affected aside from implications of reduced fitness (Araki and Schmid 2010). These concerns were also raised by Damborg and Wightman (2013) who suggested that “anthropogenic impacts to estuary habitats combined with the large role in annual Chinook production may also have influenced the scope/diversity of juvenile Chinook behaviours now observed in lower river/estuary rearing strategies”.

Release strategies

The development of release strategies that minimise negative ecological effects of hatchery fish on wild fish could also be a significant improvement. Einum and Flemming (2001) suggested that released juveniles from hatcheries should be within the size range of wild juveniles, if not of a similar size distribution. “The greatest risk of releasing large hatchery fish is that they may out-compete wild fish, endangering the natural production of the population.

Releases of hatchery fish should also complement the natural spatial and temporal patterns of abundance of wild fish in the population. That is, the number of fish released should not exceed the carrying capacity of the environment, which varies spatially within the river and through time” (Einum and Flemming 2001).

Relative “fitness” of hatchery-reared naturally-spawning adults

Einum and Flemming (2001) predict that “changes in fitness-related traits are a potential problem for released fish, and may influence their ability to survive and reproduce (see also Fleming and Petersson 2001). Their performance in the wild should therefore be expected to be inferior to that of wild fish, a pattern that is commonly observed”.

The importance of understanding the relative fitness of *naturally-spawning* hatchery fish and “wild” fish (an issue that may have high relevance to the Somass River system) has been emphasized by Williamson et al. (2010). They studied the relative reproductive success of hatchery- and natural-origin Chinook salmon in a natural environment. “Hatchery-origin fish produced about half the juvenile progeny per parent when spawning naturally than did natural-origin fish”. However, hatchery fish tended to be younger and return to lower areas of the watershed than did wild fish and this, explained Williamson et al. (2010), was related to their lower fitness.

Numerous researchers have expressed concern over the fitness of hatchery fish compared to their wild counterparts (Araki et al. 2007 a, b, c, 2008, 2009, and Araki and Schmid 2010). The genetic effects of “domestication” have been shown to reduce reproductive capabilities when fish are moved to natural environments (Araki et al. 2007). However, the use of local wild stocks is expected to produce hatchery fish having minimal differences in fitness from wild fish (Araki et al. 2007) but even then performance was lower than of wild fish (Araki et al. 2008). Einum and Flemming (2001) reported that “under certain scenarios, theoretical models suggest that long-term stocking may lead to extinction of the native population (Evans and Willox 1991, Byrne et al. 1992)”. However, Araki et al. (2008) stated that the effects of hatchery fish on wild fish populations remain a question and a concern.

Chilcote et al. (2011) expand upon this concern through their analyses of 93 populations of anadromous salmonids from Oregon, Washington, and Idaho known to contain both wild and hatchery fish. They evaluated populations containing different proportions of hatchery-reared fish admixed with those of wild-origin over a 20-year period.

It was determined that “intrinsic productivity declines as the fraction of the hatchery spawners in the natural population increases”. Thus there was “a negative relationship between the reproductive performance in natural, anadromous populations of steelhead trout (*Oncorhynchus mykiss*), coho salmon (*O. kisutch*), and Chinook salmon (*O. tshawytscha*), and the proportion of hatchery fish in the spawning population”. They determined that the magnitude of this negative relationship predicted “the recruitment performance for a population composed entirely of hatchery fish would be 0.128 of that for a population composed entirely of wild fish”; that is, it would be about 87% less.

Chilcote et al. (2011) explained that “the net reproductive performance of the population will decline under all hatchery supplementation scenarios” and that the “impact of hatchery fish from “wild type” hatchery broodstocks was no less adverse than hatchery fish from traditional, domesticated broodstocks”. Furthermore the productivity of a population “will likely be reduced if significant numbers of hatchery reared fish are allowed to spawn naturally, which would further reduce the potential for the population to rebuild”. And it appears that “integrating wild fish into the hatchery broodstock does not lessen the impact of hatchery fish on the reproductive performance of the wild population”. To conserve wild populations minimizing interactions between wild and hatchery fish will be the best long term strategy (Chilcote et al. 2011).

Somass River Chinook salmon populations, hatchery production and questions

Regarding the Somass River system and the Chinook salmon reared at the Robertson Creek Hatchery it is our understanding that the brood stock comes from the local river system and that over more than 4 decades of operation some Chinook salmon previously hatched and reared in the hatchery now spawn in this system. This spawning is unavoidable but may have had adverse consequences to the collective fitness of these local Chinook populations over time as deduced by Chilcote et al. (2011) regarding the proportion of hatchery-reared fish spawning in rivers with wild populations. Araki et al. (2008) stated that there are “several lines of evidence” that “suggest that genetic effects contribute to the lowered fitness of hatchery fish”.

It is of relevance here that the “*offspring*” of naturally spawning hatchery fish have been found “to have lower survival to smolting and lower survival from smolting to adulthood” (Chilcote et al. 1986; Leider et al. 1990 cited by Araki et al. 2008). In a review of studies relating to this topic Araki et al. (2008) and Araki and Schmid (2010) found that “in some cases, even old stocks had fitness indistinguishable from that of wild fish, but in most of those situations hatchery fish had contributed high proportions of the natural breeding population for many years, making it likely that no ‘wild’ population remained”. Araki et al. (2008) commented “that salmonids appear to be very susceptible to fitness loss while in captivity. The degree of fitness loss appears to be mitigated to some extent by using local, wild fish for brood stock but we found little evidence to suggest that it can be avoided altogether”. The general finding was one of “low relative fitness of hatchery fish, combined with studies that have found broad scale negative associations between the presence of hatchery fish and wild population performance (e.g. Hoekstra et al. 2007)”. This position is endorsed by the analyses of Chilcote et al. (2011) as explained above.

At the time of writing this report the premise under which it was initiated relates to a perceived decline of “wild” adult fish returning to spawn in the Somass River system, whereas hatchery-reared individuals released in the same spring had greater survival to adulthood. Certainly, information provided by DFO (unpublished data 2014) on the capture and return of Chinook salmon to the Somass River and Robertson Creek Hatchery show much variation from 1985 to 2012 and that on average the number of wild and hatchery-origin “River Spawners” was 80% more than those that were recorded at the hatchery (37,000 compared to 20,000) but, the requirements and capacity at the hatchery influenced the numbers of river-spawning adults; such data do not represent an accurate assessment of the partitioning of the adults based on their origin. Some adult fish that were of hatchery-origin are known to have spawned in the Somass River system and while it may be possible to identify these via a variety of tagging and marking techniques, the progeny of these fish would not have been marked, and therefore they would have been assumed to be wild. After 40 years of hatchery production it is likely that what has been considered to be a truly wild fish may not now be so, because high numbers of returning hatchery-reared individuals spawn in the Somass River system.

If it had been confirmed that the survival to adulthood of established and *truly wild* individuals is lower than that of hatchery-reared individuals it would appear contrary to almost all the comments and evidence provided above; based on specific studies and extensive reviews of literature over 50 years. But, perhaps not so if one considers that hatchery fish may have infiltrated the once wild population and this has progressively led to a decline in overall fitness and hence reduced survival? We think that this topic, if not already considered and addressed should be so for there is so much information that indicates the reverse (lower survival of hatchery-reared individuals) should be happening in the Somass River system. Unless, of course, some essential habitat components are of greater significance and influence and that progressive degradation thereof in the river and the estuary has contributed to reduced survival of “wild” offspring but not so for those from the Robertson Creek Hatchery. The findings of Meador (2014) lend support to this latter scenario under which the greater exposure to contaminants of salmon residing longer in degraded estuaries (e.g. “wild” juvenile Chinook salmon) will result in lower survival to adulthood.

Comments provided in this report are intended to help address at least some of these aspects however we did not review information on the potential for contaminants to affect the wellbeing of salmon in the Somass River estuary; we are unaware of such specific studies in this estuary.

Information that addresses these questions in relation to the Somass River system support the needs expressed by Damborg and Wightman (2013) “to improve our current understanding of estuary habitat dependencies”. In this context restored estuarine and related rearing habitat for juvenile Chinook salmon has been linked to behavioural modifications thereby adding resilience to populations faced with changing environmental conditions (Sather 2008).

PREDATION

The predation of juvenile salmonids in the estuary of the Somass River has not, to our knowledge, been examined. However, from the results of studies in other locations there are compelling inferences that this early mortality would occur due to the presence of known piscivorous animals.

It is not known how many juvenile salmon are consumed by predators in the estuary of the Somass River, however, based upon the results of the studies reported by, for example, Mace (1983), Bayer (1985), Forster and McCauley (1968), Beamish et al. (2003) it may be expected that there would be predation by, for example, fish, numerous species of birds, and a few mammals.

