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EULACHON (*THALEICHTHYS PACIFICUS*): PAST AND PRESENT

Fisheries Centre, University of British Columbia, Canada

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by
Megan Felicity Moody
and Tony J. Pitcher

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DIRECTOR'S FOREWORD

I am particularly pleased to present this Fisheries Centre Research Report (FCRR) titled "Eulachon (*Thaleichthys pacificus*): past and present", which is based on the Master's thesis of the first author, submitted and successfully defended in 2008.

This FCRR, besides making clear the precarious state of eulachon throughout much of its geographic range, also documents its importance for and uses by the First Nations of the central coast of British Columbia – a task which no other but Ms Megan Moody, herself a member of the Nuxalk First Nation, of the Central Coast of British Columbia, could have written about so credibly.

Indeed, this more than anything illustrates the importance for the Fisheries Centre and other units of UBC having students from First Nations building on their own experience and knowledge. Beside its obvious merits as a thorough account of the biology of eulachon, this credibility is a major reason why we publish this thesis as a FCRR, pending the submission of its various chapters to scientific journals.

I take this opportunity to thank on my behalf and that of Ms. Moody, Dr. T.J. Pitcher, co-author and supervisor of her thesis, Dr. W.W.L. Cheung, for his assistance with the fuzzy logic part of her analysis, Dr. D. Pauly for his suggestion to publish this report, and for editing it, and the many other persons who have assisted in the creation and publication of this document.

Ussif Rashid Sumaila, Director

UBC Fisheries Centre

May 2010

ABSTRACT

The biology of eulachon (*Thaleichthys pacificus*), a small anadromous smelt (Family Osmeridae) found only along the Northwest Pacific Coast, is poorly understood. Many spawning populations have suffered declines but as their historic status is relatively unknown and the fisheries poorly documented, it is difficult to identify the contributing factors. This study provides a survey of eulachon fisheries throughout its geographical range and three analyses aimed at improving our understanding of past and present fisheries, coast-wide abundance status, and the factors which may be impacting these populations.

An in-depth view of the Nuxalk Nation eulachon fishery on the Bella Coola River, Central Coast, BC, is provided. The majority of catches were used for making eulachon grease, a food item produced by First Nations by fermenting, then cooking the fish to release the grease. Catch statistics were kept yearly from 1945-1989, but have rarely been recorded since. Using traditional and local ecological knowledge, catches were reconstructed based on estimated annual grease production. Run size trends were also created using local Fisheries Officers and Nuxalk interview comments.

A fuzzy logic expert system was designed to estimate the relative abundance of fifteen eulachon systems. The expert system uses catch data to determine the exploitation status of a fishery and combines it with other data sources (e.g., CPUE) to estimate an abundance status index. The number of sources depended on the existing data and varied from one to eight. Using designed heuristic rules and by adjusting weighting parameters a final index was produced. Results suggest that there have been recent and extended declines in several eulachon rivers particularly the Klamath, California; Bella Coola, BC; Wannock, BC; and Kitimat, BC. Seven of the fifteen abundance time-series were used to evaluate the potential relationships between the declines and some of the factors that impact eulachon. Results suggest increases in shrimp and hake catches, seal and sea lion abundance, and the increase in sea surface temperatures were weakly associated with the declines. However, contrary to expectations, adult hake biomass showed a positive association with four eulachon relative abundance time-series, suggesting that common environmental factors influenced both species.

INTRODUCTION

The eulachon, *Thaleichthys pacificus*[1] (Richardson, 1863), a small anadromous smelt (Family Osmeridae), is found only along the North American Pacific Coast from northern California to the southern Bering Sea. It is commonly recognized as the ooligan, eulachon, hooligan, olachen, olachon, oolachan, oolichan, and oulachan. The origin of its name was originally derived from the Chinook Indian trade language. However, each First Nation group possesses a different word for the fish specific to their own language. It has also been termed the 'candlefish', as its high oil content allows it to burn like a candle when dried (Swan, 1880) and the 'salvation' fish, as it historically arrived when First Nations people were starving or low on winter food supplies, "should the run of oolachans fail, hundreds of Indians literally die of starvation" (Bland, n.d.). The eulachon was first recorded in British Columbia (BC) waters in 1866, after specimens were collected near Vancouver Island (Clemens and Wilby, 1961). In this paper the fish will be referred to as 'eulachon' as this is the most common spelling in today's literature.

Background

Biology

Eulachon return to most rivers in the early spring to spawn. In BC, they return in peak abundance to the Nass, the Kemano and the Bella Coola Rivers during March and to the more southern BC runs, the Fraser, the Kingcome and Klinaklini Rivers in April. Maps of all river locations are shown in "A review of historical eulachon fisheries". The more southern Columbia River, Washington/Oregon run peaks in abundance during February (Washington & Oregon Departments of Fish and Wildlife [WDFW & ODFW, 2005]) several months earlier than the runs in Alaska. In Southeastern Alaska eulachon can spawn as early as April whereas in the Central and Western Alaskan rivers they can return as early as May (Alaska Department of Fish and Game, 2007). The one common aspect of these rivers is that they have a spring freshet that is typical of glacial rivers (Hay and McCarter, 2000).

Mature eulachon are dark blue-grey with black speckling and a silvery white underbelly. They range in size from 135 to 151 mm (total length) in the offshore waters of California (Odemar, 1964); the mean standard lengths in the Fraser River, BC, are 150 to 180 mm (Hart and McHugh, 1944), in the Nass River, BC, 161 to 177 mm (Langer *et al.*, 1977), and 100 to 253 mm (fork length) in the Twentymile River, Alaska (Spangler, 2002). Spangler *et al.* (2003) suggest that the larger body size of eulachon in northern rivers is the result of the more favorable feeding conditions in northern latitudes. The sex of the fish can easily be distinguished during spawning, as males have a longer pelvic fin, a rougher texture, nuptial tubercles on the skin, and a large mass of muscle that develops along the lateral line. The female is smaller, smoother, shiner and has a smaller pelvic fin. Fecundity increases with age, length and weight (Spangler, 2002) and generally ranges between 20,000 and 40,000 eggs (Hay and McCarter, 2000).

Spawning occurs primarily over small gravel and coarse sand in moderately flowing water (Smith and Saalfeld, 1955). The fertilized eggs are approximately 1 mm in diameter and have an outer membrane that ruptures to form an adherent peduncle which attaches itself to the substrate (Parente and Snyder, 1970). Artificially fertilized eggs taken from the Cowlitz River, a tributary of the Columbia River, were found to hatch in 19 days in 9.4°C to 12.7°C water or 370 Accumulated Thermal Units (ATUs) (Smith and Saalfeld, 1955), while those taken from the Bella Coola River were found to hatch in 54 days in ~6°C water, or ~340 ATUs (Moody, 2004). Newly-hatched eulachon larvae are transparent, approximately 4 mm in length and feeble swimmers which move at the mercy of the river current (Parente and Snyder, 1970). There is little information on the spatial distribution of juvenile eulachon in the marine environment. Barraclough (1964) suggests that eulachon larvae and juveniles spend a considerable portion of their first two years in the plankton-rich echo-scattering layers of coastal waters. The location and marine abundance of juvenile and pre-adult eulachon in BC waters has been estimated since 1973 by the Department of Fisheries and Oceans (DFO) from eulachon caught as bycatch in trawl fisheries and in multi-species research trawls (Hay and McCarter, 2000).

[1] Translated means "oily fish of the Pacific"

The age of eulachon maturity has been estimated in the past by counting the annual rings of scales or the spatial deposition of rings on hard structures such as otoliths. Using these methods, the age of the Columbia River eulachon has been estimated between three and four years (Smith and Saalfeld, 1955), the Kitimat River, BC eulachon, between three and six years (Pederson *et al.*, 1995) and the Copper River, Alaska, eulachon between three and five years (Joyce *et al.*, 2004). Recently, Clarke *et al.* (2007) have suggested that whole eulachon otoliths possess numerous dark bands or "pseudo annuli" which make identifying the specific increments difficult and thus may be wrongly interpreted. Researchers in the past have admitted to the difficulty of interpreting eulachon scales and otolith readings and have expressed doubts concerning the accuracy of their results (Ricker *et al.* 1954). Therefore, Clark *et al.* (2007) used an alternative method which examined the seasonal oscillation of Barium to Calcium concentrations in eulachon otoliths. This method estimated the age of eulachon maturity from five rivers and determined that the more southerly populations spawned at an earlier age. The Columbia River eulachon were estimated to spawn after two years; the eulachon from the three BC rivers (Fraser, Kemano and Skeena) after three years; and the Copper River, Alaska, eulachon after four years.

Importance of the eulachon

Eulachon are an important prey species for marine and freshwater fish, mammals and birds as they provide a large amount of energy-rich food during the spring when food supplies are low. The Nuxalk people of Bella Coola and the Wuikinuxv people of Rivers Inlet both identified the beginning of their eulachon runs with the arrival of seagulls (*Larus occidentalis*), eagles (*Haliaeetus leucocephalus*), seals (*Phoca vitulina*) and sea lions (*Eumetopias jubatus*) (Winbourne, 2002). Collison (1916) witnessed eulachon followed into the mouth of the Nass River, BC, by "hundreds of seals, porpoises (*Phocoena vomerina*), sea-lions, and fin back whales (*Balaenoptera physalus*), feasting both on the olachans and upon one another." In 1997, the area-wide bird and mammal tallies for Berners Bay, Southeastern Alaska, during eulachon runs to the Berners, Lace and Antler Rivers, were 36,500 avian predators, including 536 bald eagles, and 422 marine mammals (Steller sea lions and harbour seals) (Marston *et al.*, 2002). During this study mammalian predators were found to commonly feed on eulachon in the lower reaches of the rivers whereas the birds fed farther upriver on weak or dead eulachon. The benefit for predators in consuming eulachon during this time rather than other prey is the high energy to cost ratio (Marston *et al.*, 2002) because eulachon are extremely high in lipids; their raw fish oil content has been measured at 11.21% (Daughters, 1918), 16.7% (Kuhnlein *et al.*, 1996), and 15.0 to 25.3% (Iverson *et al.*, 2002) and minimal time is needed to capture the weakly swimming fish. In addition, eulachon spawn at a time of year when many predators experience high energy costs, notably for reproduction (Sigler *et al.*, 2004). Marine fish, such as dogfish (*Squalus acanthias*), salmon (*Oncorhynchus* spp.), hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*) and lingcod (*Ophiodon elongates*) have also been identified as predators of the eulachon (Barraclough, 1964) and in fresh water eulachon are a large part of a sturgeon's (*Acipenser transmontanus*) diet during the spring (Prince, 1899).

Eulachon are also particularly important to First Nations people. They are eaten fresh, dried, smoked, salted, and are frozen whole. However, the product of greatest cultural, nutritional, social and economic value is the 'grease' rendered from the fish. Eulachon grease was produced by First Nations groups of the Central and the North Coasts of BC and by some First Nations groups in Alaska. The First Nations south of Knight Inlet did not produce grease, but caught eulachon for smoking and for fresh consumption. Eulachon grease is produced from aged or rotted fish that are cooked until the oil of the fish has separated and can be removed. The grease is a very nutritious food that is high in unsaturated fats and is superior at providing vitamin A, E and K when compared to other common fat sources (Kuhnlein *et al.*, 1982). The grease is used as a staple in many First Nations diets and is distributed widely in potlatches, traded with neighbouring Nations and relied upon as a medicine. The importance of grease is best signified by the ancient trade routes used to link the coastal First Nations with the interior First Nations. These routes are famously referred to as "grease trails" as the heaviest traffic occurred during the eulachon season to trade for grease (Collison, 1941).

Research objectives

Although the eulachon is of great importance to First Nations people its low commercial value has resulted in limited recording of past catches and few assessment surveys of spawning abundance. Thus, the status

of many eulachon systems is only known through hearsay, and the extent and cause of eulachon population declines are unknown. This project aims to summarize the information on eulachon that exists, gather new information from the local knowledge of the First Nations people, synthesize this material to examine the past history of Pacific North Coast eulachon fisheries, estimate the past and present status of specific eulachon populations, and identify any significant impacts that may have been responsible for recent declines.

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A REVIEW OF HISTORICAL EULACHON FISHERIES

Approximately 95 rivers across its endemic range in the Pacific Northwest are known to have had regular or intermittent, eulachon spawning populations (BC: 35 rivers [Hay and McCarter, 2000]; Alaska: ~35 rivers [Beth Kito 2000]; Washington and Oregon: 20 rivers [Willson *et al.* 2006]; California: 5 rivers [Odemar, 1964]). However, some of those rivers no longer have eulachon returning to them in harvestable numbers. The possible impacts are difficult to study, as data for each area are limited. Much of the existing data are unpublished and lie scattered throughout the Pacific North Coast in offices of First Nations, private consultants and provincial, state or federal governments. This section summarizes the past and current information on eulachon fisheries and eulachon populations. As information is limited, only 'key' eulachon systems will be discussed, for example those which have previously been documented and/or those which have been regularly fished by either a First Nations group or by a commercial fleet. The information collected was then used in "Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system" to estimate the coast-wide abundance of 15 eulachon systems. These abundance estimates were used to test some of the hypotheses suggested for the recent decline of eulachon populations (see *Assessing the impacts on eulachon populations*).

Sources of information

An extensive literature review was conducted using the internet and known eulachon experts from First Nations organizations, government agencies, and private consultants. Sources include published and unpublished reports and local fisheries officer reports. Also, videos on eulachon fisheries and eulachon grease making were accessed (Elsey, 1964; Cranmer and National Film Board of Canada, 1999). Formal and informal meetings[2] were also used to discuss current and past eulachon issues and to meet new eulachon experts and gather additional information.

The information collected was divided into seven geographical areas: California, Oregon/Washington, South, Central and Northern BC, Southeastern Alaska and South Central Alaska (Figure 1), each mapped and discussed separately in this section. Local First Nations' traditional territory rivers are identified for each area, along with other First Nations who were historically invited to fish in the area. A separate subsection section discusses BC's former commercial eulachon fishery. Current and past fisheries (First Nation, commercial, or recreational), past catches, past declines, current run status, and past/present management are also discussed.

Geographic range

The portion of the Pacific North Coast which encompasses eulachon-bearing rivers extends from Bristol Bay in the southern Bering Sea (Hay, 1995) in the north to Northern California (Odemar, 1964) in the south. Figure 1 displays the seven geographical areas and the sub-areas or rivers they encompass. Alaska is divided in two: Southeastern and South Central Alaska. Southeastern Alaska covers the areas of Lynn Canal/Berners Bay, the Ketchikan area and the Yakutat area, while South Central Alaska includes the Copper River of Prince William Sound and the rivers of Cook Inlet. British Columbia has been divided in three: the North, the South and the Central Coasts. The North Coast includes discussion of the Skeena and Nass Rivers. The Central Coast covers Johnstone Strait, Bella Coola, Rivers Inlet, Douglas Channel and the Gardner Canal. The South Coast includes the Fraser River Area. In the United States, Washington and Oregon are represented by the Columbia River and its tributaries, while California has six potential eulachon-bearing rivers.

[2] A workshop to determine research priorities for eulachon, February 20-22, 2007, Richmond, BC
Eulachon Crisis Gathering 2007, June 11-12, 2007, Bella Coola, BC.

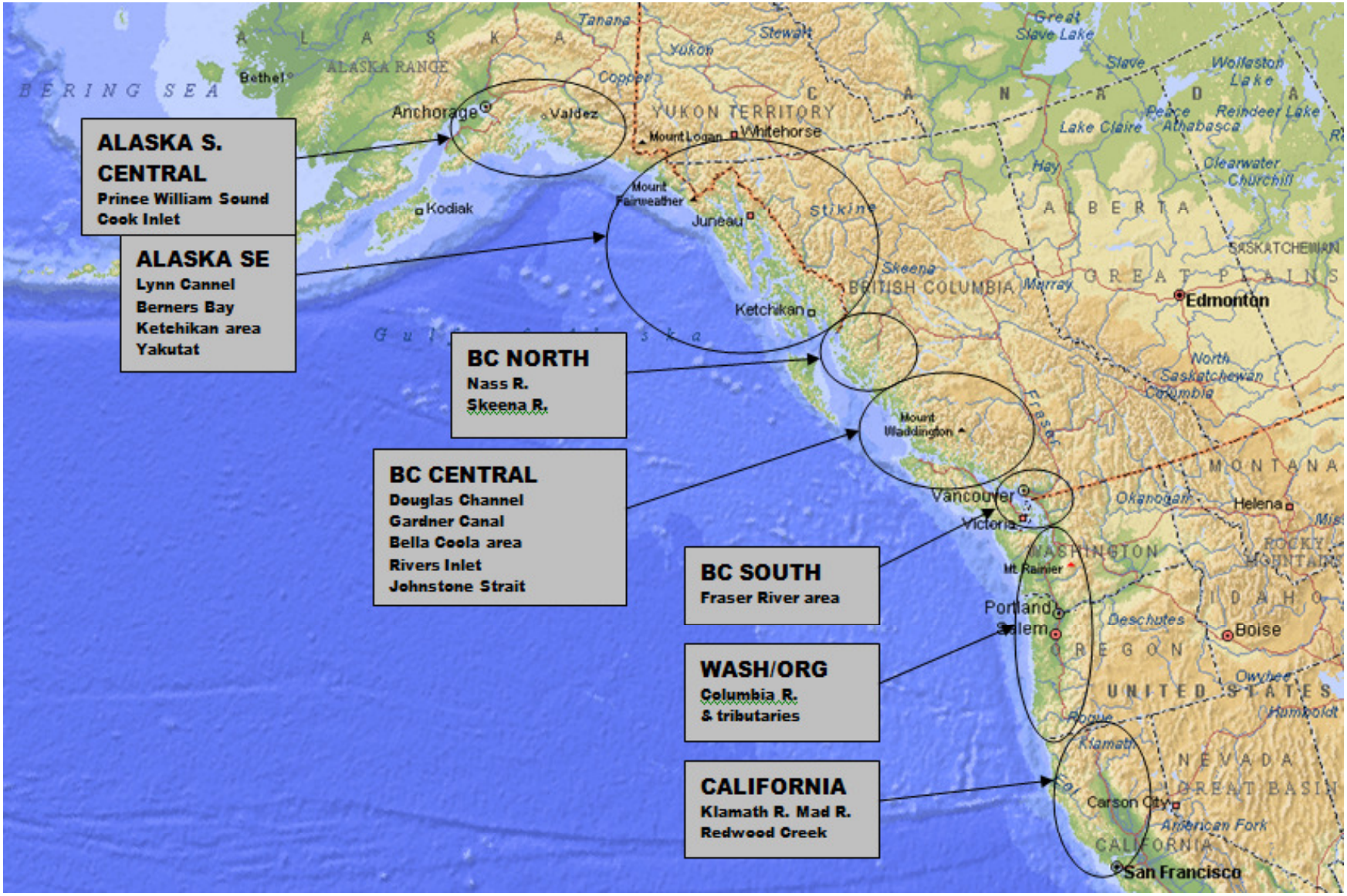

Figure 1. Locations of eulachon runs on the Pacific North Coast.