The sources and magnitude of predation are important requirements to understanding and assessing overall survival of individuals and stocks as part of sound environmental and hatchery management strategies. Beamish and Neville (2001) “suggested that the total natural mortality is made up of both an early predation-based mortality and a later

carrying capacity mortality”. They suggested that “their inability to show that predation in the early marine period regulates the number of returning salmon is because the carrying capacity mortality occurred later in the year when the slower growing, smaller fish were unable to survive the first marine winter. The combination of predation and carrying capacity mortality determines the total mortality” (Beamish et al. 2003).

Predation of juvenile salmonids in estuaries

Value of vegetative cover

“Levy and Northcote (1982) reported that most Chinook salmon and chum salmon (*Oncorhynchus keta*) fry in the Fraser River estuary left intertidal marsh channels during late ebb-tide periods. Behavioural studies have demonstrated that habitat choices by juvenile salmon involve species-specific tradeoffs between optimal foraging opportunities and predation risks (Magnhagen 1988; Abrahams and Healey 1993) or physiological stresses (Webster et al. 2007). Salt marsh habitats provide productive feeding habitats for juvenile salmon (Levy and Northcote 1982; Simenstad et al. 1982; Shreffler et al. 1992) and have been described as potential predator refugia (Shreffler et al. 1992), but the relative benefits and costs for salmon occupying shallow intertidal marsh channels rarely have been measured (Craig and Crowder 2000)” (Hering et al. 2010).

The apparent relationship between native eelgrass use and the duration of survival in Semmens (2008) experiments “suggests that native eelgrass plays an important role in predator avoidance”, and no fish “were preyed upon while in native eelgrass patches”. “Native eelgrass blades are taller and thicker than non-native eelgrass and therefore provide more vertical structure in the water column in which to hide. Additionally, native eelgrass tends to occur deeper in the intertidal than non-native eelgrass and may thus be ecologically more available as cover habitat given the proclivity for deeper water that Chinook salmon of the size tagged demonstrated,” (<135mm).

While the presence of structural cover did not change encounter rates between predator and prey, Gregory and Levings (1996) determined that escape was facilitated when vegetation was present. Therefore, the presence of cover may enhance juvenile salmonid survival during estuarine rearing (Quiñones and Mulligan 2005). In this context intertidal marshes have been identified as the most valuable habitat for juvenile salmonids rearing in estuaries (Healey 1982; Simenstad et al. 1982; McCabe et al. 1986).

Influence of turbidity on predation

Gregory and Levings (1998) found that predation of juvenile Chinook salmon by fish species including Cutthroat trout, Rainbow trout, Chinook salmon, and Coho salmon, was significantly less in the Fraser River, BC (turbidity 27 to 108 NTU) than predation in a clear water tributary river (<1 NTU). Predation by salmonids in the Fraser River remained consistently low when turbidity was about 27 NTU, but northern squawfish were more successful predators of the juvenile Chinook salmon in the turbid waters

(considered to be related to its use of other senses besides vision to locate their prey). However, despite the seeming advantages to the juvenile Chinook prey of occupation of proximal and contiguous turbid water conditions and reduced predation risk, 75% of the 35,000 fish captured during the study came from the clear water site where predation was 3 times greater based on stomach analyses.

These results imply that despite the higher risk of predation in high clarity conditions, the clear water site provided better habitat and feeding opportunities for both predatory species and their juvenile salmon prey. Conversely one may deduce that the more turbid waters provided different and relatively poorer habitat for these fish.

Predation by fish

Pacific Staghorn sculpin

Staghorn sculpin not only compete to consume the often-preferred amphipod/copepod prey of juvenile Chinook salmon (refer to Birtwell et al. 1984; DFO unpublished data, re the Somass River estuary) their diet has been documented to change as they grow to include larger fish and decapod prey (Forster and McCauley 1968; Feyrer et al. 2003). Thus, this species is not only a competitor of juvenile salmon for the same prey but also a confirmed predator of them.

Dunford (1975) implicated the Pacific Staghorn sculpin as an important predator of juvenile salmon. Levy and Levings (1978) found that this sculpin was the most dominant fish in the Squamish River estuary and, “On several occasions in their study, Staghorn sculpin were observed preying on juvenile chum salmon in tidal creek enclosures. However, the importance of this predation remains poorly understood” (cited by Beamish et al. 2003).

Mace (1983) conducted a detailed examination of predation on juvenile salmon in the estuary of the Big Qualicum River. Her studies focussed on predation by Staghorn sculpin and various species of birds. The sculpin preyed on a variety of organisms, concentrating on benthic crustaceans (particularly amphipods) and as they grew feeding became restricted to low light conditions and positively correlated with light levels during the night. Salmon fry were consumed in preference to amphipods. The smallest captured salmon fry were 40-45 mm in length. Sculpin were estimated to consume 240,000 and 40,500 chum salmon fry in 1979 and 1980 respectively in the estuary of the Big Qualicum River (representing 0.51% and 0.06% of fry populations). Predation on coho fry was greater and estimated to be 817,700 (42.97%) and 144,000 (9.09%) in 1979 and 1980 (Mace 1983).

Spiny dogfish

Beamish et al. (2003) report that during the spring through winter months of 1988 to 1991 the incidence of juvenile salmon in the diets of dogfish was determined immediately offshore of the Big Qualicum River (Beamish et al. 1992). These authors

reported that spiny dogfish were abundant at this location and time and they accounted for 94% to 98% of the total catch in bottom gillnets. The percentage of dogfish feeding on salmon differed among years: 11.9% in 1988, 0.8% in 1989, 1.1% in 1990 and 1.5% in 1991. The authors “estimates of juvenile salmon predation indicated that a minimum of 1.4% in 1990 to a maximum of 10% in 1988 of the Big Qualicum Hatchery Chinook and coho salmon releases were killed by spiny dogfish within four weeks of entering saltwater”.

Primary fish predators in the Strait of Georgia

Beamish et al. (2003) reported that “extensive studies of the diets of various species resident in the Strait of Georgia including Pacific hake, did not identify predators of juvenile salmon as important as spiny dogfish, river lamprey, and Pacific lamprey (*L. tridentata*) (Beamish and Williams 1976; Beamish et al. 1992; Beamish and Neville 1995)”. Lamprey predation alone “could account for 13% of all coho hatchery production from Strait of Georgia hatcheries in 1990 and 65% of all coho production in 1991” (Beamish et al. 2003).

Avian and other predators

Big Qualicum River estuary

Birds, especially Bonaparte’s gulls consumed more juvenile salmon than Staghorn sculpin in the estuary of the Big Qualicum River (Mace 1983). An estimated 10-25% of hatchery-reared juvenile Chinook salmon and 2-4% of coho salmon were removed by birds (Bonaparte’s and Glaucous-winged gulls, loons, mergansers, harlequin ducks and scoters) in 1979 and 1980. In 1980 predation on juvenile Chinook salmon by birds removed an average of 300,900 individuals (an estimated maximum of 354,200). Thus, considerable numbers of juvenile salmonids, representing large portions of hatchery released fish, were consumed in the estuary of the Big Qualicum River by birds and fish predators.

Campbell River estuary

Despite the presence of large numbers of Bonaparte gulls in the estuary of the Campbell River, Levings et al. (1989) were not able to quantify the predation by them on juvenile Chinook salmon (c.f. Mace (1983) re the Big Qualicum estuary). Birtwell (DFO, unpublished data) observed predation by Bonaparte gulls on pink salmon fry released in the marine waters at the mouth of the Campbell River and, in experimental predation trials consumption of 50 pink fry in shallow waters occurred within minutes by one gull.

Somass River estuary

McRuer (personal communication to M. Wright, DFO; April 2014) provided information on predators such as the Belted kingfisher, Great Blue heron, Double-Crested cormorant,

Common and Hooded mergansers, Horned grebes, as well as piscivorous mammalian predators – mink, and otter.

During the “Christmas Bird Count” (<http://birds.audubon.org/data-research>) on December 30 2012 for the Port Alberni area, the counts of potential predators were: gulls 920; diving ducks 384; mergansers 82; herons 26; grebes 10; Belted kingfisher 9; loons 6.

Consumption of fish by mergansers

The hunting performance of the common merganser (*Mergus merganser*) was evaluated by Wood and Hand (1985) in relation to prey density (juvenile coho salmon: 43 g and 2 g weight). Coho smolts were selected over coho fry and the merganser’s daily food requirement was about 400g.

During the period of seaward migration Wood (1987) investigated predation of juvenile salmonids by the common merganser. He found that “mergansers foraging on freshwater reaches of the streams ate juvenile salmonids almost exclusively whereas those foraging on tidal waters rarely ate salmonids”.