Alaska

Approximately 35 rivers in Alaska are reported to have eulachon returns, (Kito, 2000). The largest are the Unuk, Stikine, Taku, Mendenhall and Chilkat Rivers in Southeastern Alaska, the Situk River near Yakutat, the Copper River near Cordova and the Kenai, Susitna and Twentymile Rivers in Cook Inlet (Bartlett and Dean, 1994). The eulachon in the southeastern rivers return as early as April, while those in the central Alaskan rivers commonly return in May (Bartlett and Dean, 1994). The coast of Alaska has been divided into Southeastern Alaska and South Central Alaska.

South Central Alaska

Prince William Sound

The Copper River is located east of Prince William Sound (Figure 2) and is one of the larger eulachon rivers in Alaska (Bartlett and Dean, 1994). The Copper River Delta, from the west to east, consists of the five other known eulachon spawning systems: the Eyak River, Ibeck Creek, the Scott River, Alaganik Slough and the Martin River (Table 1). Although the Copper River Delta is not located immediately in Prince William Sound it is managed under the Prince William Sound Eulachon Smelt Management Plan (Moffit, 2002) and thus is categorized into this subarea. There are two fishing sectors, the subsistence fishers (which include tribal and non-tribal fishers) and a small commercial fishery. First Nations people are referred to as 'tribal members' in the United States. Most of the tribal catch in the past has come from: Ibeck Creek, the Alaganik River and the Copper River (Joyce *et al*., 2004). The closest community to the Copper River is Cordova. Alaskan First Nations, from the Eyak Tribe, reside in Cordova and in the villages of Chenega and Tatitek. The eulachon return to this region in several waves, with the largest wave commonly returning during May; however, in recent years eulachon have been found as early as January and as late as June (Joyce *et al*., 2004).

Table.1. Eulachon rivers located along the South Central Coast of Alaska.

Area	Eulachon spawning sites	Past/Present Fisheries
Prince William Sound Area[a]	Copper, Martin, Alaganik Slough, Scott, Ibeck and Eyak R.	Small tribal fishery Small recreational Small commercial
Cook Inlet	Susitna (Big and Little), Kenai, Kasilof, Twentymile R.	Small tribal fishery Small recreational Small commercial

[a]Reported by Moffitt *et al.* 2002

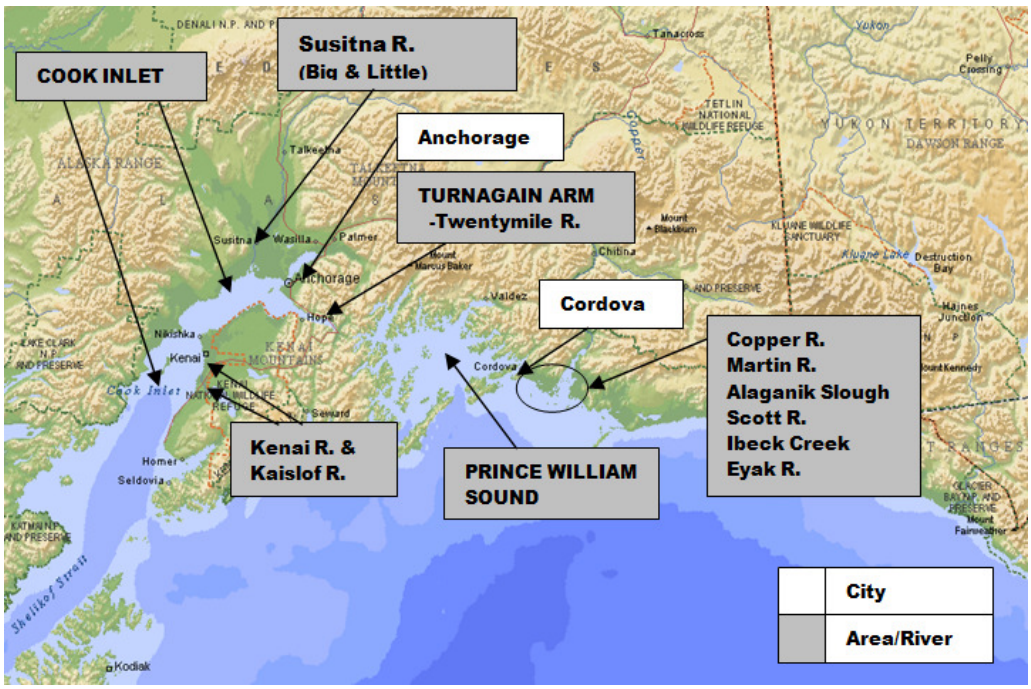

Figure 2. Locations of eulachon spawning rivers, with reference cities in the South Central Coast Area of Alaska.

The commercial fishery in this area began in 1995 as result of dramatic decreases in commercial catches of eulachon and eulachon abundance in the southern Columbia and Fraser rivers (Moffit *et al.*, 2002). The Copper River commercial eulachon fishery was first conducted in both marine and fresh water and managed through an open-access Commissioners permit. Initially eulachon were caught in marine waters by purse seine and in fresh water by dipnet. However, there were no significant catches until 1998, when a total of 78.3 t was landed (Figure 3; Moffit *et al.*, 2002). For greater control, the Alaskan Board of Fisheries established the Prince William Sound eulachon smelt management plan in 1999 and changed the fishery to a departmental test fishery. This test fishery was conducted by dip net only in the fresh water, with a maximum allowable catch (MAC) of 272 t (Moffit *et al.*, 2002). The MAC was reduced in 2000 to 182 t, due to the "apparent low abundance of fish" in 1999, which resulted in a total catch of 59.2 t (Moffit *et al.*, 2002). The MAC was again reduced in 2001 to 136.5 t because the Department had not completed the biomass estimate; and a total of 71 t was caught in 11 days (Moffit *et al.*, 2002).

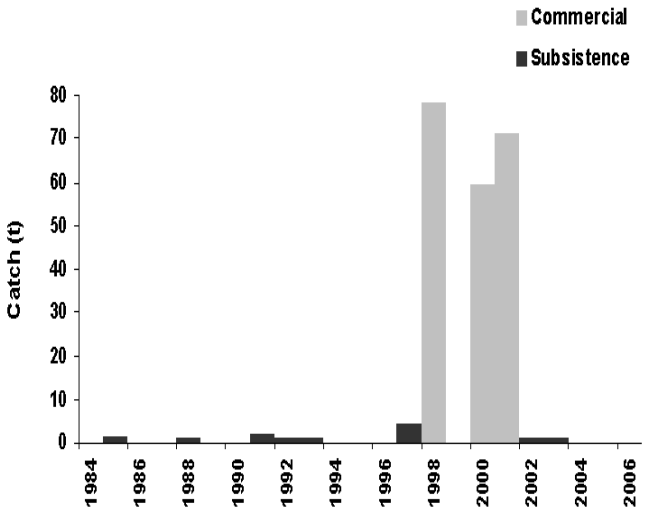

Figure 3. Eulachon commercial and subsistence catch from the Copper River Delta. Source: Joyce *et al.* (2004); Moffit *et al.* (2002).

The Alaskan Department of Fish and Game estimated the biomass for 2001 at Flag Point Channel located at the 27 mile bridge in the Copper River at between 2300 and 8000 t (Moffit *et al.*, 2002). In 2002, the test fishery bid was rejected and no commercial fishery took place. This same year, subsistence users expressed concerns regarding the commercial fishery. The Native village of Eyak requested an emergency closure to the river

for all fishers, except for federally-qualified subsistence users. Community subsistence needs were estimated during the 2002 and 2003 eulachon seasons, and ranged up to 5 t annually (Figure 3; Joyce *et al.*, 2004). Thus the biomass estimated in 2002 would seem more than sufficient to fulfill subsistence needs. However, there was no final statement made regarding what the sufficient amount was. The study did conclude that information gathered during the study would be used to assist in determining future eulachon subsistence needs for the Copper River Delta.

Cook Inlet

The Upper Cook Inlet area has two large eulachon runs, the Susitna and the Kenai, and a smaller run that returns to the Twentymile River (Table 1). Portage Creek and the Placer River, both adjacent to the Twentymile River, were reportedly fished for eulachon in the past (Spangler *et al.*, 2003). Eulachon start to return to Cook Inlet from mid-May to mid-June (Shields, 2005). This area supports subsistence and personal use fisheries and a limited commercial fishery.

The personal use fishery can occur in both salt (gillnet) and fresh water (dip net) with no bag or possession limits (Shields, 2005). Most of the catch from this fishery occurs in the Twentymile and the Kenai Rivers. The annual catches ranged between 2 and 5 t from 1993 to 2003 (Figure 4; Shields, 2005). These catch estimates are possibly under-reported as some participants confuse subsistence and personal use catch and currently there are no records for subsistence catch (Shields, 2005). However, a study conducted on the Twentymile River in 2002 estimated the subsistence use at 14.9 t (Spangler *et al.*, 2003) whereas the ADFG reported the total 2002 personal use smelt catch at 4.1 t (Shields, 2006).

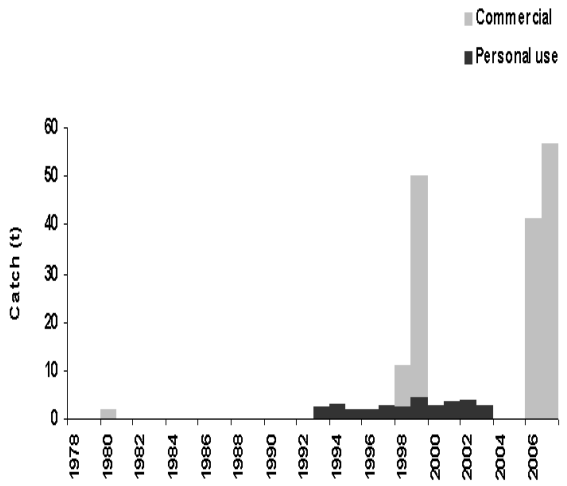

Figure 4. Eulachon commercial and sport catch from Cook Inlet. Source: Moffit *et al.* (2002); Joyce *et al.* (2004).

Commercial catches have only been recorded in four seasons: 1978, 1980, 1998 and 1999. The catches ranged from 300 pounds (0.14 t) to 100,000 pounds (45 t) caught in 1999 (Figure 4) (Shields, 2005). The commercial fishery had a catch limit of 45 t, until after the 1999 season (Shields, 2006). All catches occurred in salt water near the Susitna River and gear was limited to gillnet use, but the catch increased after dip nets were allowed in 1998. The Alaskan Board of Fisheries closed the entire commercial fishery after the 1999 season, after they adopted the Forage Fish Management Plan. The fishery was reopened in 2005 with a total catch limit of 100 t but was limited to dip net capture in salt water. There was no fishery in 2005, primarily due to logistical issues involved with getting the catch to market (Patrick Shields, pers. comm., 2007). Although there has been no biomass assessment calculated in this area, the stocks are believed to be plentiful, "undoubtedly be measured in thousands of tonnes, likely even 10's of thousands of tonnes" (Shields, 2005). The 2006 and 2007 season had commercial catches of approximately 41 and 56.7 t and eulachon returns appear to be strong with no declines in abundance seen over the past two decades (Patrick Shields, pers. comm., 2007).

Southeastern Alaska

Southeastern Alaska has approximately 16 eulachon rivers (Willson *et al.*, 2006) and has been divided into three areas: the area surrounding Ketchikan, the area of Lynn Canal/Berners Bay, and the Yakutat area (Figure 5 and Table 2). As only the Unuk River, the Chilkat/Chilkoot Rivers and the Berners Bay rivers have information on eulachon, only they will be discussed in this section.

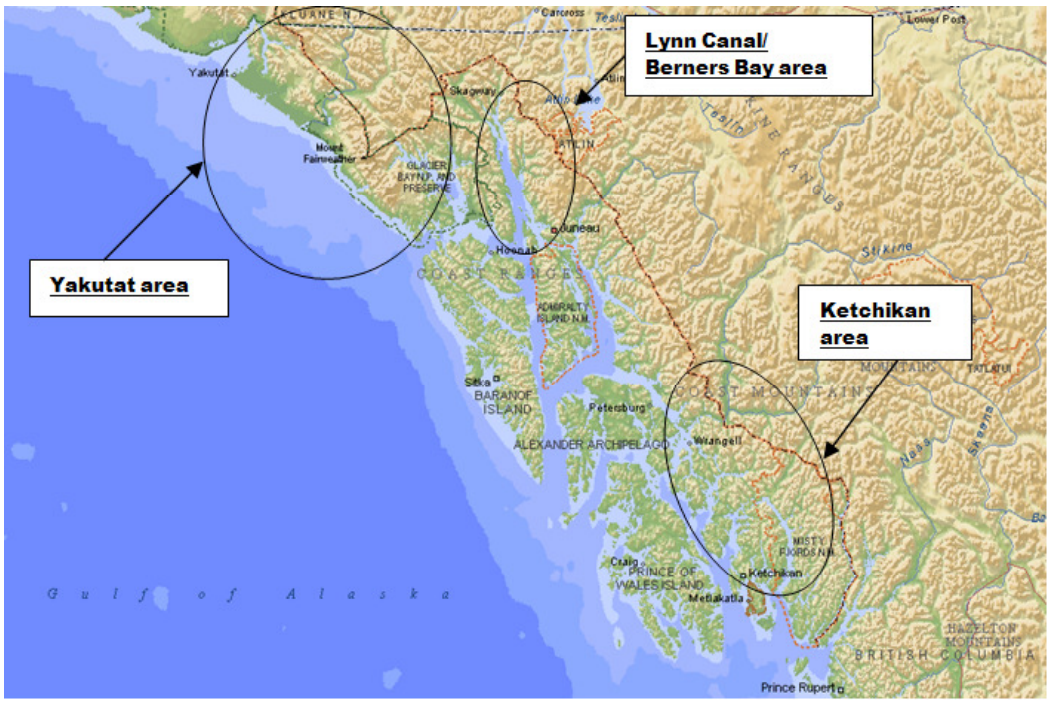

Figure 5. General locations of eulachon spawning rivers in Southeastern Alaska.

Table 2. Eulachon rivers located along the Southeastern Alaskan Coast.

Area	Eulachon spawning sites	Past/Present fisheries
Ketchikan	Wilson/Blossom, Chickamen, Klahini, Hooligan, Grant, Unuk, Bradfield and Stikine Rivers	Small tribal fishery Small recreational
Lynn Canal/ Berners Bay	Endicott, Chilkat/Chilkoot, Ferebee, Taiya, Skagway and Katzehin, Berners, Lace, Antler, Eagle, Mendenhall, Taku, Speel, Whiting and Excursion Rivers	Small tribal fishery Small recreational
Yakutat	Dixon, Fairweather, Sea Otter, Clear, Doame, Alsek, Akwe, Italio, Dangerous, Ahmklin, Situk, Lost	Unknown

Source: sites compiled by J.N. Womble and reported in Willson *et al.* (2006)

Ketchikan Area

The rivers located nearest to Ketichikan, northeast of the city, include the Wilson/Blossom, Chickamen, Klahini, Hooligan, Grant and Unuk Rivers (Figure 6). The runs in this area are considered small when compared to other runs, such as the Copper River of Prince William Sound (Bartlett and Dean, 1994). Fisheries for eulachon in this area include subsistence and personal use; however, from 1969 to 1999 eulachon were sold commercially (United States Forest Service, 2006). Since 2001, the Forest Service has conducted aerial surveys, and monitored yearly returns and catches by qualified subsistence and personal use fishers. The eulachon return to the Unuk River during the middle of March (Bartlett and Dean, 1994). The majority of subsistence and personal use catch has come from the Hooligan River, a tributary to the Unuk River. The Hooligan River is perceived by local residents to have the most consistent run from year to year when compared to other areas of the Unuk estuary (Tisler and Spangler, 2003). Prior to 2001, the Alaskan Department of Fish and Game monitored the Unuk run on a very limited basis (United States Forest Service, 2006).

In 2002 and 2003, eulachon were observed in the Hooligan River (United States Forest Service, 2006). Also, in 2003, they were observed in the Klahini River but not in the Chickamin (United States Forest Service, 2006). By 2004, the eulachon run was "well below average" and only small schools were observed in the Hooligan River, with a total catch of 0.73 t of fish (United States Forest Service, 2006). Twenty years ago, eulachon catches from the Unuk River ranged from 7 to 14 t per year (Morphet, 2005). The

2005 season saw no improvement and no catch, as the run was reportedly "very poor overall" and "absent on the Unuk River" (Morphet, 2005). The 2006 eulachon run was "nearly absent" as only 34 male eulachon and one dead female were seen in the area (United States Forest Service, 2007). It is unknown why the eulachon have not returned in good numbers to this area for the past three seasons.

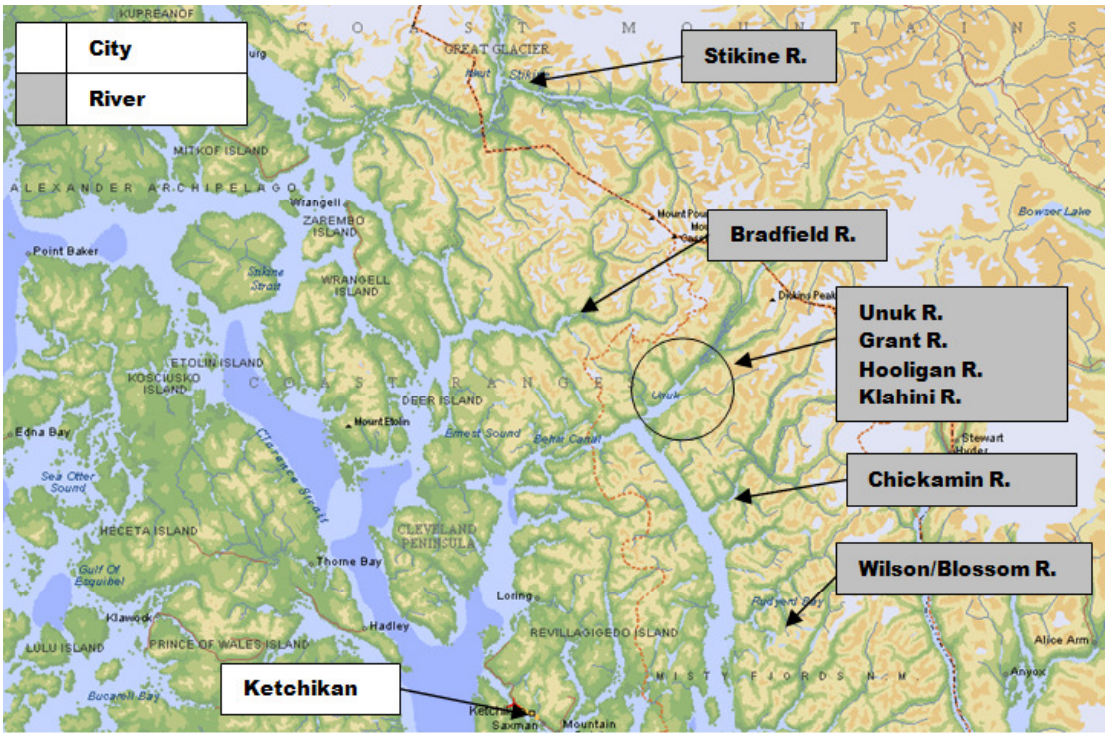

Figure 6. Locations of eulachon spawning rivers, with reference cities, in the Ketchikan Area.