Overall, Wood (1987) concluded that the maximum mortality rate did not exceed 10% for any salmonid species over the entire seaward migration. When considered in isolation even this number is high, but when combined with expected losses from other predators, losses would likely be substantially higher.

As an example, predation from 50 mergansers eating 400 g per day for 90 days could consume 20000 g and, over 90 days 1.8 million g which would represent the consumption of 1.2 million individual 1.5g fish (salmon fry or others).

Predation by otters

River otters, which are present in the Somass River estuary (McRuer *pers. comm.*, 2014), may consume salmonids and Doloff (1993) determined that at least 3,300 juvenile salmonids were eaten by two river otters and their two young in the Kadashan River, SE Alaska, during a 6-wk period in late spring 1985.

Deductions

Within the confines of the Somass River and estuary juvenile Chinook salmon would be vulnerable to predation by piscivorous mammals, birds and fish.

Irrespective of the composition of the piscivorous diet of predators in the estuary, such estimated numbers of fish consumed would be a significant loss to fish populations. However, at this time such numerical losses due to predation are speculative. We are not aware of reports that address this topic in relation to the Somass River estuary.

Predation and early marine survival

Barkley Sound

In their comprehensive review on the scientific studies on Pacific salmonids Beamish et al. (2003) did not refer to avian predation as a source of mortality, and furthermore it was discounted by Parker (1965) regarding the predation of pink salmon in Barkley Sound at the mouth of Alberni Inlet. The major predator was juvenile coho and it appeared that coho preferred to eat pink salmon compared to chum salmon. Parker believed that squid could also be a predator, but he ruled out bird predation as a significant source of mortality (Beamish et al. 2003).

According to Beamish et al. (2003) Parker's work "became a standard reference for investigators proposing that brood year strength is determined very early after entry into the ocean". Parker (1965) considered that it was unwise to consider any portion of natural mortality in the ocean as a constant and that it was difficult to forecast returns using counts made in freshwater.

The potential sources of predation of juvenile salmon at the mouth of Alberni Inlet have been identified in a number of reports. Hargreaves et al. (1988, 1990) and Hargreaves and Hungar (1990), examined juvenile salmon abundance, distribution and predation mortality in Alberni Inlet and Barkley Sound between early-April and mid-July in order to determine the abundance and distribution of juvenile Chinook, coho, chum and sockeye salmon, identify and assess the relative abundance of potential predators of juvenile salmonids, and determine the intensity of predation (Beamish et al. 2003). Sockeye salmon juveniles were the most abundant in this region, although Chinook salmon used the areas as a juvenile rearing area more than chum, coho and pink salmon.

Resident Pacific hake, walleye Pollock (*Theragra chalcogramma*) and spiny dogfish were the most important predators of the juvenile salmon but Beamish et al. (2003) advise that these deductions are preliminary and a high level of uncertainty exists because of sparse data.

Beamish et al. (2003) reported that in 1989, 7 million juvenile Chinook (equivalent to about 75% of the hatchery production) and about 12 million juvenile sockeye (> 50% of total production) may have been consumed by predators during the early sea life period in this region (lower mortalities in 1990).

Other predators of fish in this region such as the jumbo squid *Dosidicus gigas* are known to be common off the Northwest coast during warm periods (Cosgrove 2005). Burt and Associates (1998) stated that low adult Chinook salmon escapement since 1993 into the Somass River system have been attributed to "El Nino" events when large numbers of mackerel preyed upon ocean-migrating juveniles. The studies of Tovey (1999) related to the survival of juvenile Chinook salmon released from the Robertson Creek Hatchery, support this comment and she stated that "In years when large numbers of Pacific mackerel (*Scomber japonicus*) migrated into the upwelling region, marine

survival of juvenile Chinook salmon was low - independent of the conditions for growth”.

Skagit River estuary and marine survival

Beamer et al. (2005) provide additional and supportive information regarding marine survival. They provided an estimate of marine-influenced survival (estuary residency through return) for wild Chinook salmon life history types from the Skagit River over a 23-year period. (“Marine survival of parr migrants and tidal delta rearing Chinook salmon are assumed to be the same because they leave the river system at the same time and at the same size. Both life history types achieve a similar size by occupying different habitat niches within the river or tidal delta for an extended period of time. Afterwards, they migrate from the river or tidal delta environment over the same time period and enter the marine environment together. Because fry migrants enter the near shore environment much earlier than either parr migrants or tidal delta rearing Chinook salmon, we expect them to survive at a much lower rate”). Beamer et al. (2005) stated “Marine survival has a huge impact on the number of adult Chinook salmon surviving from each juvenile life history type. Our model of a 5,100,000 freshwater Chinook smolt migration could yield as few as 4,159 adults under very poor marine conditions or as high as 57,895 adults under more favourable conditions; a survival of 0.08% and 1.13% respectively”.

Columbia River estuary and early marine survival

Potential and variable sources of predation were examined in marine waters at the mouth of the Columbia River. Statements mentioned here are from Emmett and Krutzikowsky (2008) who determined that “Jack mackerel had a negative selection for under-yearling Chinook salmon, in 13 of 15 months, but positive selection in July 2003 and 2004”. They suspected that hake and mackerel ate primarily under-yearling Chinook salmon, as opposed to other salmonids, because “these salmon enter the ocean at a relatively small size (usually <120 mm FL) compared with 1+ age Chinook and coho salmon (about 150 mm upon ocean entry; Dawley et al. 1986; Fisher and Percy 1988)”.

The consumption of juvenile Chinook salmon due to predation by Pacific hake were determined by Emmett and Krutzikowsky (2008) who reported “estimates for the number of juvenile salmon eaten: 7,423,105 in June 1998, 1,153,106 in May 2003, and 6,383,106 in July 2004. For jack mackerel the estimates were 1,213,105 in July 2003 and 4,423,105 in July 2004. The larger estimated numbers consumed by Pacific hake reflects their much larger population size”. According to Emmett and Krutzikowsky (2008) these estimates of juvenile salmonids eaten by these species in the study area are relatively small compared with the number of smolts leaving Oregon and Washington rivers. They stated that “approximately 100 million salmon smolts (roughly half are under-yearling Chinook salmon) leave the Columbia River annually (W. Muir, National Oceanic and Atmospheric Administration, Cook, Washington, personal communication)”. However, Emmett and Krutzikowsky (2008) caution that their estimates of Pacific hake and jack mackerel abundance and, thus, predation, are probably low.

“Pacific hake and jack mackerel may also be food competitors with juvenile salmonids because euphausiids and small fishes are also important prey for juvenile salmonids off Oregon (Peterson et al. 1982; Emmett et al. 1986; Brodeur and Pearcy 1990; Schabetsberger et al. 2003). High densities of Pacific hake, as we observed 1998, 2003, and 2004, may have not only increased predation rates on salmonids directly, but also indirectly, by reducing salmonid food supply and thus growth rates, ultimately lengthening the time the salmonids are available to size-selective predators,” (Emmett and Krutzikowsky 2008).

Competition for prey and linkage to growth and survival

The susceptibility of juvenile salmon to predatory attacks is considered to differ from that of forage fish because they have a life history strategy of outgrowing predation by actively feeding during daylight hours; thus the importance of large size, a rapid growth rate and optimum fitness and performance characteristics. However, “during years when Pacific hake and jack mackerel are abundant, their feeding could significantly reduce the abundance of euphausiids and forage fish. This, in turn, could reduce juvenile salmonid growth rates, thereby effectively increasing their predation rates,” (Emmett and Krutzikowsky 2008). This understanding is endorsed by the analyses of Tovey (1999). She found from scale analysis that over a 10-year period the marine survival of Robertson Creek hatchery Chinook salmon was related to smolt size and early ocean growth. Marine survival was not correlated with smolt length *per se*. Tovey (1999) determined that marine survival was significantly and positively correlated with growth rates (assessed from scales taken in July and August). The number of days taken for marine scale growth to begin following hatchery release was determined to be 34 days and the rate of deposition of marine circuli 6.8 days per circulus). During this time the majority of juvenile Chinook salmon was found “to reside in Barkley Sound adjacent to the northernmost portion of the temporally dynamic Coastal Upwelling Domain and related to peaks in zooplankton biomass”.

Tovey (1999) speculated that the strong relationship between growth and survival of under-yearling Chinook salmon related to the benefits of fast growth as well as from “changes in predation intensity varying concurrently with oceanographic conditions indicative of productivity”. Her work did not address variation in survival for individuals from “hatchery” and “wild” origins in the Somass River system. However, one may assume that for fish attaining the same size with rapid growth rate that both would be equally susceptible to predation unless, as mentioned previously, hatchery fish are more vulnerable possibly due to genetic, behavioural and physiological differences.

RESTORATION OF ESTUARINE HABITAT

The following comments have been supplied with respect to rehabilitation of the Somass River estuary because much habitat as been eliminated and degraded over almost a century.

The demonstrated association between habitat degradation and reduced survival of some salmon stocks emphasizes the need to rehabilitate the estuary to a better functional state. Previous review comments and findings of researchers regarding relationships between fish and habitat features at the macro and micro scale should help guide such undertakings.

General considerations

The restoration of aquatic habitats relies upon information that is also needed for basic habitat and fish management. Ecological knowledge is fundamental to understanding the complexities of species requirements and links with their biotic and abiotic environment. The publication edited by Kelso (1996) describes restorative efforts, the complexity of the issue and its quantification (Birtwell et al. 2005).

Because ecosystems consist of a mosaic of habitats that varies with space and time, and restoration objectives are seldom met exactly, spatial diversity and flexibility in design are required. In this regard, Kemp et al. (1999) stated that river reaches of uniform depth had low habitat diversity compared with reaches with shallow and deep areas, and that fish species diversity was highest in physically-heterogeneous channels. They considered that the development of depth and velocity occurrence matrices for each functional habitat is an important step towards the goal of being able to predict the result of physical modifications on habitat frequency in river channels, whether they are changes in channel shape or discharge pattern. The likelihood of the retention of habitat diversity was greater if the channel retained its natural width and was morphologically variable.

Meaning of recovery, restoration and rehabilitation

Within water, recovery of lost function is probably of most significance to populations, communities, trophic levels and ecosystems (Minns et al. 1996). However, individuals comprise populations within communities and ecosystems, and they require appropriate habitat to carry out their life processes and sustain the trophic linkages upon which the systems are based.

In order for the Somass River estuary and contiguous waters to continue to support aquatic organisms any modified habitat has to have some functional significance, ideally approximating the condition before the changes occurred. In this context the process of recovery has been defined by Wallace (1990): "Recovery constitutes the reestablishment of community structure to within the range expected over the annual cycle within a particular habitat prior to the initial disturbance." According to Bradshaw (1996), restoration applies to a return to an original state, and that it should be thought of as applying to whole ecosystems. That is, it includes water and its quality. Restoration returns an ecosystem to a close approximation of its condition before it was disturbed (an issue not to be confused with rehabilitation which improves a system to a "good working order" (Pastorek et al. 1997).

Habitat degradation and rehabilitation

The sufficiency and quality of estuarine habitat have received attention because of their importance to the well-being of juvenile salmonids. Many efforts to rehabilitate estuaries and compensate for lost habitat have occurred over the last 3 decades in numerous locations along the southern coast of British Columbia, in Washington and Oregon and in California.

In the Smith River, California, declines in populations of Chinook salmon and steelhead trout have been attributed to habitat degradation and overexploitation (Moyle et al. 1989). Based upon historical maps (Monroe et al. 1975) and aerial photographs, the authors estimated “a 40% reduction in the surface area of the Smith River estuary between 1856 and 1966” Quiñones and Mulligan (2005).

Rehabilitation of estuarine habitats in the Salmon River, Oregon, has occurred through the removal of dikes from 145 ha of former salt-marsh habitat in the estuary. Bottom et al. (2005a, b) examined variations in the juvenile life history of fall-spawning Chinook salmon for evidence of change in estuarine residency and migration patterns following these restorative changes. They concluded that “wetland recovery has expanded life history variation in the Salmon River population by allowing greater expression of estuarine-resident behaviours. Initial results indicated that young Chinook salmon utilized restored marsh habitats even soon after dikes were removed and intertidal channels became accessible. Many of these fish dispersed into formerly inaccessible marsh habitats within days or weeks of emergence”.

The utility of certain aspects of estuarine rehabilitation and restoration has been commented upon by Hering et al. (2010): “Preserving connectivity of intertidal marsh habitats within the estuary is critical to maintaining expression of behavioural diversity in estuarine rearing salmon”. “Wetland restoration projects often attempt to recreate habitats that function equivalently to natural reference sites (Miller and Simenstad 1997; Gray et al. 2002), and fish behaviours, including residence times and movement patterns, have been proposed as important measures of restoration success (Simenstad and Cordell 2000). “The fact that most tagged salmon occupied our intertidal study channel only when water reached a minimal depth affirms that restored channels intended as salmon rearing habitat must be designed to maintain sufficient depth during high tides for salmon access. Although higher elevation tidal channels may support and export salmon prey to other areas of the estuary, they likely will not be used by salmon directly” (Hering et al. 2010). Juvenile salmon are, however, generally distributed based upon water depth, with the depth of the water occupied by the fish increasing as the size of the fish increases (McCabe et al. 1986).

Gray et al. (2002) examined the developmental state of three recovering estuarine marshes over 23 years compared with a reference marsh. They assessed the rate and pattern of juvenile salmon habitat development in terms of fish density, available prey resources, and diet composition of wild juvenile Chinook salmon. This examination revealed that “The pulse of productivity in newly restored systems indicated some level

of early functionality and the efficacy of restoring estuarine marshes for juvenile salmon habitat”.

The results of the studies by Gray et al. (2002) “indicate disparity between reference and treatment sites based on metrics for capacity, opportunity, and fish performance (realized function) even after more than two decades of recovery. However, they deduced that foraging juvenile salmonids may still benefit during early stages of marsh recovery. For example, increased production, such as the high density of chironomids after dike breaching, may increase foraging opportunities for juvenile salmon. On the other hand, trade-offs with ecosystem quality, such as poorly formed channels and increased temperature, could temper the benefits derived from increased prey quantity.”

Interpreting whether wetland restoration projects enhance ecological conditions and rehabilitate depressed species populations requires assessment of functional state or “performance.” The common paradigm that “function follows form” dictates most wetland restoration designs and evaluations and this approach assumes the functional responses of fish and wildlife is relatively coincident in space and time with structural characteristics. When explicitly tested this assumption has often proved invalid (Gray et al. 2002). For example, Moy and Levin (1991) determined structural attributes (sediment properties, macrofaunal densities) resembled reference levels after only a few years, but the complex interactions (fish abundance and diets) indicative of ecological functioning did not necessarily follow at the same rapid rate.

Restoration “success”

Reliance upon the presence or absence of a particular species over time to indicate the success of restorative measures for fish habitat is fraught with uncertainty. Because, in this instance, a detailed knowledge of ecological function is not required (Bradshaw 1996). For example, the species may persist only for years and later disappear because the underlying functions had not been addressed.

It is crucial that the development (restoration) of the ecosystem be upwards and along an unobstructed path related to structure and function. Furthermore, Bradshaw (1996) advises caution when taking any character as a surrogate for all of the development processes. It follows that for an estuarine restoration project to be successful it must reverse anthropogenic effects and restore lost ecosystem functions (Gray et al. 2002).

It is important that project designs incorporate a whole-ecosystem perspective for “ecological restoration is an holistic approach not achieved through isolated manipulations of individual elements but through approaches ensuring that natural ecological processes occur” (Hartman 2004). Furthermore, it is apparent that the time frame over which to judge success is most likely many years (Reisenbichler et al. 2003); Bradshaw (1996) gives examples of 10-year time frames. Niemi et al. (1990) examined literature from more than 150 case studies on the recovery of aquatic systems from disturbance. Disturbances which involved changes in habitat structure where the residual

stressor may remain for a long period of time provided consistently long recovery times from 5 to >52 years (Niemi et al. 1990).

DEDUCTIONS AND CONCLUSIONS

A broad range of selected articles and examples has been used in this brief review to assist an understanding of the topics presented. Not all of these topics have been treated equally and many are focussed on investigations of aquatic habitat in the Somass River estuary and on juvenile Chinook salmon. Throughout this review the term “habitat” refers to all parts of the aquatic or terrestrial environment, and for fish, this includes water and its quality.

The lives of fish, like most wild animals in their competitive environment, can be partitioned into simple critical components: feeding and growth, maintaining health fitness and performance, avoidance of being eaten and successfully reproducing to provide healthy progeny. Aside from misadventure, all of these functions lead to perpetuation of populations, stocks and species. Their full expression is facilitated by a “healthy” environment within which naturally-varying factors outside our control may exert their influence. Fish, for example, have successfully adapted to these variations; notwithstanding current concerns over the effects of global warming on ocean processes and declines in the survival of many stocks of Chinook salmon (R.J. Beamish, Research Scientist; *pers. comm.*, May 2014). On the other hand, human-induced changes to habitat have sometimes led to adverse impacts on organisms. In this instance changes have occurred to levels outside the adaptive capacities of affected organisms. Thus, naturally-varying factors and human-induced changes may act together to influence survival and population success. Human-induced changes are possible to manage and this review addresses some of the anthropogenic impacts on the estuary of the Somass River and Alberni Inlet and relationships to the wellbeing of Chinook salmon.