Lynn Canal/Berners Bay

The Chilkat, Chilkoot, Taiya, and Ferebee Rivers are all eulachon rivers that flow into Lynn Canal (Figure 7). The Chilkat River supports one of the larger eulachon runs in Southeastern Alaska (Betts, 1994). The Chilkoot River flows parallel to the Chilkat River, but its run is restricted to the lower part of the river, as the river is short. Both of these rivers support catches by the Chilkat and Chilkoot Tlingit people and local sports fishers. The Taiya River eulachon run is reportedly small and is not fished (Betts, 1994). The eulachon arrive to these rivers between mid and late May and are caught for one to two weeks (Mills, 1982). The eulachon commonly arrive a few days earlier to the Chilkat River (Betts, 1994). The fish are caught with long-handled dip nets from shore and the catch is prepared fresh, fried, boiled, smoked, frozen and used to render oil (Betts, 1994). The Tlingits of Klukwan and Haines are one of only a few First Nations groups in Alaska which catch eulachon to render oil (Mills, 1982).

A 1990 study of the Chilkat and Chilkoot river eulachon fisheries was initiated in response to local concern over the perceived decline in eulachon and concerns over modifications to the Haines airport (Betts, 1994). Mills (1982) estimated the total catch for Klukwan and Haines at 6 t in 1983 and 5.4 t in 1987. Historic documents and respondents from this area indicate that catch levels were once much larger during the early part of the twentieth century. Two reasons given for the smaller catches are the use of small dip nets instead of large in-river nets and the overall low strength of the run (Betts, 1994). Early, but good, returns were seen in both rivers during 2001 (Chilkat Valley News, 2001) but less productive runs were reported between 2002 and 2004 (Bigsby, 2004). In 2005, the Chilkat River saw "appreciable numbers"; however, the adjacent Chilkoot River run failed to materialize (Morphet, 2005). Past disappearances have been reported for both rivers, as the fish were said to have "disappeared" from the Chilkat River for five years after highway construction during the 1940s (Betts, 1994) with a similar "dry spell" during the late 1980s (Morphet, 2005). The 2006 eulachon returns to the Chilkoot River were very

good, as the river was described as "choked" with eulachon and "surging in black swaths" (Morphet, 2006).

Berners Bay is located 65 km north of Juneau, Alaska (Figure 7). Berners Bay has three eulachon rivers that flow into it: the Berners, Lace and Antler Rivers. The eulachon usually begin to spawn in this area between late April and early May (Sigler *et al.*, 2004). As these rivers are located at the edge of Tlingit traditional territories, they are not caught by the Tlingits (Betts, 1994). However, the Berners Bay eulachon have been studied in recent years because of their importance to the diet of the Steller sea lion (*Eumetopias jubatus*). Eulachon were found to have the highest fat content (15.0 to 25.3%) of 26 species of forage fish and invertebrates in Prince William Sound (Iverson *et al.*, 2002). The Steller sea lion was listed in 1990 as a threatened species under the US Endangered Species Act (National Marine Fisheries Service, 1992) and one of the leading hypotheses suggested that the rapid decline of Steller sea lions in the Gulf of Alaska and the Aleutian Islands was due to nutritional stress (Trites and Donnelly, 2003).

Two factors supporting the nutritional stress hypothesis are a reduction in overall prey abundance or a change in the relative abundance of different types and quality of prey available (Trites and Donnelly, 2003). The recent studies in Berners Bay focus on the aggregation of Steller sea lions during eulachon runs (Marston *et al.*, 2002; Sigler *et al.*, 2004; Csepp and Vollenweider, 2006). One objective of these studies was to estimate the biomass of prespawning aggregations of eulachon using hydroacoustic surveys (Sigler *et al.*, 2004; Csepp and Vollenweider, 2006) and a system of dip-netting catch per unit effort (Marston *et al.* 2002). The mean index of eulachon abundance calculated in 1996 was found to be more than twice that calculated in 1997 (Marston *et al.*, 2002), and in 2002 eulachon abundance was higher than in 2003 (300 t vs. 113 t) (Sigler *et al.*, 2004). Although different abundance calculation methods were used, it appears that overall eulachon abundance declined during each of the projects. In addition, the eulachon returns during the 2006 season were reported as "very low" (Csepp and Vollenweider, 2006). Eulachon spawning rivers have also been reported in the Yakutat area (Figure 8); however, there is very little information on them, other than that eulachon are known to have spawned in them at one time in the past (Willson *et al.*, 2006).

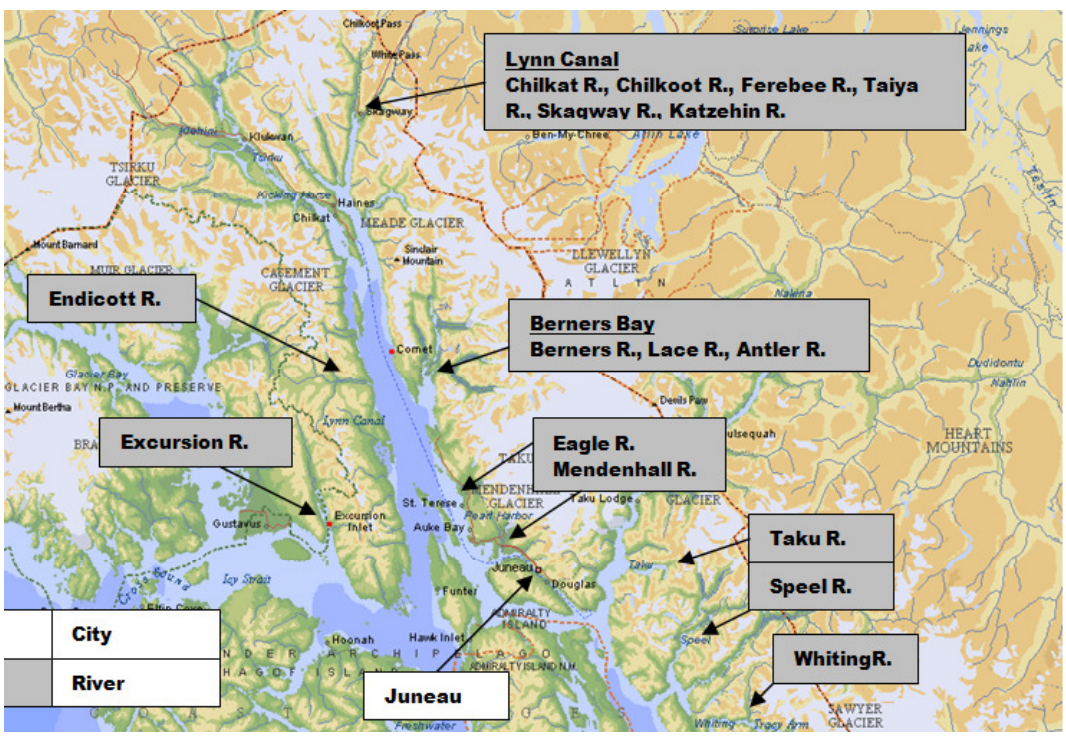

Figure 5. Locations of eulachon spawning rivers, with reference city, in the Lynn Canal/Berners Bay Area.

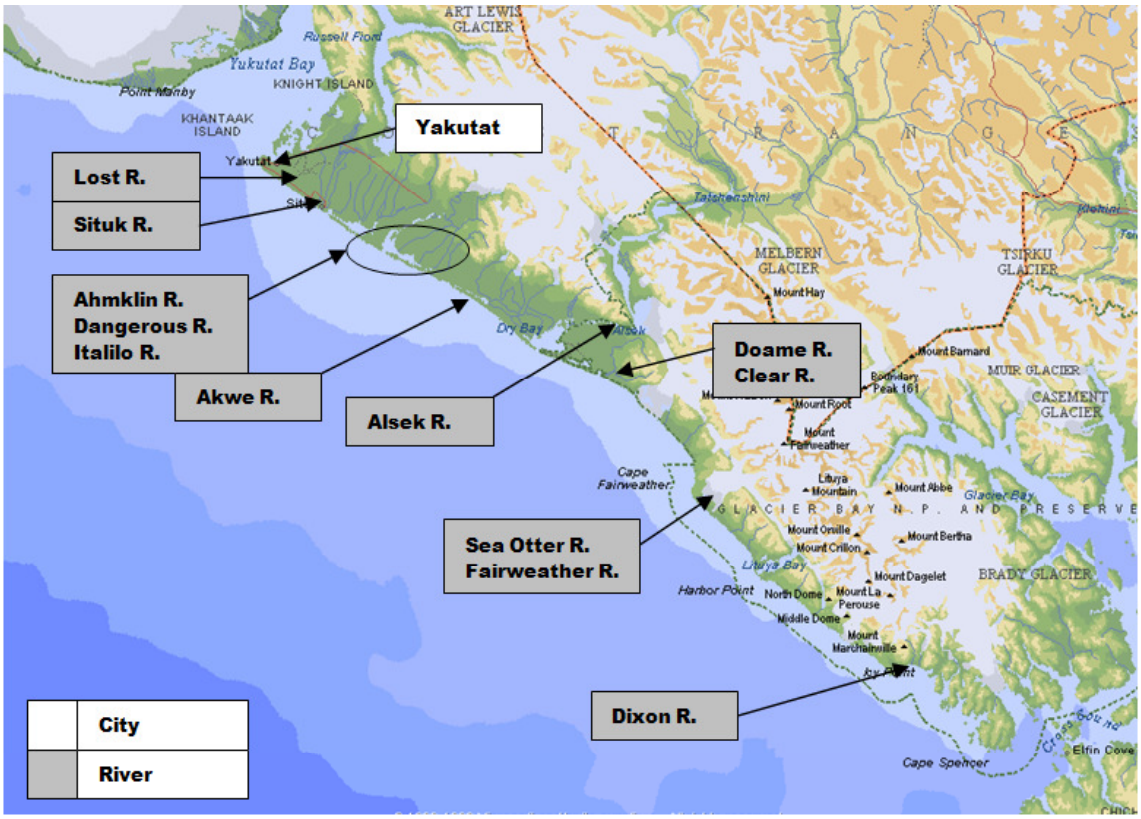

Figure 8. Location of eulachon spawning rivers, with reference city, in the Yakutat Area.

British Columbia (BC)

The BC coast has approximately 35 eulachon rivers (Hay and McCarter, 2000). However, of these, only the Nass and the Fraser River previously supported significant commercial catches. In the early twentieth century, small commercial catches were reported in the areas of Knight Inlet, the Skeena River District and the offshore areas between the mainland and southern Vancouver Island from 1917-1929 (Canada Bureau of Statistics, 1917-1976). The majority of BC eulachon fisheries today are conducted, in-river, for food consumption by First Nations people. These will be discussed separately throughout this section. Three separate sources have been used to estimate the total BC eulachon commercial catch (Figure 9):

- Canadian Bureau of Statistics: fisheries statistics of Canada 1917-1976;
- Fisheries and Oceans Canada, Pacific Region, BC commercial catch statistics (1951-1995);
- Eulachon catch statistics (1878-1941) from the Nass and Fraser River, figure 12 p. 14 (Clemens and Wilby, 1946).

These three data sources follow a similar trend in years when the data overlap. They also complement each other, as one data set ends and the next data set begins. Each data set fills in missing data giving a continuous BC commercial eulachon catch time series. The graph indicates that commercial catches were highest in the early 1900s and the late 1950s. The highest catches were taken from the Nass River (~400 t) in 1903; however, these catches became minimal after 1920, with the last year of commercial catch reported in 1935 (~12 t). Thus the majority of commercial catch taken after 1920 reflects primarily Fraser River catch.

BC North Coast

Nass River

Rivers: Nass and tributaries (Bear and Rainy) Fisheries: First Nation fishery, commercial fishery (1877-1935).

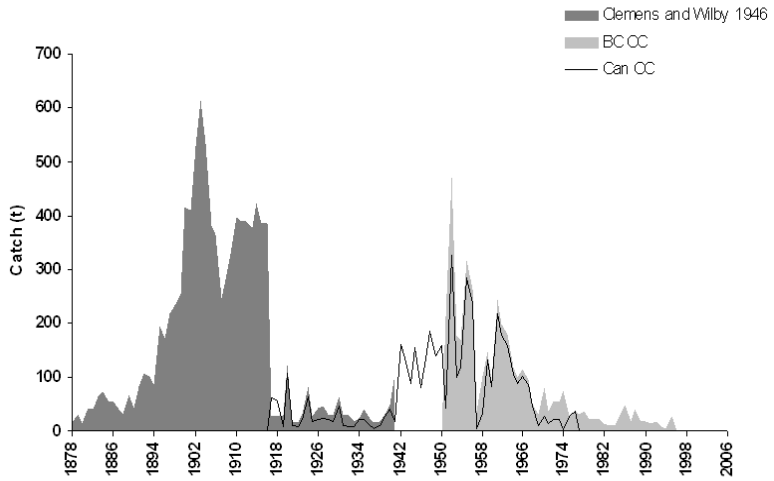

Figure 9. British Columbia commercial eulachon catch reported by three sources: (1) Canadian Bureau of Statistics (1917-1976) (2) BC commercial catch statistics (DFO 1951-1984; DFO 1985-1995) (3) Clemens and Wilby (1946).

The Nass River in Northern BC has? one of the largest eulachon runs in BC (Figure 10). It has been argued that the Nass River produces a superior quality of eulachon, richer than other rivers along the British Columbia Coast (Collison, 1916; Barbeau 1952). The river was termed Nass, meaning "food depot", by the Tlingit people of south-eastern Alaska because they, as well as other First Nations people from the Interior and from the Queen Charlotte Islands, traveled great distances to the area to trade with the Nisga'a, "people of the Nass" (Collison, 1916). It was observed in 1810 by the vessel, the Hamilton, that "300 canoes arrived at Nass Roads in one day in the middle of March and another 300 in one day at the beginning of April" (Gibson, 1992).

There are four main communities located today in the Nass Valley: Gitwinksihlkw (Canyon City), Lakalzap (Greenville), Gilakdamiks (New Aiyansh) and Gingolx (Kincolith) (Petch and Vallieres, 1979). Nass River eulachon usually arrive in early March and are fished mainly by the Nisga'a people. There are also Tsimshian people from Port Simpson, who are recognized as fellow tribesmen by the Nisga'a, and are permitted to fish for eulachon on the lower Nass (Collison, 1916).

The Tsimpsheans say that the Nass river clothes them and the Skeena river feeds them, because the Haida, from Haida Gwaii, and other tribes who are prohibited from fishing for the Oulachan in the Nass, come and purchase the oil from them, paying blankets for it, while the salmon of the Skeena supplies them with abundant supplies of food (Brown, 1868).

It should be noted that Nisga'a and Tsimshian people during the late 1800s were closely associated, and thus written records taken by white explorers and missionaries sometimes refer to both groups as the same people, "so closely are the deeds of the Thaimshim associated with the Indians of this river [Nass], that it is not unusual to hear these tribes referred to by the same name, or as the people of Thaimshim" (Collison, 1916). The "Thaimshim" was described by Collison (1916) as "the great wonder-worker of the past, whose deeds are linked with the traditions of both Tsimsheans and the Nishkas." The tribes from Alaska, as well as the Haida and Tsimshian, fought unsuccessfully to obtain control over the Nass eulachon fishery and had to settle for trading to obtain their eulachon and eulachon grease (Collison, 1916). Today, there is a small catch that is taken for fresh consumption by local, non-native residents.

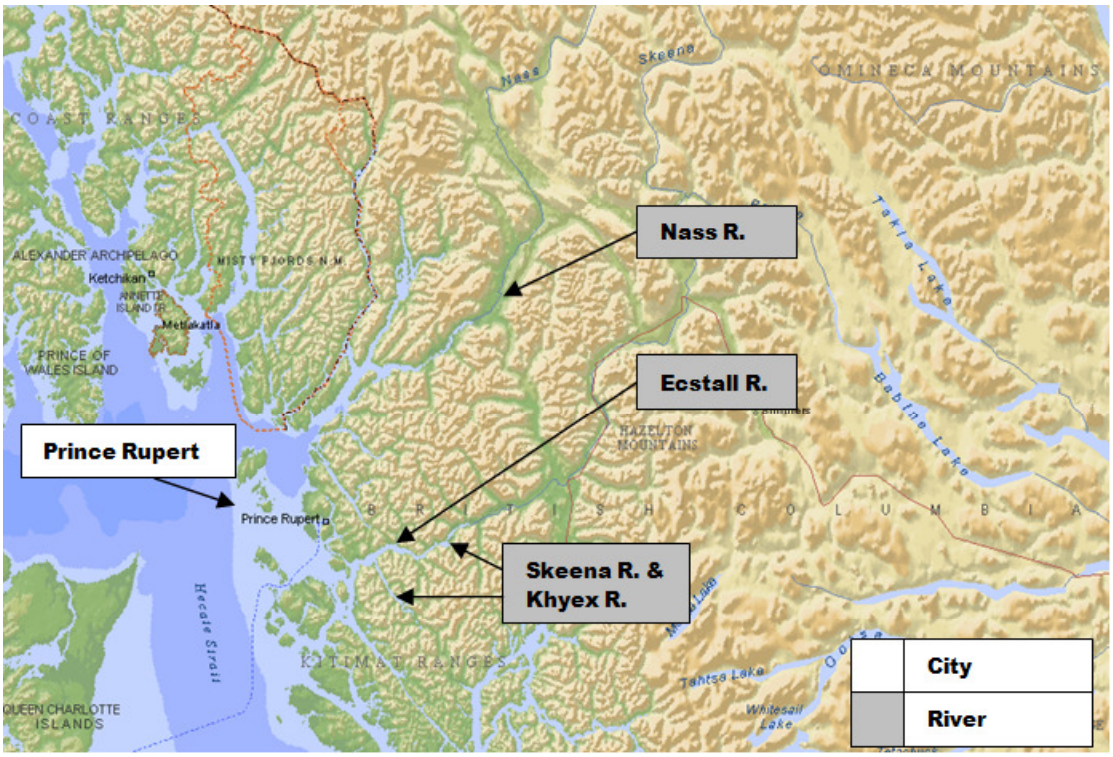

Figure 10. Locations of eulachon spawning rivers, with reference city, in the North Coast Area of British Columbia.

Historically, the Nisga'a held complete control over the area's eulachon run. "Oolichan oil assured the Nishga of wealth, power and a continuing source for barter. In the valley itself, each Nishga household consumed huge amounts of the oil each year" (Petch and Vallieres, 1979). In a summary of the Nass Fishery, published in 1916, it was reported that "each [Nass] household...[would] have from five to ten tonnes of fish, and more, from which to extract oil or grease" (Collison, 1916). In 1914 the Nisga'a people petitioned the government to grant them exclusive rights over the Nass eulachon fishery, but the petition was rejected by the Fisheries Inspector, J.T.C. Williams, because he held the opinion that other natives in the area, such as the Tsimshian, also had fishing rights and that there was no interest by "whites or Japanese" to enter into the eulachon fishery (Williams, 1914). However, he also commented in the same letter:

"In the event of [others] entering this industry I should recommend that the Department formulate regulations for the protection of these fisheries, with special reference to the hereditary rights of the Indians. In the mean time it would be advisable for whites and Japanese to continue purchasing the Oolichans they require from the Indians" (Williams, 1914).