Research and monitoring studies have been carried out over many decades in Alberni Inlet, and although some have been quite specific and addressed particular topics related to fish and aquatic conditions, others have been very broad in nature. A lack of integration among some studies is unfortunate but understandable. For almost 70 years concern has been expressed over salmon and the need to protect them. However, understanding how juvenile chinook salmon use their environment and what constrains this use and what consequences there may be, has only occurred in a rudimentary way over the last 4 decades. Unfortunately, since the 1930s many statements have been dismissive of ecological concerns because of a lack of appropriate knowledge and understanding; for example, of fish behaviour. Increased knowledge has provided the basis for better-informed opinion and with a paucity of ecological information for the Somass River estuary there has been a tendency to rely on inferences based upon results from other studies. It is perhaps logical that this has happened, but caution is required when using such inferences. Some of these aspects are presented below and additional comments are provided in various sections of this report.

Concerns and historical assumptions

Not all assumptions regarding the effects of pollution in the Somass River estuary have been proven accurate. Information on the ecology of Chinook salmon was less in the 1940s than it is today and therefore it is understandable that some forecasts and expectations of impacts were imprecise. It is also problematic to base expectations of effects in nature from certain studies undertaken in the laboratory if the latter do not mimic, or use species found in, the region of concern. In this regard, the information gathered under certain Port Alberni mill monitoring programs, while of significant value in their own right, are not necessarily relevant to Chinook salmon in the estuary. A few examples of concerns are presented below (most abstracted from the main text). They are not intended to be overly critical but instead exemplify the diversity of opinion and the lack of substantiation or misunderstanding. They provide reasons for expressing caution when factual information is lacking.

- *“the presence and accumulation of pulp fibre in the anticipated amounts is not considered deleterious since there are no anadromous fish or sessile bottom forms in the part of the Inlet likely to be affected.”*(Tully 1949).
- *“Townsend showed that fish would avoid a region of oxygen deficiency in the presence of an alternate region of sufficiency. Consequently it would be reasoned that the pollution maximum in the Inlet would constitute a barrier to migration, assuming the fish would remain in the less polluted waters in the lower reaches of the Inlet. Contrary to this, it has been observed (Tully, unpublished) that the adult salmon continue their spawning migration into polluted areas. Townsend also observed, that both the spawning and the seaward migration occurred through the over-polluted region in Gray's harbour, resulting in the death of the fish. It may be concluded that the presence of the pollution maximum would not alter the migratory habits of the salmon and trout in the Inlet. Evidently the fish cannot realize that a more suitable habitat exists beyond the maximum pollution, and so accelerate their migration through the limited region. Consequently the pollution must not exceed values' likely to be deleterious to the fish that remain in the region for a considerable time.”* (Tully 1949).
- *“Evidently the fish naturally avoid the polluted zones, when an alternative unpolluted zone is within their cognizance”*; *“It may be reasoned that, if the pulp mill sewage enters a stratified body of water at a low density, so that it is stable at or near the surface, only the upper waters would be polluted, and a suitable habitat should exist for the fish underneath the polluted zone.”* (Tully 1949).
- *A dissolved oxygen concentration of 5 mg/L was considered to be appropriate for the well-being of fish and not be harmful to them.* (e.g. Tully 1948, 1949; Alderdice and Brett 1957)

- “It is concluded that 40% saturation with dissolved oxygen represents a reasonable limit of tolerance in a sea-water fishery”. (Tully 1949).
- It was estimated in the late 1950s “that under present conditions, interference with seaward-migrating salmon might only be anticipated from the effluent “slug” in the immediate vicinity of the outfall if such migrants were to remain in this restricted area for a period in excess of about two days. But, “such behaviour is considered to be improbable”. (Alderdice and Brett 1957).
- “Lethal conditions for salmonids have not arisen in Alberni Harbour since the pulp mill was installed in 1947”. (Waldichuk 1987).
- Even though greater dissolved oxygen depression had occurred since the pulp mill started operating; it was “not considered to hinder adult salmon migration.” (Morris and Leaney 1980).
- “Overall, results indicate that historical impacts of paper mill effluent in Alberni Inlet no longer pose a risk to migrating sockeye salmon and that current Pulp and Paper Effluent Regulations effluent quality standards are protective of fish.” (Hatfield 2013b).
- In 1985, during summer dry conditions, the DO below 2m depth in Alberni Harbour dropped to <3 mg/L. It was suggested that adult sockeye “can only migrate through the upper 2-m layer without severe low-oxygen impact” but that “low returns, below expectations, of sockeye salmon during 1985 and 1986 have been attributed to poor ocean survival.” (Waldichuk 1987).

These, and similar statements were made without specific knowledge of the behaviour of salmon, the conditions experienced by them and potential consequences to their fitness and performance. Choices that we deemed appropriate for the fish to make in recently deteriorated conditions were not necessarily made by fish whose behavioural repertoires previously facilitated survival. Research from the natural environment as well as the laboratory now confirms these latter aspects. In this context, a study in recent years on adult salmon migration was undertaken in a year of abnormal climatic conditions not representative of usual or extreme conditions that influence migration. On the basis of these studies it is premature to assume, as it was, that there will not be any adverse effects in the future on migrating adult salmon and precautionary statements would be more appropriate.

K. Hyatt (Research Scientist, DFO, *pers. comm.*, 2014) elaborated on the behavioural response of adult sockeye salmon (and other species) to behaviourally thermoregulate and occupy a “volume of preferred water” in which DO ranges between 1.2 mg/L and 4.6 mg/L, and temperature between 9°C and 15°C at the head of Alberni Inlet. In the absence of thermal constraints it would be expected that adult salmon would choose to occupy waters of higher DO that were not so stressful or lethal with prolonged exposure. Delayed non-feeding adults exercise choice and occupy waters which meet thermoregulatory and

metabolic needs (survival traits) because temperature seems to be the dominant directive and controlling factor rather than dissolved oxygen. Thus, it is expected that hypoxic waters at depth will continue to pose a threat to adult salmon, and especially when migration is delayed. Non-feeding adults returning to spawn are able to reduce metabolic demands by behavioural thermoregulation which results in movement to deeper waters, unfortunately containing very low and potentially stressful to lethal levels of dissolved oxygen (but they too may exert metabolic demands) in Alberni Inlet. Such behavioural traits are adaptive and it is speculated that in less polluted environments such equivalent deeper and cooler waters may be of higher dissolved oxygen levels and therefore potentially less harmful. Therefore, it is probable that DO was much higher at depth pre-pulp mill and that thermoregulatory behaviour may not have resulted in debilitation and death of adults whose migration was delayed; it is likely that delays occurred, however, as a minimum water flow in the Somass River was not assured and river temperature likely increased as a consequence of summer low flows and warm climate.

Wild versus hatchery-reared Chinook salmon

The concern which partly stimulated this review was the topic of differential survival of “wild” and hatchery-reared individuals to adulthood. We could not substantiate this with the data that was reviewed; which revealed a much poorer survival of hatchery-raised individuals. The unavoidable spawning of previously hatchery-reared individuals in the Somass River system, and the production of progeny over 4 decades of hatchery operations casts doubt as to whether truly wild Chinook salmon currently exist in the system. It is known that marked hatchery-originating adults spawn in the river in greater numbers than do those which are not marked, and while it may be tempting to identify these unmarked fish as truly wild, it is most likely that they originate from a mix of progeny from both river-spawning adults and hatchery brood stock, themselves possibly linked to generations of hatchery-reared fish. Hence, the progeny of these river-spawning fish which are not visibly identifiable as such nor are they tagged as are those from the hatchery are, therefore, assumed as wild. Because of this ambiguity the expression “wild” is used to designate a river-origin mix of progeny from truly wild and previously hatchery-reared individuals. The contribution of fry from respective river spawning “wild” and hatchery-reared individuals is unknown.

Extensive reviews of research documents have shown how “domestication” of fish has led to performance and behavioural deficits which translated into poorer survival and furthermore, the lower production of progeny from such hatchery-reared individuals when spawning naturally. It is possible that such adverse traits may be inadvertently applied to what are thought to be wild Chinook salmon in the Somass River. We are not aware of studies that address this topic in this river system, but the importance of the issue for the longevity of the stocks is obvious.

The findings and predictions of Chilcote et al. (2011) based on an examination of populations of salmonids containing different proportions of hatchery-reared fish admixed with those of wild-origin over a 20-year period, are cause for concern. The circumstance of mixed-origin spawning Chinook occurs in the Somass River system;

naturally-spawning Robertson Creek Hatchery-reared individuals spawn with those of river-origin. Based on the reviews of Chilcote et al. (2011) it is expected that reproductive performance of wild Chinook salmon will decline as the fraction of spawning hatchery-reared individuals increases in the natural population.

Phenotypic life history diversity from rivers with estuaries of high complexity and quality have been documented to result in greater returns of adult Chinook salmon than others not provided with such environmental opportunities that foster resilience in populations. Thus, despite uncertainties of the origin of juvenile Chinook salmon in the Somass River system and forecasts of reduced reproductive performance, reducing environmental constraints on these fish and improving their habitat will be beneficial to these mixed-origin Chinook salmon.

Interactions of river-origin and hatchery-origin juvenile Chinook salmon

Some studies have examined the interaction between hatchery and “wild” juvenile Chinook salmon. But, the positive identification of all river-origin or all hatchery-origin individuals is a fundamental and a serious impediment to understanding whether the ecology of each is different. Despite this obstacle some researchers have attempted such a separation primarily through inference using differences in size, and visual markings of small percentages of released hatchery-reared individuals.

Competition for space

Aside from changes to water quality that have been shown to restrict and limit the horizontal and vertical living space for juvenile salmon in the Somass River estuary, it was documented that about 66.5% of estuarine habitat has been lost or degraded. Intuitively, one would expect a consequence of this reduction in quality and quantity of habitat to the organisms that depend upon it.

The influx of millions of hatchery-reared individuals into the estuary at the present time may be expected to result in the displacement of some “wild” fish and also promote density-dependent interactions; most probably over food resources. Although the numbers of fish released from the hatchery have been estimated to be less than those considered as “wild”, on some occasions this has not always been the case and millions more hatchery-reared fish have been added to the system. Unfortunately the egg production of “wild” river spawning adults is not known, neither is the egg-to-fry survival. Consequently there are no accurate determinations of the numbers of fry produced in the river system. In contrast, these metrics are known for the hatchery production of juvenile Chinook salmon. Numbers of wild fish in the lower Harbour area were documented to peak in June in the 1970s and also more recently. Peak numbers of “wild” individuals have been documented in May before hatchery-reared fish enter the estuary however it seems probable that the influx of millions of hatchery fish may mask the abundance of “wild” fish in the estuary and Harbour.

Recent observations in the Somass River and estuary have documented both hatchery-reared and small “wild” juvenile Chinook salmon in populations using riverine and estuarine habitats. The observation of fewer fish in the estuary compared with much higher numbers in very different riverine habitat inferred that fish were either more widespread among contrasting estuarine habitats or had moved from (voluntarily and/or through displacement) the estuarine areas, but neither was verified.

Competition for food and dietary overlap

Intra-specific competition for food between “wild” and “hatchery individuals will likely occur because their requirements are similar; this has not been examined in the Somass River estuary. These fish are facultative, opportunistic predators and have shown fidelity to certain habitats (also exemplified through the prey in their diet).

Inter-specific completion is highly probable based on the studies of the diet of fish in the estuary and demonstrated dietary overlap. Such competition is possible among Threespine stickleback, Pacific Staghorn sculpin, Chum salmon, Coho salmon, Rainbow trout, Starry flounder, and Shiner perch (Birtwell; DFO unpublished data).

Growth rate

The result of increased competition and associated energy requirements has been found to result in differences with growth which in turn have been related to survival; poorer growth rate leading to poorer survival. It was not possible to separate the growth rate of hatchery-reared juvenile Chinook salmon from those of river-origin. However, in 1975 the growth rate of juveniles from river and hatchery combined was comparable to that of juvenile Chinook salmon in other estuaries. We are unaware of studies that have examined the separate growth rate of these fish of different origins while in the Somass River estuary, presumably due to the lack of identification of respective groups of fish; however tagging technology could be used to examine this aspect.

Examples provided in this review suggest competition for food resulted in a poorer growth rate of individuals in estuaries where populations of wild juvenile Chinook salmon have been augmented with hatchery-reared individuals. Studies of the survival of Robertson Creek Hatchery Chinook salmon was determined to relate to growth rate during early marine life in Barkley Sound. The performance, fitness and behavioural deficits in hatchery-reared salmon compared to their wild counterparts have been demonstrated in the laboratory and the field; they are inferior to those of wild individuals. It is plausible that such traits result in poorer survival through increased susceptibility to predation, diminished prey capture and feeding, and growth. These factors and others presumably relate to the low and variable returns of hatchery-reared fish to adulthood.

Ecological aspects

Hatchery-reared fish are released at a larger size and at a different time during the seaward downstream migration of river-originating juveniles, permitting a period of brief

identification of differences due to size. However, specific residence times, examinations of habitats used and assessment of benefits cannot be precisely determined over the estuarine use period.

Some hatchery-reared juveniles were present in the Somass River estuary in July (1975) after the majority had departed; they were of a similar size to “wild” individuals. This finding infers that not all hatchery fish migrated to the estuary at the same time and that within their population some individuals of the size of river-origin fish were present. The fate of these fish is unknown but inferences from the survival of other stocks wherein juveniles migrate to the ocean in late June and July (e.g. Birtwell et al. 1987) have been recently shown to have higher survival than those entering Georgia Strait at an earlier time (R.J. Beamish Research Scientist; *pers. comm.*, May 2014).

Because of the relative lateness of release of hatchery-reared individuals into the Somass River system (c.f. river-originating juveniles), the period of use and residence of these fish is likely shorter than that of those from river-spawning adults whose progeny move to the estuary at a smaller size. It was estimated that the residence in the estuary of individuals from the Robertson Creek Hatchery was between 10 and 31 days and their presence spanned a 6-week period. The residence of “wild” juveniles was greater than 4 weeks based on mark-recapture data obtained later in the estuarine use period and therefore probably underestimated the residence time; estuarine presence was over at least 4 months (March is probably when the first juvenile Chinook salmon enter the estuary).

To better understand how juvenile Chinook salmon utilise the estuary and what constraints and benefits there may be, requires focussed and coordinated/integrated studies. Earlier studies addressed the presence, and the timing of their arrival and departure. There have been no studies specifically addressing residency and not all habitats have been sampled, neither have all potential impacts been addressed.

Chinook salmon and degradation of estuarine habitat

Few studies have examined the relationship between habitat quantity, quality and function in the estuary of the Somass River even though significant industrial and urban development has led to its degradation. Some studies of fish distribution have occurred in the last 17 years and while they have revealed the presence of fish in differing locations within the estuary they were not standardized to location nor did they always account for, or examine, factors influencing fish use of, and the value of, their habitat. Most recently, observers recorded fish in a variety of habitats; the program has been limited but provided information of fish presence and distribution but not reasons for the occupancy of these habitats and the function they provide.

Almost all the studies that we reviewed have inherent deficiencies and have been carried out under limitations in design and scope (such studies are not inexpensive). They have added to knowledge of the Somass estuary and its use by juvenile salmon, but it will only be through a more thorough co-ordinated approach that many of the concerns associated

with estuarine residence of juvenile Chinook salmon will be understood. Numerous monitoring studies under the national EEM program have increased knowledge on the changing environmental conditions, differences in PME toxicity, and benthic habitats. These studies are not specifically designed to address the concern over juvenile Chinook salmon and constraints to their survival. One may deduce some interactions and effects from these studies but by doing so there is an increased risk to their accuracy.

Fisheries and Oceans Canada and others undertook studies in the 1970s in the Somass River estuary and provided evidence for direct and indirect adverse effects on fish and their habitat from PME and other industrial and urban developments. The inhibition of marine phytoplankton photosynthesis due to, for example, coloured PME and the consequential effects of limiting autotrophic and heterotrophic productivity at depth had implications to such waters being occupied by salmon. Not only would food be impoverished in the water column, replenishment of dissolved oxygen would be limited and hypoxic conditions not alleviated.

Studies of benthic organisms revealed a complex interaction of PME and fresh waters resulting in changes in community structure. The availability of prey and the diet of the juvenile Chinook salmon reflected degrees of habitat quality and habitat fidelity, but growth rate of combined initially-larger hatchery-reared and smaller “wild” juvenile groups was similar to that in other estuaries. Studies on vertical and horizontal fish distribution in near shore intertidal regions of the estuary, examinations of the diet of fish related to benthic organisms, results from *in-situ* studies coupled to confirmatory results from laboratory toxicity and behaviour experiments, led to the conclusion that certain estuarine habitat conditions effectively constrained the living space for juvenile salmon - laterally and vertically. Habitat conditions were potentially lethal to fish in some locations. Not all these studies were thorough but collectively they revealed a need for improved environmental conditions to safeguard aquatic organisms.