Prior to this letter, a factory had been built on the Nass River to manufacture eulachon oil (Clemens and Wilby, 1946). The commercial sale of oil by those other than First Nations lasted for approximately ten years from 1877-1878 (Canada, 1877-1914). At first, eulachon oil was seen by non-First Nations as a potential money-making business for British Columbia. However, the demand was never achieved overseas as the product was mainly sold locally to First Nations. The oil was "eagerly purchased by the natives of the neighboring coast, at a rate of one dollar per gallon, so that none remained for export, so as to test the extraneous market" (Canada, 1878). Although the oil market did not succeed, eulachon were commercially caught until around 1935, with the highest catches coming during the 1910s (Figure 11). These catches were sold fresh, smoked and salted. During the late 1940s a small commercial fishery existed, and was run solely by First Nations, who sold their fresh catch directly to commercial buyers. However, by the 1950s the Nisga'a declared that eulachon were no longer to be sold commercially. The 1949 Native Brotherhood of BC Convention held at Bella Coola and the 1955 Nisga'a Tribal Council Convention at Greenville, introduced and adopted the following resolution "no Nass River caught Oolicans be sold commercially to any fresh fish processors, cold storage, cannery, or reduction plants, retail market shops, or to any other commercial enterprise outlets." This did exclude the sale of eulachon by resident

First Nations to other First Nations in the Prince Rupert area for the purpose of home consumption (Province of British Columbia Legislative Assembly, 1968). However, during the late 1960s and 1970s there was debate regarding the commercial sale of eulachon to other First Nations. A local First Nation fisher was fined in 1967 for the private sale of eulachon to members of the Port Simpson First Nation (Province of British Columbia Legislative Assembly, 1968). In 1983 the British Columbia Fishery regulation stated "no person shall buy, sell, attempt to sell, barter or have in possession for commercial purposes any eulachons caught in District No.2" (Gordon, 1983). Today, trade of fresh eulachon and eulachon grease still exists between First Nations throughout this area. In the past few years, trade has even occurred between the Nisga'a and other BC First Nations who previously had eulachon runs (e.g. the Nuxalk Nation of Bella Coola).

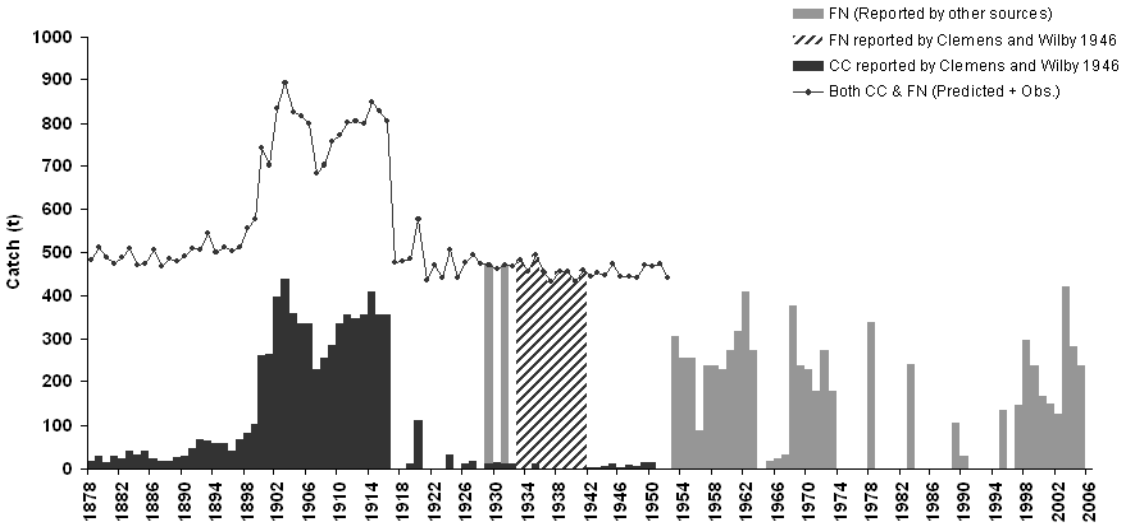

Figure 11. Eulachon catch from the Nass River. First Nation (FN) catch (diagonal stripes) and commercial catch (dark bars), Clemens and Wilby 1946. FN catch reported in 'other' sources (light grey bars) see Appendix 1. Estimated catch = FN estimated + commercial catch, Clemens and Wilby (1946; line).

The eulachon run on the Nass arrives around the middle of March; however, Nisga'a fishers believe there are at least two spawning runs, with the second arriving at the beginning of April (Langer *et al.*, 1977). River conditions vary from year to year during the eulachon season, and fluctuate between complete ice blockage and completely free of ice. Fishing successfully in this area depends a lot on the weather and ice conditions. In the past, eulachon were commonly caught through the solid ice with large conical nets. If the ice was too thin and broke up during the main run, fishing had to wait until the ice cleared out and be conducted from boats (McNeary, 1974). However, ice cover has not occurred on the Nass River since 1988 (Pickard and Marmorek, 2007). Today, eulachon are still caught using large conical nets which are checked using motorized punts (author's personal observation).

Over the past few centuries, the Nass River has supported large catches of eulachon, both by First Nations and by a commercial fishery. In the early 1840s it was reported that "the Tsimshians brought more that 30,000 gallons of oolachan oil to Fort Simpson annually" (Gibson, 1992). If this amount is converted to tonnes of fresh eulachon, using the parameter of 14.1 gallons/t of fresh eulachon, this would equal approximately 2,100 t. This is probably an accurate estimate for this time period, as other estimates indicate that the "Indian fishermen land[ed] thousands of tons" of eulachon a year (Collison, 1916). Although it is difficult to obtain an accurate estimate of the quantity of eulachon taken from the Nass River during the late 1880s and into the early twentieth century, the author has attempted to estimate an approximate catch time series using Nass River catch data from Clemen's and Wilby (1946) commercial catch data from 1878-1941 (Figure 11). These catches are highly erratic and it was suggested that part of the irregularity results from changes in methods of recording statistics, as it was common practice in the early part of the time series to include catch taken by First Nations and local residents (Clemens and Wilby, 1946).

These catches appear to be very low, as others during this time have reported First Nations catches of thousands of tonnes of eulachon annually (Gibson, 1992; Collison, 1916). Thus, presuming that these

statistics consist only of commercial catches and do not include First Nation catches, a considerable portion of the total catch would be missing. For example, Clemens and Wilby (1946) report a total 1929 catch of 13.1 t. However, a separate fisheries report recorded 9,000 cwt or 457 t of eulachon; it stated that this catch was not included in the regular reporting schedules because the fish were "caught by Indians for their own consumption" (Department of Marine and Fisheries and the Dominion Bureau of Statistics, 1929). Thus the catch reported by Clemens and Wilby (1946) must only have been commercial catch. First Nations catches were reported on the same graph by Clemens and Wilby (1946) in a separate, short, time series, from 1933 and 1941. This catch range (433-482 t) was used to randomly generate an approximate estimate of First Nations catches from 1878-1952 where only commercial catches were reported. These randomly-generated values were then added to the total catch reported by Clemens and Wilby (1946) to give an approximate estimate of total catch from the Nass River during this time (Figure 11).

By the 1940s catches had decreased substantially, as the First Nations of this area and in other areas of BC continued to adopt the "white man's food and manner of life", and eulachon were not caught on the same "gigantic" scale as in the past (Collison, 1941). Although the catch in recent decades may be smaller than in the past, the eulachon remain an integral part of the Nisga'a and Tsimshian culture and diet.

The abundance of the Nass River eulachon run has reportedly varied in the past: "The quantity of the run of fish has varied; there have been peak years when the abundance of the oolachan baffled description, and years when it has not been so plentiful; but it has never, to my knowledge, completely failed" (Collison, 1941).

The Nisga'a people first expressed major concerns for the Nass run in 1968, after they suspected that log driving practices were having negative effects on the run. Log driving began on the Nass River in 1962 and continued until 1976. These operations released logs into the river, separately and in bundles, to transport the logs to the tide water at Nass Harbour. Unfortunately, log recovery rates were less than 10% of initial releases and massive log jams were formed throughout the area (Orr, 1984). In response to these concerns, the Fisheries and Marine Service of Canada carried out a study on the Nass River eulachon from 1969 to 1971 (Langer *et al.*, 1977) and by 1978 no uncontrolled release of logs was permitted (Orr, 1984). As a result of the study, logs had to be towed, under control, to Nass Harbour and timing restrictions were applied to delay the start-up of towing until after the eulachon had spawned and their larvae were gone. The Nass River is one of the few rivers in BC that has not seen any major reductions in eulachon abundance over the past ten years. However, a decline may be more difficult to identify in this system, as the river and the run are large in comparison to other BC eulachon rivers, and fishing effort is not as high as in the past. Only one annual biomass estimate has been made for this system, based on data collected during the 1983 season, and was estimated at 1780 t (Orr, 1984; McCarter and Hay, 1999). Since 1997, the Nisga'a Fisheries has monitored the annual catch on the Nass River and recorded annual catches and hours of effort (Figure 12). The Nass River eulachon run appears to have adequately supplied First Nations with catches ranging between 146 and 420 t from 1997 and 2005 (Figure 12). In 2006 a fairly strong return was reported but no major fishery occurred as extensive ice cover limited the fishery (EcoMetrix, 2006).

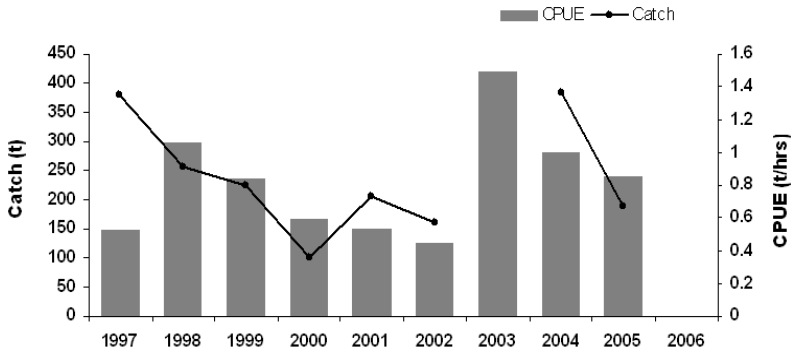

Figure 12. Eulachon catch and CPUE for the Nass River.
Source: Nisga'a Fisheries and Wildlife Department (2007).

Skeena Area

Rivers: Skeena River and its tributaries Ecstall and Khyex Rivers
Fisheries: Small First Nation fishery, small commercial fishery (1924-46)

The mainstem of the Skeena and its tributaries, the Ecstall and Khyex Rivers, support the only eulachon runs in this area (Figure 13). From 1924-1946, the Canadian Bureau of Statistics recorded commercial eulachon catches from the Skeena Area. These catches ranged from 17.3 t in 1924 to 1.0 tonne in 1935 (Canada, 1917-1976). All other eulachon fisheries in this area were traditionally conducted by members of the Tsimshian First Nation, whose members include the Metlakatla, Lax Kw'Alaams, Kitsumkalum and Kitselas Bands (Ryan, 2002). The Ecstall River was the only river fished by the Tsimshian, for the production of eulachon grease. The Ecstall eulachon were said to be of a different or "better" quality than the Skeena eulachon; as these eulachon were considered dry and bitter (Don Roberts, Kitsumkalum member, pers. comm., 2006). Experienced fishers from the area report that the run was historically small and short-lived. Thus the Tsimshian members usually obtained most of their eulachon catch from the Nass River (Roberts, 1997). In the 1950 DFO Fisheries Officer annual narrative report for the Prince Rupert waterfront, the eulachon of the Skeena and Ecstall rivers were reportedly "not fished commercially or for food purposes" (DFO, 1941-73).

A study on eulachon life history, habitat use and spawner abundance was conducted on the Skeena River during the 1997 season and abundance was estimatedat 3.0 t (Lewis, 1997). Don Roberts, a Kitsumkalum member, was hired by the Tsimshian Tribal Council in 2000 to monitor the status of the Skeena eulachon. Roberts and his crew conducted plankton tows for the capture of eggs and larvae and set gillnets to capture adults. The run to the Skeena historically returned during the first week of March; however, in the past decade, it has occasionally returned earlier, during mid to late February (Don Roberts, pers. comm., 2006). By the mid 1990s the run to the Skeena area noticeably declined, with very few eulachon observed or caught between 1997 and 1999 (Don Roberts, pers. comm., 2006). In 2005, Roberts reported a good run in the area, but only in comparison to the previous ten year average. However, in 2006 there was virtually no run to the Skeena River (Don Roberts, pers. comm., 2007; EcoMetrix, 2006).

BC Central Coast

Douglas Channel
Rivers: Kitimat and Kildala Rivers
Fisheries: First Nation fishery

The Kitimat and Kildala Rivers are located in Douglas Channel (Figure 13). Both rivers were historically fished for eulachon by members of the Haisla First Nation. However, in 1972, eulachon fishing was curtailed on the Kitimat River as pollution by industrial and municipal effluent discharges made the eulachon foul-tasting and inedible (Tirrul-Jones, 1985). Prior to 1972, eulachon were caught for smoking and drying, and for producing eulachon grease. Annual catches from the Kitimat River, reported by DFO Fisheries Officers, from 1969-1971, ranged between 27.2 and 81.6 t (Figure 14) with additional catches taken from the Kildala and the Kemano Rivers. The eulachon run to the Kitimat River usually peaks during mid to late March but they have also been captured in late April and May (Kelson 1996). Eulachon grease had previously been produced in vast quantities in the 'Old Village' of Kitamaat (IR 1). According to a report by Tirrul-Jones (1985) the consultants estimated that at one time "at least 40 nets set…at one time and [if] worked seven days. Each net would catch a minimum of 1.8 t with 40 nets working 508 t of eulachon were caught in a week's time." Therefore, there was a significant amount of eulachon historically caught from the Kitimat River.

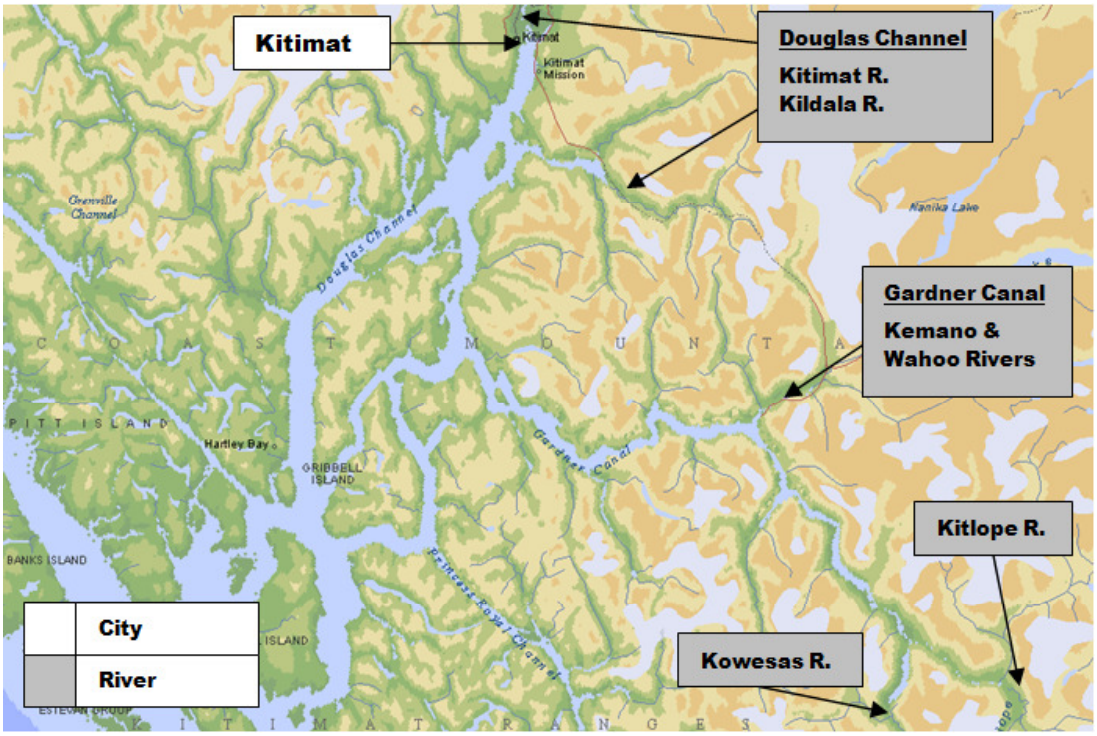

Figure 13. Locations of eulachon spawning rivers, with reference city, in Douglas Channel and Gardner Canal Areas.

A study on eulachon distribution on the Kitimat River and a preliminary stock assessment were conducted by DFO during the 1993 season (Pederson *et al.*, 1995). The total estimated spawning biomass was calculated at 22.6 t or about 514,000 individuals (Pederson *et al.*, 1995), significantly less than past catches. The last strong run returned to the Kitimat River in 1991 and runs from 1992-1996 were estimated at half the size of 1991 (Farara, 2000). During the years 1994, 1995 and annually since 1998, Eurocan Pulp and Paper Company collected eulachon abundance and CPUE data from the Kitimat River (Figure 15); from 1994 to 1996 the estimated abundance ranged from 527,000 to 440,000 individual spawners and since 1998 even less, between 13,600 and <1000 (EcoMetrix, 2006). CPUE was estimated between 50 and 60 fish per 24-hr gill net (7.6 m x 1.8 m, 3.8 cm mesh) set from 1994-1996 but since 1998 the CPUE has been less than 2 fish per 24-hr gill net set (EcoMetrix, 2006). It should be cautioned that the CPUE estimates represent the sampling effort designed for the collection of a small sample of fish to be used for taint evaluations and not the fishing effort of the Haisla eulachon fishery. However, even if fish were still caught for consumption, the returns would be too small to support a traditional fishery. The 2006 run was the lowest recorded and virtually non-existent, with <1000 spawners estimated (EcoMetrix, 2006). The abundance estimates were calculated using gill netting catches and split beam hydro acoustics (2001-2002 only); thus it is cautioned that these sampling methods are uncommon and do not represent the true abundance; however, they do illustrate the relative abundance trend for this system. Since 1972, the

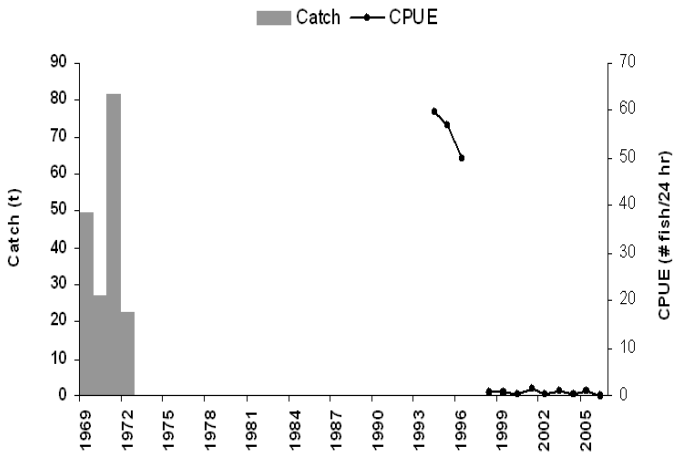

Figure 14. First Nation eulachon catch and CPUE from the Kitimat River.