The statistical analyses conducted by Birtwell (1978; DFO unpublished data) were expected to reveal significant differences or similarities among locations of fish capture and among selected habitat quality variables and metrics of fish. Because the data were grouped over a study period from April to July, encompassed differing habitat conditions and most importantly, amalgamated “populations” of juvenile Chinook salmon of river- and hatchery- origin migrating to and from the estuary, large variation in the data reduced the ability to differentiate among most aspects examined. In this context, the influx of hatchery individuals could have masked effects that may have otherwise been evident for “wild” juveniles. Similarly amalgamating numbers of fish captured from different habitats during their estuarine presence detracted from the resolution of any subtle effects. Statistical analyses did not reveal differences in numbers caught between habitats but did reveal the influx of larger hatchery-reared individuals into the estuary through a significant difference in certain metrics (length, weight, condition).

In hindsight the study design was insufficient to tease out all but the most severe influences of habitat, and this was not revealed. It was shown that all habitats sampled were occupied over time (not surprising perhaps considering the facultative behaviour of

these fish); there was fidelity to habitats despite impoverished food resources in different locations and residence of hatchery fish and “wild” fish occurred for weeks. Unfortunately the inability to visually differentiate between hatchery-origin and “wild” fish over the study period was a major impediment to examinations of the cause and effects of habitat change. This concern still exists but techniques are available to help alleviate these concerns through tagging and tracking technology which would permit a better understanding of fish (“wild” or hatchery-origin) interactions with their habitat.

Thankfully, many studies have been conducted in estuaries in the Northeast Pacific Ocean. Although no study can be expected to address all ecological concerns, results from many co-ordinated broad and also specific studies may be relied upon to assist understanding how juvenile Chinook salmon from river and hatchery-origin survive to adulthood and the constraints and limitations to this success. Many examples of these studies are presented in this report. However, the somewhat unique circumstance in the Somass River estuary is that of industrial and urban development and the presence of hypoxic waters at depth; a legacy from the Port Alberni Pulp and Paper mills’ operations and other activities. Because of this atypical situation, it would be prudent to conduct focussed co-ordinated research that will not only provide information on the ecology of juvenile Chinook salmon but at the same time monitor the changes in habitat and specifically their function. It is the functional aspects of habitat to support the life stages of these fish that requires management and protection.

Predation and survival

Even though predation has been identified by many researchers as the primary cause of mortality in juvenile salmon, this aspect has not been studied in the Somass River estuary. It cannot be assumed that both hatchery-reared and “wild” fish die in the same proportionate amounts when consideration is given to the relatively poor performance of naïve hatchery fish in their new environment and the correspondingly better performance of “wild” individuals. But, if size (indicative of swim speed) is related to a reduced risk of predation perhaps the smaller “wild” fish would be more vulnerable in the same locations; notwithstanding the learned behaviour of these fish to reduce predation risk. Or perhaps the greater the potential impact due to contaminants to exert their effects and increase susceptibility to predation of those individuals that reside longer in the estuary. Furthermore, competition for food may also influence survival via growth rate. While some of these comments have validity based on research findings, these topics have not been studied in the Somass River estuary and are, therefore, speculative. It is obvious that there are constraints to survival of the juvenile fish but the sources responsible for this have not been quantified in this estuary.

If estuarine habitat is limiting in some capacity, and is coupled with correspondingly increased selective predation, for either or both hatchery- and river- origin juveniles, it may be expected that there would be some adverse consequences to populations. Strategies to improve the survival of hatchery-reared fish prior to release have been considered, for example, conditioning to predators, and suggestions made to release fry at the same time (size) as naturally-reared fry begin their seaward migration. Such options

may be impractical or inappropriate for the Somass River system but any changes that may be made that result in hatchery-reared fish more closely matched in survival behaviours to those produced in the wild would, intuitively confer a benefit (notwithstanding the concerns expressed by Chilcote et al. (2011) and the need to minimize interactions between these groups for long-term benefits).

Port Alberni mill

Were it not for the efforts of the Port Alberni mill owners, their compliance with operating conditions, modifications to effluent treatment, and environmental and toxicity monitoring, there would be a paucity of information relating to aquatic conditions at the head of Alberni Inlet over the last 20 years.

Data generated by consultants for respective Port Alberni mill operators have added to long-term data sets, which has permitted changes and trends to be identified. At the present time and under the current operating conditions improvements in water quality have been revealed from that which was determined more than 2 decades ago. Currently (April/May 2014) there is evidence of photosynthetic activity in marine waters at the transitional boundary between the halocline and deeper marine waters within the Somass River estuary because of super-saturated levels of dissolved oxygen at these depths. Although this is not unique at this time of year its presence is encouraging for such conditions existed before the mill commenced operations, but not found in the 1970s.

A lower mill effluent colour will permit light penetration to greater depth and improve phytoplankton productivity and the production of oxygen. It would be expected that this, in turn, will benefit organisms that may feed upon such resources and they too would become prey within the pelagic zone of the estuarine food chain. Persistence of this condition (for its' positive environmental benefit) would be very encouraging, and be of value to migrating and residing juvenile salmon in the coming months (June/July) and into the fall. Such conditions prior to the Port Alberni mill prompted Tully (1949) to state "it is concluded that the oxygen distribution observed in the upper 50 to 100 feet of the inlet is largely a result of the rank growth of phytoplankton occurring during the summer. Aside from the fact that the *phytoplankton is a dependable cause of supersaturation in the upper zone*" (in reference to the upper zone of marine waters below halocline) "its contribution to the observed states cannot be calculated".

Monitoring and inferences

The monitoring studies carried out for the mill have not always been of direct assistance in revealing how environmental conditions in the estuary may constrain or facilitate use by juvenile salmon. In this regard the determinations of acute toxicity of mill effluent through laboratory bioassays in which a "pass" or "fail" relates to whether $>$ or $\leq 50\%$ of test fish survive in a 96-h exposure has little relevance to fish inhabiting the Somass River estuary. The results have high value in comparative assessments of effluent toxicity by using a standard protocol. Even the assumption of "no toxicity" is erroneous when

<50% of test fish may die (and without regard to debilitating sub-lethal effects) yet the effluent would be considered as not toxic.

Other results of effluent “toxicity” have been provided, especially through the EEM program. Some of the tests were more sensitive and appropriate, but suffer in terms of relevance to the Somass River estuary. Comments about this topic have been elaborated upon in this report, but no criticism applies to those who must perform such tests to comply with regulatory requirements.

Complimentary laboratory and field studies

Our concern over laboratory bioassay results relates to how they may be used to infer or conclude circumstances in the estuary of the Somass River. A number of reports have deduced the zone of influence of the mill’s effluent from laboratory-derived tests (we are not aware of recent *in-situ* studies that would help define the influence of PME on organisms in the estuary). Furthermore, there is no guarantee that results determined in the laboratory will be mirrored in the environment and vice versa. Accordingly it seems most logical that a combination of laboratory and field tests should be carried out. Unfortunately results from studies in the environment will reflect the integration of many and varying influences and therefore detract from a precise identification of effects from one source alone (as exemplified in examinations of the benthos along the eastern shoreline); this does not imply they have no merit but that teasing out effects is a logistical and statistical challenge. However, the benefit of carrying out combined studies will provide for more meaningful assessments and lessen the concern over the extrapolation of results from laboratory tests and their reliance on inferences.

The combination of laboratory-based and *in-situ* studies on the migration of adult salmon provide an example showing where complimentary studies may enhance understanding of salmon behaviour and factors influencing their choices and wellbeing. It is known that depressed levels of dissolved oxygen exist in the upper Inlet sub-halocline waters and threaten the wellbeing of adult salmon that may occupy these waters, especially if migration is delayed. Variation in dissolved oxygen occurs and is often low at depth in summer when adult Chinook salmon are migrating, and before them, the majority of sockeye salmon. Therefore, it is very likely that these fish could encounter water quality conditions that would be potentially harmful. It seems inappropriate therefore for an explicit statement of no level of concern, such as “Overall, results indicate that historical impacts of paper mill effluent in Alberni Inlet no longer pose a risk to migrating sockeye salmon and that current Pulp and Paper Effluent Regulations effluent quality standards are protective of fish”. We consider support for such a definitive statement is not currently available, for reasons already stated. It has been demonstrated that areas of habitat degradation can seriously impact fish because of their behavioural repertoires and prevailing environmental circumstances, and relative to the Somass River estuary, the latter part of this statement has not been proven specifically, and the former part is questionable.