Haisla people have traveled to the Kemano River or the Kildala River to fish for eulachon; however, in recent years these rivers too have suffered major declines.

Gardner Canal
Rivers: Kemano, Wahoo (Kemano tributary), Kowesas and Kitlope Rivers
Fisheries: First Nation fishery

The Kemano, Kowesas and Kitlope Rivers are located in Gardner Canal (Figure 13). The Haisla Fisheries Commission has monitored the Kowesas and Kitlope Rivers intermittently over the past two decades and the Kemano River has been monitored annually and studied extensively since 1988 (Lewis *et al.*, 2002; Lewis and Ganshorn, 2004). In 1996, DFO issued three commercial eulachon licenses for Gardner Canal. However, once the Kitamat Village Council was informed, the fishery was curtailed and a committee was formed to develop an "Oolichan Management Plan" (Haisla Fisheries, 2007). This section will focus on the Kemano Rivers as the source of the bulk of the recent Hasila eulachon catch.

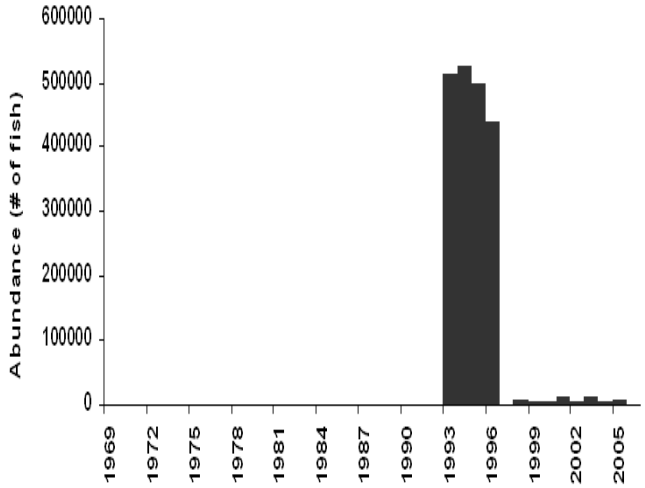

Figure 15. Estimated eulachon abundance in the Kitimat River. Source: EcoMetrix (2006).

Kemano River eulachon return to spawn in late March to early April (Lewis *et al.*, 2002). The Kemano/Wahoo confluence is made up of the Aluminum Company of Canada (Alcan) Kemano powerhouse discharge and the flow from the Kemano River and its tributaries. The Kemano eulachon monitoring program was started by Alcan in 1988 and continued until 2004 on the Kemano/Wahoo Rivers (Lewis and Ganshorn, 2004). Alcan's interest in the eulachon stems from their operation of the Kemano plant, a hydroelectric generating system, in the Kemano watershed (Lewis *et al.*, 2002). As part of an environmental management plan, Alcan has monitored the abundance of eulachon and worked cooperatively with the Haisla First Nation to monitor the eulachon fishery (Lewis and Ganshorn, 2004). The power plant is part of the Kitimat-Kemano project initiated by the BC government during the 1940s. The power plant began operations in 1954, and diverts an average of 133 m^3/s of continuous water, or 57% of the flow on a mean annual basis, from the Nechako Reservoir into the Kemano River (Lewis *et al.*, 2002).

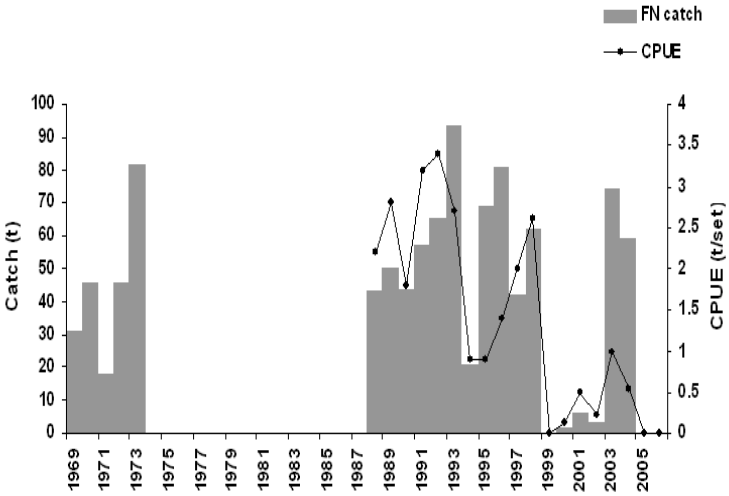

Figure 16. Eulachon catch and CPUE from the Kemano River. Source: DFO (1969-1973); Lewis *et al.* (2002); Lewis and Ganshorn (2004).

This river system is fished by the Haisla people and their guests, comprising several bands of First Nations located throughout the Kemano and Kitimat valleys. Fishing for eulachon is conducted using mainly seine nets and dip nets, however, occasionally the traditional Takalth net (conical net) is used as an indicator of abundance. DFO annual narrative reports indicate that Kemano River eulachon catches from 1969 to 1973 averaged 44.3 t annually (range between 18.1 t to 81.7 t; DFO, 1967-1973). More recent reports from Alcan indicate an average annual catch of 57 t from 1988 to 2002 (range 32.5 and 146.5 t; Lewis and Ganshorn, 2004; Figure 16). The recent eulachon catches

are based on verbally (hailed) numbers reported daily by eulachon fishers.

The Kemano eulachon studies contain rare data on catch per unit effort (CPUE), reported in tonnes of eulachon caught per set (Figure 16). The CPUE was found to be useful as an indicator of abundance as it was positively correlated with other measured indicators of abundance on the Kemano River, such as, annual egg drift (r = 0.77) and the sum of egg mass volume (r = 0.9) (Lewis *et al.* 2002). Kemano River eulachon appear to have declined between 1988 and 1998, with no returns in 1999 (Lewis *et al.*, 2002). The run remained depressed with low catches and low CPUE between 2000 and 2002; however, by 2003 there was a marked improvement in both values (Lewis *et al.*, 2002). This trend did not last, as catch and CPUE declined again in 2004, and no catches were taken in 2005 and 2006, as the run failed to return (EcoMetrix, 2006). Eulachon were seen in the Kemano estuary in 2007. However, they did not ascend the river (comment made by Ken Hall, member of the Haisla Nation during the Eulachon Crisis Meeting held in Bella Coola, BC June 10-11 2007). It should be noted that the Kemano eulachon reports contain extensive data on river hydrology, adult life history, biology, run timing, distribution, habitat use, larval size, migration timing, density and egg-larvae survival.

Bella Coola Area
Rivers: Bella Coola, Paisla Creek, Necleetsconay, Dean, Kimsquit, Aseek, Taleomy, Noeick, Kwatna, Quatleena
Fisheries: First Nation fishery

Ten rivers in the Bella Coola area were known to have eulachon spawning populations (Figure 17). The Dean and the Kimsquit Rivers are located in the upper Dean Channel, the Taleomy, Noeick and Aseek Rivers in South Bentinck Arm, the Kwatna and Quatlena Rivers in Kwatna Inlet, and the Bella Coola River, the Neceleetsconay River, and Paisla Creek, in North Bentinck Arm. Historically, the four largest runs were the Bella Coola, Kimsquit, Taleomy and Kwatna Rivers. These were also locations of old Nuxalk village sites. Prior to the infectious disease epidemics of the late 1800s, these villages were inhabited and the rivers fished annually for eulachon. However, when these Nuxalk populations were decimated, they were all relocated to the Bella Coola area, and the Bella Coola River was the only river regularly fished for eulachon. Thus the majority of information for this area comes from this river. The next section provides a detailed description of the Nuxalk eulachon fishery and the Bella Coola River eulachon population.

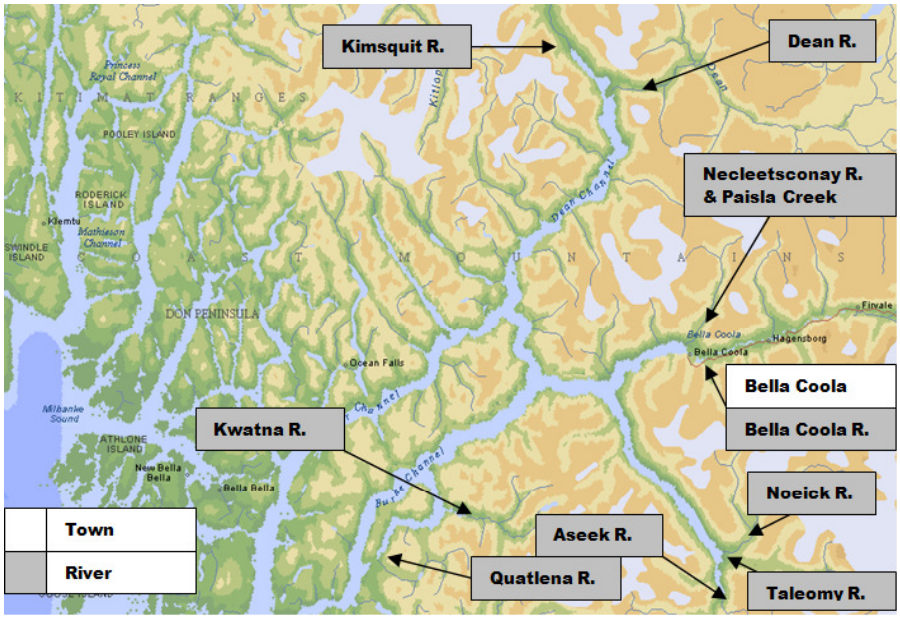

Figure 17. Locations of eulachon spawning rivers in the Bella Coola Area and the town of Bella Coola.

Rivers Inlet Area
Rivers: Wannock, Chuckwalla, Kilbella and Clyak Rivers
Fisheries: First Nation fishery

The Rivers Inlet area has four known eulachon rivers: the Wannock, Chuckwalla and Kilbella Rivers of Rivers Inlet, and the Clyak River at the head of Moses Inlet, located just north of Rivers Inlet (Figure 18). Previously, a large run returned to the Clyak River but has not been observed since the 1940s (Winbourne, 2002). The eulachon of this area were fished by the Wuikinuxv Nation (previously spelt 'Oweekeno'). However, in the Canada Sessional Papers there are records of smoked eulachon and barrels of salted eulachon taken from the Rivers Inlet area and transported to the Skeena District between 1888 and 1892 (Canada, 1878-1914). The amounts ranged between 75 and 125 barrels of salted eulachon and between 200 and 2000 lbs (0.09 t and 0.9 t) of smoked eulachon.

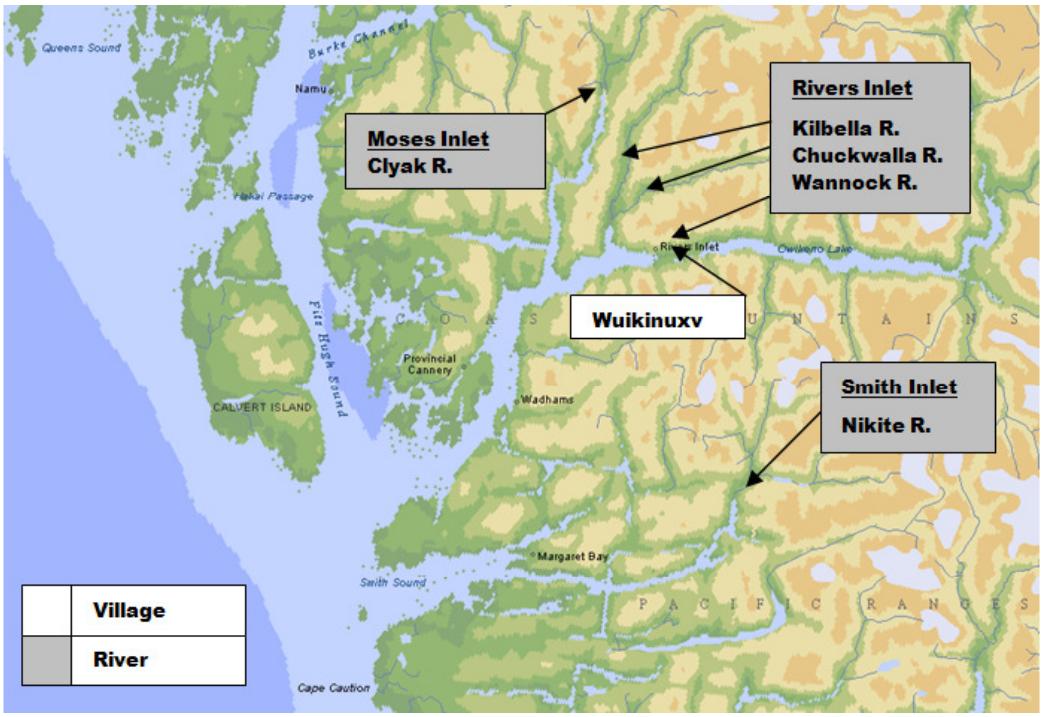

Figure 18. Locations of eulachon spawning rivers and Wuikinuxv village in Rivers Inlet Area.

The Wuikinuxv village is located on the Wannock River, between Oweekeno Lake and the head of Rivers Inlet (Figure 18). Due to accessibility, the Wannock River was the most regularly fished of the four rivers. The lower reaches of the Chuckwalla and the Kilbella Rivers were usually only fished when the Wannock run was small. Catches by the Wuikinuxv people are small compared to other areas on the Pacific Coast. However, this may be indicative of a small village population and not necessarily a small eulachon run. Today the on-reserve population is approximately 83 residents (Department of Indian Affairs and Northern Development Canada, 2007) whereas, the population in 1968, as recorded by DFO Fisheries Officers, was only slightly larger, at 150 (DFO, 1967-68 & 1971). The only catch figures reported for these rivers were found in Fisheries Officer's annual narrative reports for 1967, 1968 and 1971, with catches of 1.81, 2.27 and 4.54 t, respectively, on the Wannock (DFO, 1967-68 & 1971). The runs during the early 1960s were also described by the Fisheries Officers as being "sufficient" and "adequate" to meet the needs of the Wuikinuxv people.

Community members interviewed in the 2002 Central Coast eulachon project reported that the run to the Wannock River had been gradually declining since the 1970s (Winbourne, 2002). The last fishable run occurred in 1986 (Burrows, 2006); however, the run has been "poor" since 1994 (Frank Johnson, pers. comm., 2007). In 1997, a study was conducted on the Wannock River, in an attempt to measure the

spawning biomass. However, virtually no eulachon eggs or larvae were found in any of the 376 samples taken from the river (Berry and Jacob, 1998). In spite of this, the Wuikinuxv community members caught approximately 150 kilograms of eulachon from the Kilbella and Chuckwalla Rivers in 1997 (Berry and Jacob, 1998). Also in 1997, eulachon larval surveys were conducted in Central Coast mainland inlets, Rivers and Smith Inlets being two of those sampled. The combined spawning biomass of these two areas was estimated at 6.46 t (McCarter and Hay, 1999). Smiths Inlet has never been previously reported as possessing an eulachon run. Nevertheless, this study suggests that because larvae were captured in the tows, there may be a small eulachon run in the area. The Nekite River, located at the head of Smith Inlet, is most likely the eulachon bearing river in which these larvae originated, as one eulachon larvae was found amongst in-river plankton tows during the 2002 Bella Coola eulachon study (Winbourne and Dow, 2002).

Since 1997, no eulachon have been caught in the Rivers Inlet area. To determine the current abundance in 2005 and 2006, the Wuikinuxv Fisheries Department conducted spawner abundance surveys on the Wannock River. Only eleven adults were captured in 2005, with an estimated 2,700 adults returning to spawn (Burrows, 2005). In addition, three adults were captured in the Kilbella River (Burrows, 2005). In 2006, the study was repeated, with no adults captured, although nets were removed early because of requests made by elders, and an estimate of 23,000 adult spawners was calculated (Burrows, 2006). The suggested reasons for the decline of the eulachon in this area, given by 2002 Wuikinuxv interview participants, strongly indicate the commercial shrimp trawl industry, logging operations and changes in the environment (Winbourne, 2002).

Johnstone Strait Region
Rivers: Kingcome, Klinaklini, Franklin, Stafford, Apple and Homathko Rivers
Fisheries: First Nation fisheries

This area, referred to by McCarter and Hay (1999) as the Johnstone Strait Region, has six known eulachon rivers: the Kingcome River of Kingcome Inlet, the Klinaklini and Franklin Rivers of Knight Inlet, the Stafford and Apple Rivers of Loughborough Inlet and the Homathko River of Bute Inlet (Figure 19). In 1997, larval surveys were conducted in this region, and larvae were found at the head of Thompson Sound, suggesting eulachon spawning in the nearby, Kakweiken River (McCarter and Hay, 1999), thus identifying this river as another potential eulachon spawning river in the region. The eulachon migration to these areas occurs during April, with the peak of abundance returning by the middle of the month (Common Resources Consulting Ltd., 1998).

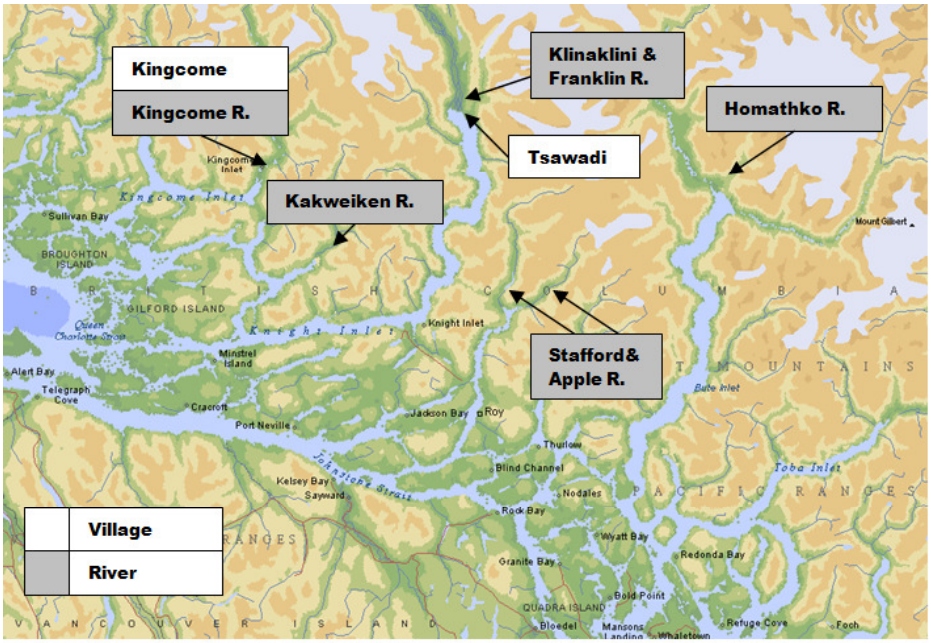

Figure 19. Locations of eulachon rivers with reference villages, in the Johnstone Strait Region.