Habitat features, water quality, restoration and rehabilitation

The mechanisms by which Somass River estuarine habitat changes have occurred, and which may be continuing, are not fully understood, but there are strong inferences from research studies that help explain functional aspects of habitat, use by juvenile salmon and limitations upon them. Examples of these relationships with respect to, for example, habitat type, temperature and dissolved oxygen have been provided and juvenile Chinook salmon shown to use many habitats. But, it is not known whether adverse water quality in shallow surface waters will restrict the vertical and horizontal living space of these fish at the present time. Seasonal changes will result in elevated temperature in the waters tidally immersing the intertidal zone and eventually attain levels that will stress the fish. This seasonal change is expected and although habitat occupancy may be influenced it may not deter fish from temporary excursions into potentially lethal waters to feed. Lower levels of dissolved oxygen occur with elevated water temperature and together these factors may exert their effect and limit feeding. In this regard, the probability of capturing a juvenile Chinook salmon in the Fraser River estuary occurred at similar temperature/oxygen combinations (16°C - 17°C and 8 mg/L - 9 mg/L DO).

In the Somass River estuary the highest temperature when a juvenile Chinook was captured was 22.5°C and this fish would have been expected to be under thermal stress, similarly individuals caught in waters where dissolved oxygen was below 75% air saturation values would also be under hypoxic stress (one fish was captured in waters with dissolved oxygen levels of 2.8 mg/L; 32% saturation). The deduction that both temperature and dissolved oxygen exert influences on fish occupation of habitats has not been rigorously examined but it is understood.

Many important habitat features and the importance of habitat connectivity have been presented in this report and provide a source of reference. In the Somass River estuary, these aspects are important considerations regarding efforts to identify, improve or enhance (rehabilitate) fish use and the function of intertidal areas. Dendritic channels and slough habitats have been identified as important habitat components for salmon but the quality of waters within them can vary from those in more open tidally-flushed regions. Previous studies on conditions in the estuary have been biased toward the sites selected for fish capture and have not reflected the full range of conditions in all habitat “types” and functions. It is important to recognize these areas and to obtain detailed information to validate or refute their value for juvenile Chinook salmon.

A current concern relates to the discharge of domestic waste/sewage from the city of Port Alberni. It is discharged into surface waters near the middle of the upper estuary. The contribution of this material to the BOD load of the estuary is significant and accordingly the organic input and its’ distribution into tidal channels and other important nursery and rearing areas for many organisms is a concern. It is possible, based on studies elsewhere, that dissolved oxygen depression could occur in organically enriched areas preventing the fish from fully utilizing them, as well as having a negative impact on prey production. The impact of this discharge requires study as it could influence and possibly complicate efforts to rehabilitate the estuary. Studies have documented the impacts of discharging

sewage onto an intertidal region in the Fraser River estuary and the resultant stressful and lethal conditions that compromised the wellbeing of, and killed, juvenile salmon and other species.

Adult salmon returns; “pristine” and “contaminated” estuaries

Much of the foregoing material has been concerned with natural and altered habitat due to the industrial and urban development in upper Alberni Inlet. The waters and surrounding areas receive wastes from these developments and this review has not addressed the potential for contaminants other than PME to affect survival of fish and ancillary aspects related to impacts on different trophic levels. One may deduce that there have been significant changes to the quality and sufficiency of the Somass River estuary for almost 70 years and a legacy of pollution that has limited the living space and support systems for salmonids. It has proven difficult to identify relationships between some of these aspects and the wellbeing of fish and other organisms, and no fully-integrated studies have been carried out. Reference to studies in other locations provide valuable insight into habitat quality and sufficiency and its impact on fish, but few have addressed the integration of effects on such habitats to the survival of juvenile Chinook salmon and their return to natal streams.

At a different analytical scale than most of the projects referred to in this review, two studies provide information that is appropriate to consider in the context of the current state of the Somass River estuary to support Chinook salmon; comments from these reports are presented here.

Meador (2014) reported the results of analyses spanning 37 years related to 20 hatcheries and the survival to adulthood of previously-released juvenile salmon, and the degradation (by contaminants) of estuaries through which these fish migrated. His results revealed that “for all years combined, juvenile Chinook transiting contaminated estuaries exhibited an overall rate of survival that was 45% lower than that for Chinook moving through uncontaminated estuaries, which was confirmed when tested year by year”. Meador (2014) cautioned “These observations have important implications for wild juvenile Chinook that spend more time in the estuary compared with hatchery-reared fish”. “If contamination is indeed the causative factor limiting the smolt-to-adult return rate for hatchery Chinook, then the extended time expected for naturally reared Chinook may lead to even more dramatic impairment. This is also relevant for any other salmonid at this life stage that may reside in an estuary for an extended time. If this level of reduction in survival for wild fish out-migrating through contaminated estuaries is occurring, it will likely be manifest in large changes to population abundance and structure as demonstrated with life history modeling.”

These cautionary statements cannot be accepted without consideration of the effects of other changes in the estuarine environment that may influence survival of juvenile Chinook salmon. Contaminated estuaries are also locations where industrial and urban development has occurred resulting in habitat loss and degradation. It is not surprising therefore that Magnusson and Hilborn (2003) were able to demonstrate a direct link

between estuarine condition and survival of salmon through their entire life history showing that pristine estuaries have much higher Chinook salmon survival than do degraded estuaries. Hence, the deductions of both Magnusson and Hilborn (2003) and Meador (2014) that degraded estuarine habitats have poorer returns of adult Chinook salmon than those which are less, or not, degraded, are a reflection of the integration and cumulative effects of all physical, chemical and biological factors. The specific causes for reduced performance of individuals are more difficult to define. Studies that have shown these general relationships have essentially masked specific causes of impacts but through their integrative approach have revealed effects on populations of returning adults. Information from many field and laboratory studies provides insight into the value of habitats and their functional benefits, and the optimisation of conditions for the wellbeing of fish. Additionally, these studies have also identified the constraints and limitations due to natural factors and contaminants.

The analyses of Meador (2014) provide additional information and guidance regarding contaminants as factors to consider when searching for causative factors affecting the survival of salmon (and other organisms). The concerns expressed by both Meador (2014) and Magnusson and Hilborn (2003) are as germane to understanding the problems of habitat change in the estuary of the Somass River and the impacts on salmon as are those expressed by Chilcote et al. (2011) regarding the negative consequences of interactions between individuals of wild- and hatchery-origin.

Conclusions

The Somass River estuary supports not just juvenile Chinook salmon, but also millions of other seaward-migrating salmonids and other temporary and permanent organisms. There continues to be concerns and constraints (albeit mostly inferred) to habitat use due to a legacy of Port Alberni mill operations, and wastewater discharges from the mill and from the city of Port Alberni.

Co-ordinated studies (in contrast to the numerous uncoordinated projects that have been carried out) are necessary to understand the impacts of constraints - specifically in habitats of known importance to successful rearing and the survival of juvenile salmon. Much information exists on the impacts of mill effluents and industrial and domestic waste but Port Alberni Harbour and the Somass River estuary are unique areas. While generalisations of impacts can be implied based on past studies, what should be done to understand and alleviate any impacts also requires site-specific information; studies which include statistical rigour. It would be most unfortunate if decisions are made which do not take into account studies of habitat change in this area to assist rehabilitation efforts. At the present time modifications to the method of discharging municipal waste into the estuary are being considered. It is crucial that any changes take into account the current circumstances of the discharge, prevailing habitat conditions in the estuary and benefits that may accrue to aquatic organisms.

Certain constraints to the functioning of estuaries that have been degraded can be alleviated because of knowledge and understanding that has been gathered over many

years. However, other factors exerting their influence such as those in the Pacific Ocean must be accepted, and they may override habitat constraints inherent in estuaries. Thus rehabilitation of estuarine habitat will be a function of changes that may be made and managed, together with those that are not possible to control. Accordingly, only after numerous years of monitoring salmon returns and the factors that affect them should it be possible to identify some causes related to survival; it will be a difficult challenge in a changing environment. There will be a need for specific field studies to verify associations and benefits related to survival. If there continues to be differential survival of “wild” and hatchery-reared juvenile Chinook salmon in the Somass River estuary, determination of causative factors will likely prove extremely difficult for reasons already presented. We found no information supporting better survival strategies of hatchery-reared individuals over their wild counterparts, and questions arose as to whether significant numbers of truly wild Chinook salmon are in the Somass River system.

However, and in recognition of results from other studies and assessments encompassing many years, one may safely infer that improvement to estuarine habitat will benefit Chinook salmon and potentially increase population resilience and survival. But, validation of these actions will only be possible through co-ordinated programs, aspects of which have been exemplified in this review.

Strong and compelling inferences supported by evidence from analyses of salmon survival-to-adult return data indicate the importance of estuaries which are in an unconstrained functional state which permit the expression of different life history strategies thereby facilitating stock survival and resilience (the role of hatchery fish in this scenario requires careful evaluation). Thus, improvements to degraded areas which support rehabilitation of such functions and the provision of space for their full expression should be undertaken. Knowing what steps to take for maximum benefit will be possible from the results of studies identified in this review and other documents, but it is probable that *in-situ* studies will be required to focus attention on critical aspects and to document the persistent benefit of change.

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