The First Nation people who fish for eulachon in this area have been referred to in the past as, 'Kwakiutl', by photographer and ethnologist Edward S. Curtis (1915) and German ethnographer Franz Boas (1909), but were also known as members of the Kwawkewlth Agency (Raibmon, 2000). Today they are known collectively as the Kwakwaka'wakw. I was informed by Fred Glendale, a member of the Da'naxda'xw/Awaetlala, and son of the hereditary chief of Knight Inlet, William Glendale, that the head of Knight Inlet or Tsawadi village is the traditional territory of the Da'naxda'xw/Awaetlala, one of the member groups within the Kwakwaka'wakw (Fred Glendale, pers comm., 2007). Some of the other First Nations in the surrounding villages are invited to fish for eulachon by the Da'naxda'xw/Awaetlala. According to Curtis (1915), these First Nations included the Qagyuhl[3] (Kwaguilth) of Fort Rupert, Mamalelekala (Mamalilikulla) of Village Island, and Tlauitsis (Tlowitsis) and Matilpe (Matilpi) of Turnour Island. It has been reported that in the late 19th century, as many as 2,000 people annually visited the Tsawadi village. However, by the late 1960s, only a few family groups returned regularly to manufacture oil (McNair, 1971).

Kingcome Inlet is the traditional territory of the Tsawataineuk First Nation who also historically allowed other First Nations from surrounding villages to fish for eulachon in the Kingcome River. According to Curtis (1915), these included Koeksotenok (Kwicksutaineuk) of Gilford Island, Guauaenok (Gwawaenuk) of Drury Inlet, Hahuamis (Hakwamish) of Wakeman Sound and the Komkytis of Thompson Sound. Today, there is a permanent village in Kingcome Inlet, with a population of approximately 100 people (Midori Nicolsen, pers. comm., 2006/7), although both areas are only accessible by boat. The Stafford, Apple and Homathoko rivers were not known to have been fished commercially or by First Nations.

The First Nations people in this area held strong beliefs regarding the protection of the eulachon. In 1883, Captain Edward Brotchie traveled to Knights Inlet to engage in the eulachon fishery. However, the Kwawkewlth people "refused to sell, give, or allow him to catch any" or to even take any of the plentiful black cod (*Anoplopoma fimbria*), for fear that the eulachon would be "ashamed and never come back" (Swan, 1881).

"Knight's Inlet (Twawattee)…is the great place of resort for all Kwaw-kewlth tribes. The delicious oulachan, so highly prized by the natives as an element of food, visit this place in unlimited numbers, and every year, without fail afford these Indians a carnival of delight" (Canada, 1882).

Since the rivers of Knight and Kingcome inlets were the only rivers fished regularly in this area, only they will be discussed in this section. The Klinaklini eulachon run was generally larger than that of the Kingcome River. This trend can generally be seen in the annual catches recorded by DFO from each river, between 1943 and 1977 (Figure 20). The eulachon catch in Knight Inlet was estimated to be between 18 and 90 t annually during this period. In the late 1800s, the Kwakwaka'wakw were recorded as having caught "immense quantities" for food, oil and as articles of trade (Swan, 1885). Kingcome Inlet catches have occasionally been included with Knight Inlet; however, when reported separately, they were estimated at around 9 t annually (1960 and 1966; Common Resources Consulting Ltd., 1998). In the early 1900s, the annual combined grease production of Knight and Kingcome Inlets was approximately fifteen hundred gallons (Curtis, 1915). When this amount of grease is converted to tonnes of fresh eulachon, using the parameter of 14.08 gallons/tonne of fresh eulachon, the catch equals approximately 100 t of fresh eulachon. This estimation is comparable to years of high catches (91 t) recorded by DFO (Figure 20). In the past there have been a few years of commercial eulachon catches taken from this area (Figure 20). These commercial catches in the 1940s were caught and used for food supplies in the fur farm industry (Common Resources Consulting Ltd., 1998). This led to several separate demands by the First Nations in this area to reserve the eulachon fishery for their exclusive "use and benefit" and to stop commercial fishing in the area (Common Resources Consulting Ltd., 1998). Thus commercial eulachon fishing in the area was banned by DFO in 1947 to preserve "an ancient and traditional food supply for the Indians" (Common Resources Consulting Ltd., 1998). The only other eulachon fishery in this area was conducted by white fishers from Sointula (Figure 20) who supplied small quantities of fresh eulachon for consumption by the local people in the Alert Bay area, (Common Resources Consulting Ltd., 1998).

[3] The spellings are those used by Curtis (1915) and the names in brackets are the spellings used today

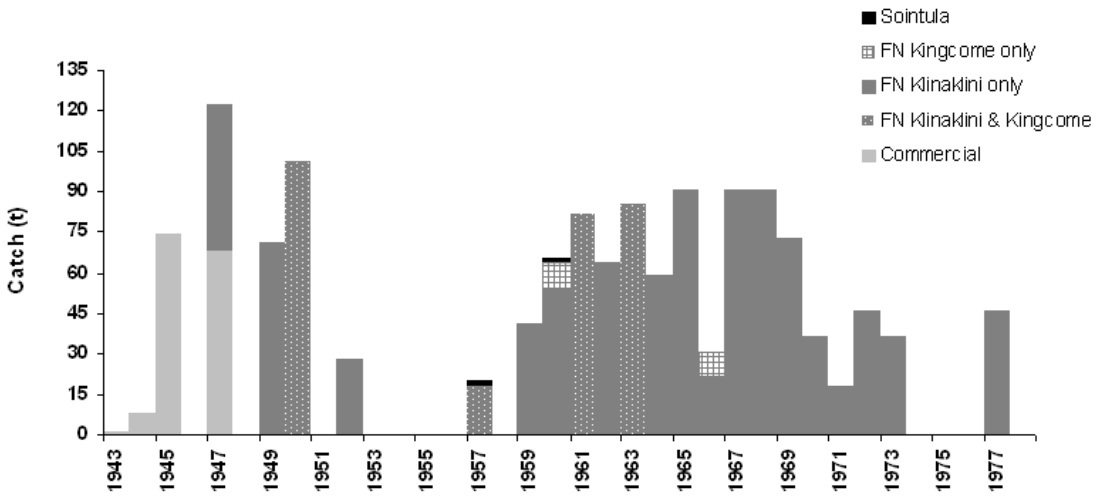

Figure 20. FN and commercial eulachon catches recorded in Knight and Kingcome Inlets. Commercial catch (light grey), Klinaklini First Nation (FN) catch (dark grey), Kingcome FN catch (grey checkered), Klinaklini and Kingcome FN catch (dark grey with spots) and Sointula fishers (black). Source: Common Resources Consulting Ltd. (1998).

Declining runs in the Kingcome River were first reported in 1973, as a "very small" run was seen in 1971 and "light catches" were reported in 1972 (Common Resources Consulting Ltd., 1998). There is limited documentation for these river systems after 1977 and throughout the 1980s. By the mid 1990s, several BC eulachon runs, including the Klinaklini River, were thought to be in decline (Hay and McCarter, 2000). A 1995 study estimated the Klinaklini River's spawning biomass at approximately 40 t, which was thought to be approximately 15% of the historic run size (Berry and Jacob, 1998). A similar 1997 study on the Kingcome River, estimated the biomass at 14.35 t, also thought to be a fraction of past runs (Berry and Jacob, 1998). Larval surveys conducted in 1994 and 1997, estimated the approximate eulachon spawning biomass of the Johnston Strait Region at 107.43 t and 48.28 t, suggesting a greater than 50% decline in abundance between the 3 years (McCarter and Hay, 1999). By 2000, the Kingcome run was reported to be "poor or nil" and the Klinaklini "very low" (Hay and McCarter, 2000). However, in 2001 the Kingcome run improved and was considered "good" in 2002, with approximately 330 gallons of grease produced (Midori Nicolsen, 2002). Since then the run has fluctuated. Midori Nicolsen, a member of the Tsawataineuk First Nation and a participant in the Kincome eulachon fishery, confirmed that the 2003 and 2004 seasons were poor and only an average run was seen in 2005 (Midori Nicolsen, pers. comm., 2007). In 2006, the Kingcome run was absent and only small returns were seen in 2007 (Midori Nicolsen, pers. comm., 2007). Over the past few decades, the Klinaklini River has suffered years with low returns, although never a complete failure of the run (Fred Glendale, pers. comm., 2007). Robert Duncan, a member Da'naxda'xw/Awaetlala and an eulachon fisher, witnessed low returns during the 2004 and 2005 seasons (Robert Duncan, pers. comm., 2007). But in 2007, the Klinaklini returns improved and, overall, it appeared to be a "very good run," (Fred Glendale, pers. comm., 2007).

<u>BC South Coast</u>

<u>Fraser River Area</u>
Fisheries: Fraser River and the Squamish River
Rivers: First Nation fishery, Commercial Fishery, large recreational fishery

The two known eulachon rivers in the South Coast area of British Columbia are the Fraser and Squamish Rivers (Figure 21). Of these, the Fraser River has the largest annual eulachon run and eulachon catches. The eulachon usually begin to ascend the Fraser River at the end of March and run until the middle of May (Robson, 1993). The Fraser River is one of the larger eulachon rivers on the Pacific Coast and eulachon travel long distances up the river to spawn. The farthest distance that eulachon have been known to spawn is Hope (154 km east of Vancouver; DFO, 1940-1979; Figure 21). However, more commonly they do not pass Chilliwack (100 km east of Vancouver; Duff 1952) and the main spawning areas seem to be in the

thirteen km between Chilliwack and Mission (Scott and Crossman, 1973). The three fishing sectors on the Fraser include First Nation, commercial and recreational. Recent runs have been so poor that no eulachon have been captured from any of these fishing sectors. The First Nations groups that have participated in the Fraser River eulachon fishery in the most recent years are the Musqueam, Tsawwassen, Kwantlen, Kwikwetlem, Katzie and Tsleil Watuth First Nations (DFO, 2004; Figure 21). However, other groups from the Stȯ:lō population[4] have fished for eulachon in the past. These groups caught eulachon for fresh consumption and for smoking, but did not produce eulachon oil (Duff, 1955). The reasons for this can only be surmised. One reason may be that First Nations in this area historically did not need eulachon grease for winter survival, as the climate is much milder than that of Northern British Columbia. Or it could be possible that eulachon of the Fraser River were not captured when their fat resources were most plentiful, thus making grease production ineffective. A Musqueam First Nation man once reported that he had no recollection of eulachon being caught "going up the North Arm" as the fish migrated up the main river and were later swept down the North Arm in a weakened condition. Thus eulachon caught in the North Arm were "good for eating fried but were mainly smoked" as the "oil was all gone [thus] they kept better" (Forbes and Harris, 1974-1989).

[4] Stȯ:lō historically was the collective name of the First Nations located along the Upper Fraser River. However, the Stȯ:lō Nation today consists of 11 bands and the Stȯ:lō Tribal Council includes 8 bands.

Figure 21. Approximate locations of eulachon rivers, First Nations reserves, and cities in the Fraser River/Vancouver Area.

The First Nations and recreational fisheries were estimated to generate a catch of 10 t of eulachon annually (Hay *et al.*, 2003) although, at one time, a considerable portion of the eulachon catch was taken by First Nations and local residents for personal consumption (McHugh, 1941). Recreational and First Nation catch data are limited for the Fraser River. However, for the Mission District between 1956 and 1982 some reports are available from local DFO Fisheries Officers (Figure 22). The only First Nations catch reported separately came from the Steveston District, for the Musqueam First Nation (Figure 22). The reported Musqueam catch was multiplied by six as an approximate way to include the catch of the other five main Fraser River eulachon fishing Nations. This is probably low as there were probably more than five First Nations groups fishing for eulachon historically. One year of recreational catch was found reported from the Steveston District, in 1982 (1,000 pounds or 0.45 t); thus a portion of recreational catch from the Fraser River is also missing from Figure 22. Therefore, the total recreational catch is probably slightly underestimated in this figure. However, this graph gives an approximate account of First Nation and recreational catches on the Fraser River for approximately thirty years. The total First Nation catch for the 2003 season was estimated to be 5,674 lbs or 2.57 t (DFO, 2004).

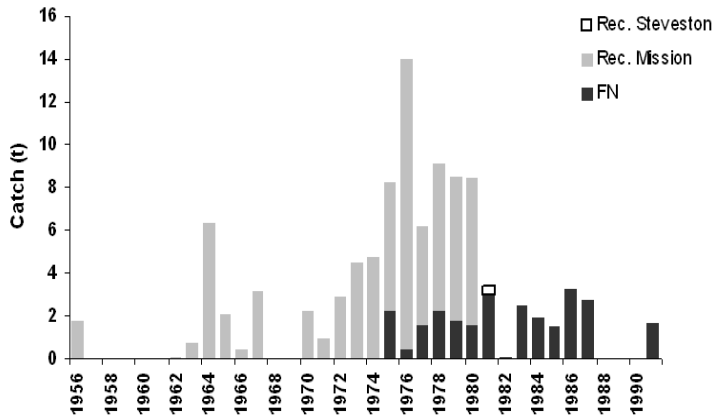

Figure 22. Recreational and First Nation eulachon catches in the Fraser River. Source: FN catches- (Fast, 1992); Steveston catch- (Forbes and Harris 1974-1989); Mission catch- (DFO, 1940-1979).

Historically, there was no limitation on the recreational fishery and catches were submitted voluntarily using a log book program (DFO, 2007). The daily limit was set at 20 kg, with a possession limit of 40 kg (DFO, 2007). Due to low returns, the recreational sector was closed from 1998-2000 (Hay *et al.*, 2003) and reopened from 2001-2004, after in-season estimates of abundance increased. Daily limits during this time were reduced to 5 kg/day and fishing times were restricted to daylight hours (Hay *et al.*, 2003). Since 2005, the recreational fishery has remained closed.

Today, the Fraser River commercial eulachon fleet is small, with a total of 16 eligible license holders, but has occurred since the early part of the twentieth century (Hay *et al.*, 2003). A limited fishery was initiated in 1997, after more than 70 fishers participated during the 1996 season, an increase from the past average of 22, when rumours of future management changes circulated (Hay *et al.*, 2003). The commercially caught eulachon have mainly been used for local food consumption, but in the past catches were also exported, as a source of feed, for fur farmers in the State of Washington (McHugh, 1941). In 1903, the market value of the eulachon province-wide was placed fifth among the fisheries of British Columbia. However, since 1938, the value of the fishery has been insignificant (McHugh, 1941). Historically, the commercial fishery has been managed passively and driven by market demand. Thus the commercial catch is not a good indicator of relative abundance (McHugh, 1941) as the catch variations most likely reflect fishing pressure only half of the time (Ricker *et al.*, 1954).

The state of the Fraser River eulachon run first became worrisome in 1939, as local fishers and buyers voiced concerns, resulting in an investigation and the introduction of daily catch forms in the commercial sector (McHugh, 1941). The conclusions of the 1939 investigation of catch statistics, suggested the run had declined from 1921 to 1939 (McHugh, 1939). From 1941 to 1954 the run was thought to have improved as there was a gradual increase in catch (Ricker *et al.*, 1954). First Nations in this area have noticed declines in the run since 1952, as the eulachon are no longer seen spawning in some areas (Bailey, 2000).

As mentioned previously, the area upstream of Mission was the main spawning ground for the Fraser eulachon. From 1957 to 1961 the eulachon run failed to return east of Mission and much concern was expressed in 1961 by the Fisheries Officer, J.B. Hawley, who worked in the Mission-Harrison District:

"No Oulachons have been reported in the Mission Area this month. I am of the opinion that the Oulachon run to the Fraser River is not receiving the protection it deserves. Numerous local fishermen are of the same opinion. These runs are no longer able to support a commercial fishery in my opinion" (DFO, 1940-1979).

In response to demands made by the United Fishermen and Allied Worker Union and the Native Brotherhood of BC, and possibly due to the lack of eulachon returning to their traditional spawning grounds, DFO announced changes to the regulations of the Fraser River eulachon commercial fishery in 1957. In "the interests of conservation" for eulachon, the use of drag nets and trawls were banned, the commercial fishery was closed during the weekend, and portions of the Fraser River, east of Mission Bridge and a portion of Pitt River, were closed for commercial purposes (Anonymous, 1957). Thus, the commercial fishery was limited to the use of drift gill nets, which commonly take more of the larger sized males allowing the smaller females to get through (Anonymous, 1957). It is possible that this type of eulachon fishing gear, unique to the Fraser River, is the reason that this is the only river to report that "males predominate early in the run and appear to be more numerous at all times than the females, which arrive later" (Scott and Crossman, 1973).

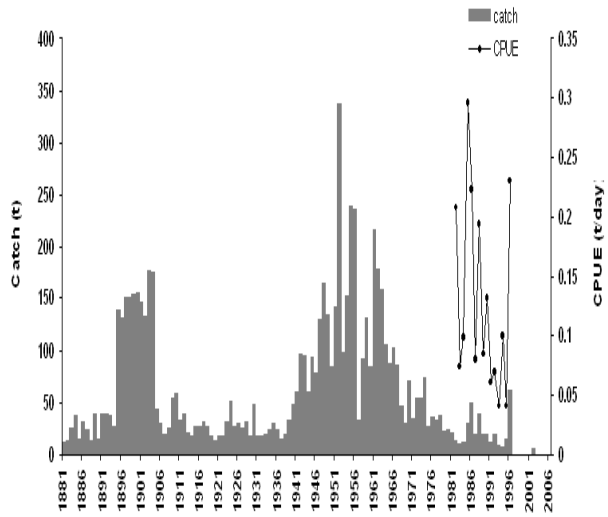

Figure 23. Commercial catch and CPUE from the Fraser River. Sources: catch 1881-1940 Clemens and Wilby, 1946; catch 1941-1953 (Ricker *et al.*, 1954); catch 1954-2000 (Hay and McCarter 2000); catch 2001-2006 (DFO, 2007); and CPUE data (DFO, 2008).

Other rivers such as the Kemano River (Lewis *et al.*, 2002), the Nass River (Langer *et al.*, 1977) and the Bella Coola River all report that females arrive first.

Although the stock has seen small declines over several decades, a sharp and very noticeable decline in catches occurred in 1994 (Hay and McCarter, 2000). Early in the 1994 season, a moratorium was requested by the Musqueam First Nation, and then later declared by DFO, due to conservation concerns (VISTA Strategic Information Management Inc., 1994). The fishery was closed in 1997 and commercial catches have only been taken in two of the last ten seasons, 2002 (5.76 t) and 2004 (0.44 t) (DFO, 2006). On average, between 1941 and 1996 commercial catches were approximately 78 t annually (Figure 23).

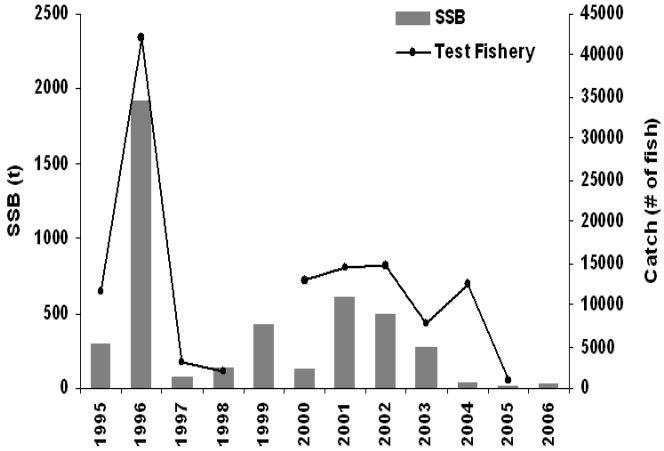

Figure 24. Euchalon spawning stock biomass (SSB) and number of euchalon caught in the test fishery in the Fraser River. DFO 2007.

Current management

Currently DFO uses three pre-season and one in-season indicator, to manage the Fraser River eulachon fishery (Therriault and McCarter, 2005). These indicators include Fraser River egg and larval surveys, the eulachon offshore biomass index from the shrimp survey, Columbia River catch and the Fraser River test fishery. The Fraser River test fishery is the only indictor for in-season abundance (Figure 24). It originally began in 1995 and operated on the number of cumulative catches. The reasoning behind the test fishery was that when less than 5,000 pieces (individual fish) were caught, it indicated a low return, but when 10,000 or greater were caught, it indicated a good spawning run, and all sectors were open to fishing

(DFO, 2004). As it is self-funded and in the past few seasons all other indicators have pointed to low abundance, the test fishery has not operated since 2005 (DFO, 2006).

The pre-season indicators are used as either a reference point for the next year's run strength or a measurement of the current year's run strength. The offshore eulachon abundance indices are based on the annual shrimp trawl surveys conducted by the DFO Science Branch in May. These surveys have been conducted since 1973. The West Coast Vancouver Island (WCVI) estimates are used as a reference point for the next year's Fraser River run as it is generally accepted that the WCVI eulachon consists of Fraser and Columbia River eulachon (Therriault and McCarter, 2005). The Columbia River catch is considered an indicator for the current year's Fraser run strength, as it is fished in January and February, before the Fraser run begins. It has been suggested that when Columbia River catches are less than 500 t, Fraser River eulachon may also suffer depressed catches (Hay *et al.*, 2003). Lastly, the Fraser egg and larvae surveys provide an estimate of spawning biomass and an indication of the past year's run strength (DFO, 2006; Figure 24). The Fraser spawning stock biomass (SSB) has been estimated by DFO from 1995 to 2006. The biomass peaked in 1996 and has been very low from 2004-2006 (Therriault and McCarter, 2005). Hay *et al.* (2003) have suggested that a low SSB (<150 t) is a cause for concern, and if it is low for two consecutive years, all fishing should be curtailed.

Mixtures of positive and negative indicators make it hard to decide when or if to open this fishery and for which sectors (Hay *et al.*, 2003). For 2005, the First Nations eulachon fishery was slated to open if 7500 pieces were caught in the test fishery. However, fewer than 900 were caught and no fishery occurred in any of the three fishing sectors for 2005 (Hay *et al.*, 2003). For 2006, all three fishing sectors were closed to eulachon fishing due to conservation concern (DFO, 2006).

Washington/Oregon

There are approximately twenty rivers within the states of Washington and Oregon that have had eulachon spawning runs (Willson *et al.*, 2006; Table 3). The Columbia River is the largest eulachon river in both of these states, and possibly the largest eulachon run in the world (Washington and Oregon Department of Fish and Game [WDFW & ODFW], 2004). The discussion for this area will focus on the Columbia watershed (Figure 25). The lower Columbia River separates the states of Washington and Oregon. Therefore, the Columbia mainstem is managed jointly by both states. The eulachon enter the lower Columbia River in early to mid January and peak in abundance during February, in the tributaries (WDFW & ODFW, 2005). The eulachon travel annually up the Columbia River mainstem as far as the Bonneville Dam. However, prior to the dam being built, they were known to travel as far as the Hood River (Smith and Saalfeld, 1955), approximately 35 km farther upstream. The eulachon are also known to return, although less regularly, to the Columbia River tributaries i.e., Grays, Skamokawa, Cowlitz, Kalama, Lewis and Sandy Rivers (WDFW & ODFW, 2001).

Table 3. Eulachon rivers located in the states of Washington and Oregon.

State	Rivers	Past/Present Fisheries
Washington[a]	Bear, Naselle, Nemah, Wynoochee, Quinault, Queets, Nooksack	
Both States	Columbia River and tributaries: Grays, Skamokawa, Elchoman, Cowlitz, Kalama, Lewis and Sandy	Large commercial Large recreational
Oregon[b]	Yaquina, Siuslaw, Umpqua, Coos, Coquille, Sixes, Elk, Euchre, Rogue, Hunter, Pistol, Chetco, Winchuck	

Source: [a]WDFW 2001; [b]Willson *et al.* (2006).

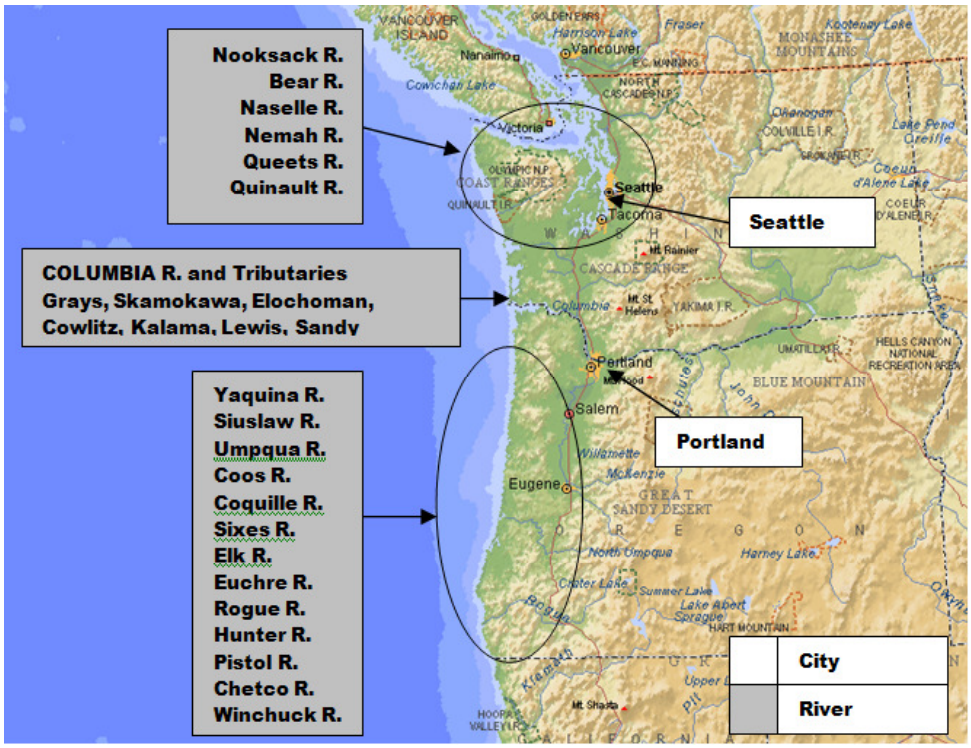

Figure 25. Eulachon rivers with reference cities, in the states of Washington and Oregon.

The Columbia River eulachon fishery currently has three sectors: a small tribal fishery and large commercial and recreational sectors. The First Nations of the lower Columbia River have fished for eulachon for centuries. This is the subsistence sector of the eulachon fishery and involves the members of the Yakima Nation. The Yakima Nation includes members of the Cowlitz Band, whose annual catch is relatively small when compared to the commercial catch (WDFW & ODFW, 2001). The commercial fishery first began around the late 1800s (Hinrichsen, 1998) and has since supplied fresh bait for sport sturgeon anglers and fresh fish for the market. Prior to 1995, the commercial and recreational sectors had only minor regulatory changes; from 1960 to 1977 the commercial fishery was open year round, 3 ½ days per week, but beginning in 1978 the season was expanded to seven days per week (WDFW & ODFW, 2005). This is the largest commercial eulachon fishery in the world, with landings averaging 953 t annually from 1938-1989 (WDFW & ODFW, 2004; Figure 26). However, during the 1993 and 1994 seasons, commercial landings were down (226.8 t and 19.5 t, respectively) resulting in 1995 fishery restrictions that reduced the number of fishing days per week (WDFW & ODFW, 2004). Further restrictions were introduced to the commercial fishery between 1997 and 2000, resulting in the fishery being modified to a test fishery to provide fisheries managers with the data needed to assess run strength and provide biological samples (WDFW & ODFW, 2004). The very popular dip net sport fishery, which was historically open year round, had limited openings during the low runs of 1997-2000 and 2004-2006 (WDFW & ODFW, 2005). This fishery occurs primarily in the tributaries and catches rarely occur in the mainstem of the Columbia River (WDFW & ODFW, 2001). Limited creel census data suggests that the catch of the recreational fishery, which involves thousands of participants when the eulachon run is abundant, may equal that of the commercial fishery (WDFW & ODFW, 2005). The daily limits for the sports fishery range between 10 and 20 pounds (4.5 and 9 kg) per person in Washington and 25 pounds (~11kg) per person in Oregon (WDFW & ODFW, 2005).

Until the mid 1990s, commercial landings were quite stable in the Columbia River, with the exception of 1984, which was thought to have been affected by the 1982-83 El Niño event (WDFW & ODFW, 2004). Even though the Columbia River catches declined suddenly in 1993, historical documents indicate that major declines have occurred in the past:
"[Eulachon] was once abundant in the Columbia, but that stream being now disturbed by the traffic of steamers, it is only now in exceptional years that they are caught there in any quantity" (Brown, 1868).

"Formerly resorting in enormous shoals to the estuary of the Columbia River, [eulachon] disappeared suddenly about the year 1837, and continued to absent itself for many years, until recently when it suddenly reappeared in shoals as numerous as of yore" (Canada, 1877).

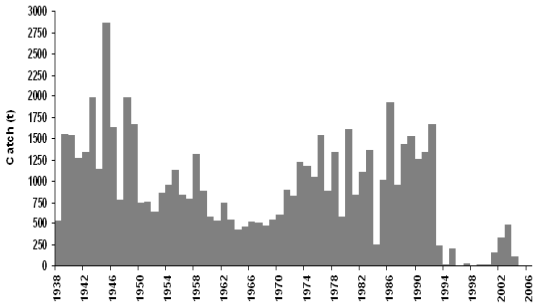

Figure 26. Euchalon commercial landings the Columbia River.

A 1999 petition to list the Columbia River eulachon under the Endangered Species Act was reviewed and accepted by the National Marine Fisheries Service, but a listing was not proposed "due to the lack of adequate information for stock status determination" (WDFW & ODFW, 2004). The runs to the Columbia tributaries have also failed in some years. The Cowlitz River eulachon were reported to be scarce (1938, 1949, 1959 and 1979) and absent (1950-51, 1965 and 1977) in some years (Hinrichson, 1998). The Sandy River run also disappeared in the past (1988 to 1999) however, in 2000 the run returned and in 2003 there were commercial landing for the first time since the 1980s (WDFW & ODFW, 2004). The Columbia River eulachon returns remained at record lows between 1994 and 2000, but improved CPUE in the commercial fishery and large larval abundance suggested the abundance had improved between 2000 and 2003 (WDFW & ODFW, 2005; Figure 27). However, poor returns were again seen in 2004 and 2005, with record low commercial landings in 2005 (0.09 t; WDFW & ODFW, 2005). The 2006 season was considered "poor" with only slight improvements in commercial catch (5.94 t; WDFW & ODFW, 2005). These are, however, extremely small when compared to historic catches.

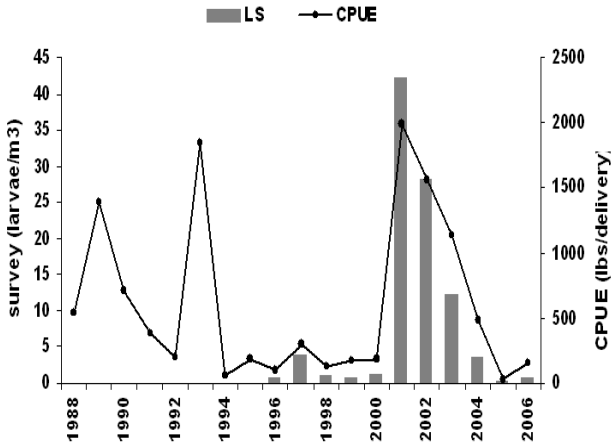

Figure 27. Eulachon larval survey estimates (LS) and CPUE from the Columbia River. Source: ODFW & WDFW 2005.

California

Rivers: Klamath, Redwood, Mad, Smith and possibly the Russian
Fisheries: First Nation (Yurok tribe) and recreational fisheries

Historically, the major eulachon rivers in California were the Klamath River in Del Norte County and the Mad River and Redwood Creek in Humboldt County (Odemar, 1964). There are incidental reports of eulachon returning to the Smith River; however, these runs were not large or regular (Moyle *et al*., 1995). The southernmost capture of eulachon was off the coast of California in April 1964, five miles southwest of Bodega Bay, Sonoma County (Odemar, 1964). As a result of these catches, the California Department of Fish and Game increased the most southern range of eulachon, to approximately 180 miles south of the Mad River (Figure 28). Six fish were also captured near the mouth of the Russian River in April 1963. However, no runs have ever been reported returning to this river or any other river south of the Mad River (Odemar 1964). The eulachon runs in northern California start in December and January and peak in abundance during March and April (Larson and Belchik, 1998). In California, eulachon were never commercially important, yet they were fished recreationally and were of great importance to the Yurok

Tribe. The only reported commercial catch occurred in 1963 when a combined total of 56,000 lbs (25 t) was landed from the Klamath River, the Mad River and Redwood Creek (Odemar, 1964).

Until the mid 1970s, the Mad River and Redwood Creek had heavy eulachon runs (Moyle *et al*., 1995), but the Klamath run has been the largest in California (Fry, 1973), and last had a "noticeable" run during the late 1980s, according to Yurok Tribal elders (Larson and Belchik, 1998). One member of the Yurok tribe reported that the last large run of eulachon occurred in 1988, with a smaller run in 1989, and only a "few" were caught in 1990 and 1991 (Larson and Belchik, 1998). During the 1996 season, the Yurok Tribal Fisheries Program attempted to capture eulachon in the Klamath River, spending a total of 119 staff hours, with no success. However, one Yurok tribal member captured one eulachon in March 1996 while fishing for lamprey (*Lampetra tridentate*; Larson and Belchik, 1998). Thus the eulachon have virtually disappeared from this area since the early 1990s. The California eulachon are not the only anadromous fish in this area to suffer major declines. Moyle (1994) reported that the eulachon was one out of thirteen California anadromous fishes in decline. He also developed a subjective scale to identify the factors contributing to the decline of these fishes and determined that the greatest impacts on the eulachon in this area were: water degradation (e.g., logging and urbanization), diversions (e.g., dams and irrigation), ocean conditions (e.g., El Niño) and predation (enhanced populations).

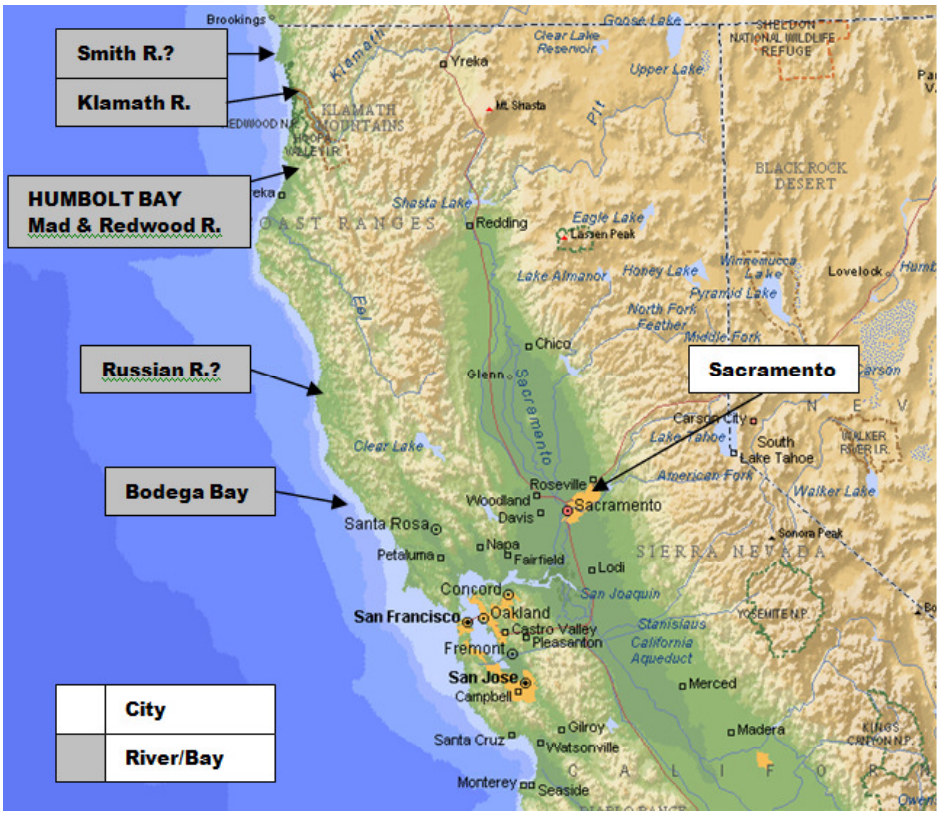

Figure 28. Eulachon river locations with reference city, in the state of California.

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ESTIMATING HISTORICAL CATCHES OF THE NUXALK NATION EULACHON FISHERY

> *It's… a lost segment of our society so to speak, the Nuxalk society, because there's a big gap there now. What do you do in the spring time? What do you do before winter ends?* [White] *people like to watch for the groundhog but our people used to get ready to make eulachon grease.*
>
> (048 Nuxalk Interviews, 2006)

INTRODUCTION

For millennia, eulachon and the oil rendered from the fish have been an important source of food for coastal First Nations as well as being central to social, ceremonial and economic activity. The process of rendering the oil from the eulachon has long been a tradition in most coastal First Nations communities that have spawning eulachon populations. To study this process, its fishery, and the current status of a specific eulachon river, one British Columbia First Nations community was selected, the Nuxalk Nation.

Regional overview

The Nuxalk Nation, a First Nations community located on the Central Coast of British Columbia, have caught eulachon and rendered its oil for thousands of years. During the 1860s, smallpox and other infectious disease epidemics devastated the native villages in the Bella Coola Valley[5]. It has been estimated that the population of this area was reduced by three quarters (Kirk, 1986). This horrific loss of life led to the assemblage of all remaining survivors in the area at one location, Q'um'kuts[6]. This is the site of today's village and the home of the Nuxalkmc[7], today recognized as the Nuxalk Nation. The Nuxalkmc reside in the Bella Coola Valley at the head of North Bentinck Arm (Figure 29). This region is characterized by steep terrain and heavy rainfall, ranging from glacier-capped mountains with elevations up to 3000 m, to deep inland saltwater fjords. The rivers and estuaries in Nuxalk territory are inhabited by six species of Pacific salmon (*Oncorhynchus* spp.) as well as many other species of fish, including the eulachon. The eulachon returned in large numbers every spring to the Bella Coola River. It was the first fish to return after the winter and as a result was often called the "salvation fish" (Harrington, 1967). In 1999, the eulachon failed to return in large numbers to the Bella Coola River and for the past 9 years (including 2007) this pattern has continued. These low returns have also occurred in the other rivers located within Nuxalk Territory.

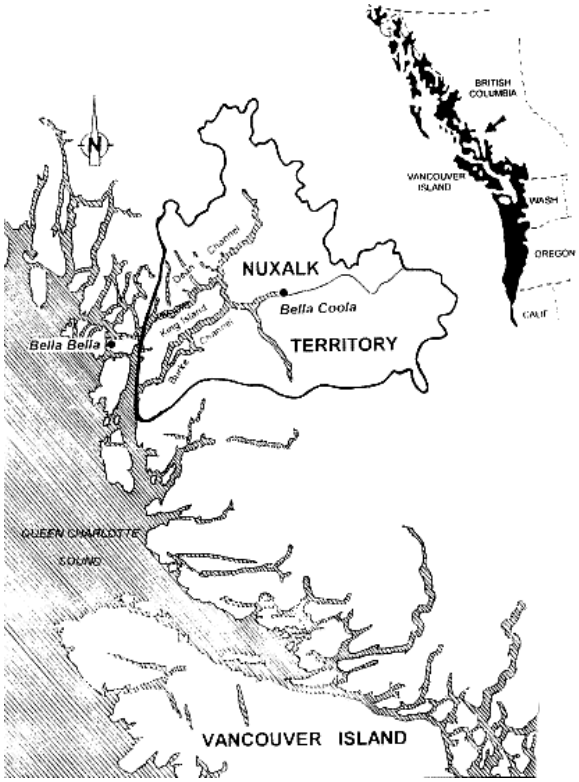


Figure 29. Map of Nuxalk Nation territory. Source: http://www.nuxalk.net/html/maps.htm. Accessed 2010.

[5] Talio, South Bentinck, Kimsquit and Kwatna
[6] Main village of the Nuxalkmc
[7] Nuxalk people

The Bella Coola River drainage is 5,130 square km (Environment Canada, 2008) and begins where the Talchako and Atnarko Rivers converge approximately 55 km east of North Bentinck Arm. The Bella Coola River, at the town site of Bella Coola, lies at 52.4°N latitude and 126.7°W longitude (Environment Canada, 2008). It flows westward through the valley before it exits into the Bella Coola estuary. Additionally, the estuary encompasses the outflow from Paisla Creek and the Necleetsconnay River, both located just north of the Bella Coola River. Figure 30 displays the Bella Coola estuary and the outflows from all three rivers.

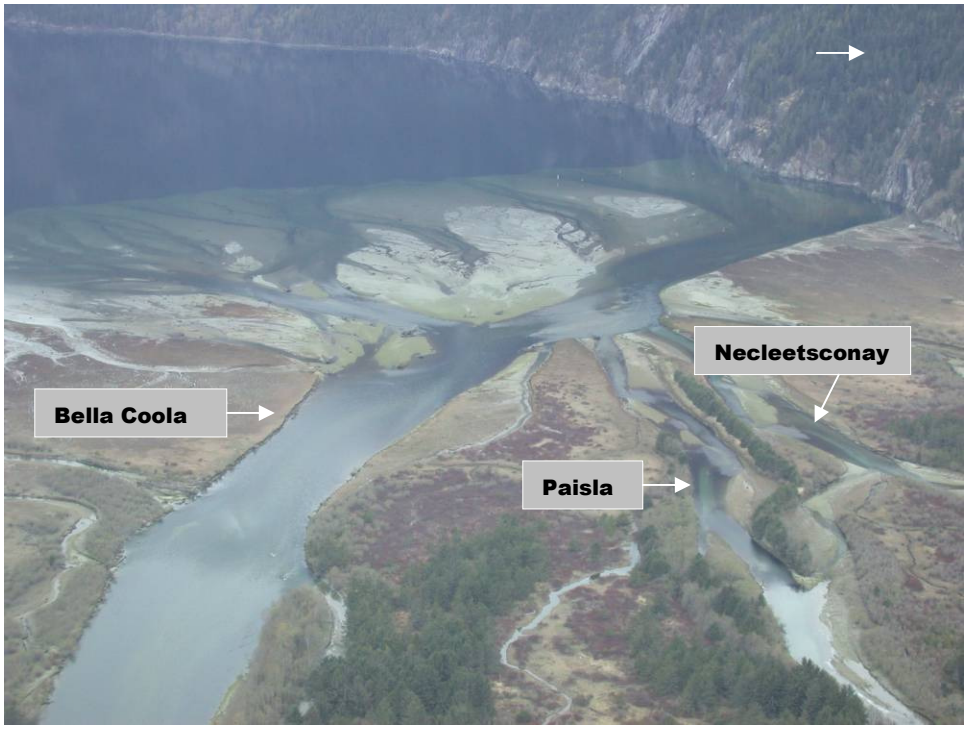


Figure 30. The Bella Coola estuary comprised of the Bella Coola River, Paisla Creek and the Necleetsconay River. Source: Nuxalk Fisheries Department; Jason Moody photo.

There are a total of ten rivers in Nuxalk territory, including the Bella Coola River, that have or have had eulachon runs in the past. These rivers were confirmed in 1998, when the Nuxalk Nation Band Council chartered a plane and counted the rivers with eulachon spawning in them. Wally Webber, a Nuxalk Nation member and a DFO contractor at the time, and Harvey Mack, a Nuxalk Nation Councilor, both participated in the flight. The ten rivers include the Dean and Kimsquit Rivers in the Dean Channel, the Taleomy, Noeick and Aseek Rivers in South Bentinck Arm and the Kwatna and Quatlena Rivers in Kwatna Inlet. Previously, these rivers had been regularly fished for salmon and eulachon by members of the Nuxalk Nation. However, in the early 1900s, the Canadian government enacted the reserve system which put aside small patches of land for First Nations and restricted them to these areas. As a result, a total of seven reserves[8] (Department of Indian Affairs and Northern Development Canada, 2007) were marked out around old village and fishing sites throughout Nuxalk territory. However, after the decimation of the Nuxalk population in the late 1800s, and the gathering of the surviving Nuxalk people in today's village of Bella Coola, the only rivers that were regularly fished for eulachon were the Bella Coola River and the nearby Paisla Creek.

The study

Study objectives

The Eulachon has not been recognized as an important commercial species in British Columbia. Therefore there have been little documentation of past catches and only recently, any examination of yearly

[8] Bella Coola, Noosesek, Taleomy, Kwatlena, Kemsquit, Chatscah, Skowquiltz River

abundance. The purpose of the study was to use interviews to attempt to describe past eulachon abundance trends and to calculate past eulachon catches in the Nuxalk eulachon fishery.

Approach

To study the Bella Coola eulachon fishery and the eulachon grease making process, interviews were conducted and traditional ecological knowledge (TEK) and local ecological knowledge (LEK) was collected. Twenty-seven Nuxalk eulachon grease makers and eulachon fishers, as well as, two non-native Nuxalk community members, who had previously participated in the fishery, were interviewed in early 2006. During the interviews, the participants were questioned on several topics including past eulachon fishing experience, past fishing methods, the social and economic importance of the eulachon, the production of grease, the grease-making process, the change in past abundance and the possible reasons for the eulachon decline. The information collected was used to examine the changes in the Nuxalk eulachon fishery, examine past eulachon abundance trends and, finally, to estimate past eulachon catch sizes from grease production.

Rationale

I chose the Nuxalk Nation as a case study because, as a member of that Nation, I have a deep concern for the Bella Coola eulachon run. As a child, I fished for eulachon with my family and witnessed the production of eulachon grease. Later, I worked as the Nuxalk Fisheries Manager to study the status of the Bella Coola eulachon. My initial fear that participation in the study would be difficult to obtain, because I was a member of the community, proved to be groundless. Participants were quite willing to take part in the study, perhaps because I had previously worked with some of them or perhaps because many of them were friends and relatives. The topic of the eulachon also appeared to be an uncontroversial topic within the community. Most participants shared a feeling of sadness towards the loss of the eulachon and many asked the same daunting question "what happened?" In order to address this question, trends in abundance and the amount of eulachon caught in the fishery needed to be known. In order to calculate past Bella Coola eulachon catches from grease production, it was first necessary to have an understanding of the Nuxalk eulachon fishery and the eulachon grease making process. Thus the interviews provided background on the importance of the eulachon fishery, changes in the fishery, and in depth detail on the grease making process.

METHODS

I conducted field research[9] while living in the Bella Coola community for two months in 2006. Living on the Nuxalk reserve and based at the Nuxalk Integrated Resource (NIR) office, I interviewed participants at their homes or at the NIR office. The final location of an interview depended on where the participant felt most comfortable. The goal was to work with someone from each family group within the Nuxalk community. The criteria were simple: the individual had to have been involved in the eulachon fishery and/or the grease-making process for at least one season. There were some families that made grease more often than other families, but at least one representative from each Nuxalk family group was included. The voices of those presented here are the expressions of twenty-seven Nuxalk individuals, and two non-First Nation community members (Table 4). They represent a subgroup of the Nuxalk community who were involved in the eulachon grease making process. Participants were selected through nonrandom purposive sampling. An initial contact list of the most prominent Nuxalk grease makers and eulachon fishers was provided by my father, Qwatsinas (Edward Moody), a Nuxalk Nation member and a resident of Bella Coola for fifty-seven years. He advised me on the main 'grease' families and provided a list of names of those whom had participated regularly in the eulachon fishery. From there, those that actually participated in the study, were either on the list or were referred to by someone on the list. I eventually had a final list of fifty participants whom I tried to contact initially by letter and then, if their address was unknown, by phone. Unfortunately it was not possible to interview all fifty people in the time period allotted. Some people were sick, out of town, or chose not to participate. The interviews were concluded when the allotted time was up.

[9] The interview methods were approved by the UBC Research Ethics Board (see Appendix 2 for approval certificate)

Table 4. General characteristics of 2006 Nuxalk interviewees.

Interviewee categories	Average age (years)	Range of ages (years)	Number of participants
All participants	64	43-86	29
Male	62	43-81	22
Female	73	58-86	7
Role in eulachon fishery			
Everything (fisher, cook, misc. helper[a])	64	50-81	14
Fisher and misc. helper	60	60-86	9
Misc. helper only	80	74-84	4
Nuxalk participants	65	43-86	27
Non-Native but married to Nuxalk	59	57-60	2
Total number interviewed			29

[a]Includes: collecting rocks, skimming the grease, preserving the grease, net mending, etc.

Interview procedures

In December 2005, when visiting family, I was able to casually introduce my project to some of the potential participants as I saw them at community gatherings. In January 2006, to contact and introduce my project in more detail to all fifty potential participants, each was sent a descriptive letter (Appendix 3) and a consent form (Appendix 4). My next visit to Bella Coola in February 2006 was used to conduct the interviews[10]. Semi-structured interviews were used, as knowledge varied with each participant. The participants involved in all aspects of grease making (fishing eulachon and making the grease) seemed to be most knowledgeable regarding the amount of eulachon caught and the amount of grease made. If the person caught eulachon but failed to participate in the making of the grease, fishing activities were known but the amount of grease made was not. Finally, the participants whose main task involved preserving the grease had general knowledge of the eulachon fishery but knew much less about the actual catch. The first part of the interview involved the systematic gathering of information and thus allowed the comparison of data between participants. The latter half consisted of more open-ended questions, where the participant could express opinions and raise questions regarding the eulachon decline thus illustrating the viewpoint of the Nuxalk community on the current issues surrounding the decline.

Data management

Twenty-two of the twenty-nine interviews were digitally recorded and the recording downloaded onto a laptop computer. Each of these interviews had a typed transcription. Five of the interviews were not recorded, at the request of the participant; however, the main points were written down during the interview and later summarized and typed into a MS Word document. At the end of the field season the participants were supplied with a printed transcript of their interview and if requested, a digital copy. Hence, each participant was given an opportunity to make changes to their interview transcript if they felt it was necessary. Once all interviews were transcribed they were saved as text files and imported into the qualitative software program, N6[11]. The N6 program assists in organizing large amounts of non-numerical and unstructured data, such as the kind of data that is made during interviews, note taking, etc. (QSR International Pty Ltd., 2004). The program is also used to assist in interpreting and searching for patterns in the data. However, for this study, N6 was used solely for data organization. This was done by creating nodes or categories. A total of twenty-four, free-node categories and a total of eight, tree-node categories

[10] Each person was contacted by phone, and if they agreed to participate, a time for an interview was scheduled. Before the interview started, the nature of the research was explained and the participant was asked to sign a consent form; this indicated their voluntary participation. On the consent form, the participant specified if their name was to be used or if they would like to remain anonymous. Of the twenty-nine participants, fourteen preferred to have their name used and fifteen preferred to remain anonymous. Any information that was used from anonymous participants was referred to by coded number. All information gathered, has been kept confidential and under lock and key at all times.

[11] N6 = NUD*IST Version 6, and NUD*IST stands for Non-numerical Unstructured Data * Indexing Searching and Theorizing

were created (Appendix 5). A free node is a category that has only one topic, for example 'predators' or 'weather', whereas a tree-node has one topic and several subtopics, for example 'abundance' with the subtopics: 1960s, 1970s or 1980s. To sort the text into these nodes, each of the interviews had to be read, usually several times, and the corresponding text coded to the appropriate free or tree node. For example, text from all interviews, related to abundance in the 1980s was coded into the category 'abundance-1980s'. A text file report for each category was then made from within the N6 program, including all related quotes for the category. A report was printed for each free node and for each tree node. The reports greatly decreased the amount of time needed to search for quotes or information on a specific topic.

RESULTS AND DISCUSSION

Grease making

Figure 31. Nuxalk 'stink box' full of fresh euchalon. Source: Ruby Saunders photo.

The grease (sluq'[12]) extracted from the eulachon (sputc[13]), formed an integral part of Nuxalk culture, as it was distributed widely in potlatches, traded with neighboring communities, and relied upon for its nutritional and medicinal uses. The production of eulachon grease, involved many activities which included: preparing the camp, catching the fish, 'aging' the fish, cooking the aged fish and eventually extracting, purifying and preserving the grease. The entire grease making process took approximately three weeks to complete and involved many people and many hours of laborious work. The first tasks started a few weeks before the fish arrived and involved preparing the camp for operation. The site was cleared of overgrown bush, firewood was cut and hauled, nets were mended and the 'stink' boxes and 'cooking' boxes were set for operation.

The 'stink' box

Table 5. Amount of canoe loads of eulachon (per day) to fill a 'stink' box.

[Canoe loads (1000 lbs)]/day	Converted to metric tonnes (t)	amount (t) x days to fill
3	1.3	4.0
4	1.8	5.4
5	2.2	6.7

The stink box was the container where fresh eulachon were placed, for fermentation, hence the name (Figure 31). The fish were fermented in order to release more of their oil. The stink boxes varied in size but were approximately twelve to fourteen feet wide, twenty feet long and three and a half feet deep (Kuhnlein *et al.*, 1982). The bottom was earthen and covered with cedar boughs, to allow blood drainage. If the blood was not drained, the grease produced would be dark and red (010 Nuxalk Interviews, 2006). A stink box could hold up to 10 t of fish but more commonly held between 5 and 8 t (010 Nuxalk Interviews, 2006).

According to Kuhnlein *et al.* (1982) a stink box held approximately 6 t of eulachon. This estimate was corroborated by some of the fishers interviewed. Two of the fishers estimated that a canoe held about 1000 lbs (or 454 kg; 009 and 016 Nuxalk Interviews, 2006) and another two fishers stated that it took about three days to fill a stink box when unloading three to five canoe loads of eulachon per day (003 and 009 Nuxalk Interviews 2006), resulting in 4.0 to 6.7 t per box, supporting Kuhnlein's 1982 calculation of 6.3 t per stink box (Table 5).

The fish were left in the stink box for approximately eight to ten days, depending on the weather. If it was a warm year, the fish would age faster and the cooking would need to be started earlier. Some years when there was snow on the ground, the fish would decompose more slowly. "One year it took about two weeks for them to [ferment] to the point where we could cook the grease out because it was too cold. They

[12] Nuxalk word for eulachon grease, pronounced 'slooq'
[13] Nuxalk word for eulachon, pronounced 'spooth'

wouldn't break down. It was like they were in a big refrigerator" (Russ Hilland Nuxalk Interviews, 2006). A sign that the fish were properly aged was the fullness of the stink box. When a full box was reduced to half of its original contents, the fish were ready (010 and 047 Nuxalk Interviews, 2006). Another sign was the condition of the eulachon's eyes. Jimmy Nelson Sr. recalled his father telling him to "watch the eyes" because when they turned red, the fish were ready to cook (Nuxalk Interviews, 2006). If it took more than a day or two to fill the box, a divider was placed between the older fish and the freshly caught fish and the first cooking started with the oldest batch. Some grease makers liked to start cooking earlier so that their grease was mild or less 'strong'. "Our grease is a little mild compared to guys that keep them ten to twelve days. We start at five days. Still fresh almost… we get less grease but we like it that way" (Harvey Mack Nuxalk Interviews, 2006).

Cooking

Once the eulachon were aged for the appropriate amount of time, they were placed into the 'cooking' box. The cooking box was a separate box from the stink box. The box was situated next to the stink box, on top of a layer of bricks and clay. The clay was placed around the wooden parts of the box to keep them from burning. Under the box was a small dirt trench used to house the fire. A chimney was also placed at one end of the trench to release the smoke of the fire while the opposite end was open, to access the fire.

The first step of the cooking process was to fill the box approximately a third of the way with water and to heat it until it boiled. This step usually took a few hours thus was started early in the morning. Ten out of the fourteen participants who were 'cooks' reported that the boxes were commonly four feet wide by eight feet long and approximately three to four feet deep. All fourteen stated that the bottom of the box was metal and the same size as a piece of plywood (eight feet by four feet). The eulachon were then transferred from the stink box to the cooking box, in galvanized metal wash tubs. The tubs had large slits on the bottom, to allow any remaining blood or slime to drain. Previously, other methods were used to transfer the eulachon, such as baskets, wheelbarrows or five gallon oil buckets. The aged eulachon were then added and the mixture simmered for another three to five hours. The corners of the box were not exposed to the fire, thus the mixture had to be stirred constantly. The amount of time that it took the mixture to cook depended on the weather, as the box was above ground and exposed to the wind and cool air. The cooking was complete when the fish were mashed to a pulp. At this stage, the grease would rise to the surface. The fire was kept to a minimum and the mixture left alone to allow the grease to settle. There was a delicate temperature balance to keep, if the grease was too cold, a skin would form on the top, making the grease difficult to extract, but if there was too much heat, the mixture boiled and the grease sank back into the mash (038 and 047 Nuxalk Interviews, 2006). The grease was traditionally removed with hand-made wooden scoops but these were later replaced, by some, with metal bread pans. Once the grease was removed, it was placed into large pots or buckets for the purification process.

Purification process

The purification process consisted of re-cooking and straining the extracted grease. The process removed any remaining fish particles or water from the grease. Traditionally, the Nuxalk used hot rocks to reheat the grease. These fist-sized rocks would be heated in the fire, removed with wooden tongs, cleaned and then placed into the container of grease. One elder Nuxalk woman described the rock purification process:

Table 6. Change in Nuxalk interview participant's grease consumption from when they were a child until 1999.

Did your grease consumption change? (Results from 19/29 participants)	%
Not at all	11
A little (20-30%)	11
A fair bit (30-40%)	26
A lot (>50%)	53

"They know how to pick the rock [up] and they dip it into the cold water to clean any ashes and then they put it into the grease…then [the grease] starts to boil. Then all the stuff comes up; like the water, the steam, because it's the oil you want not the water… so it steams and then it gets rid of the water… it sort of foams, just like when you make jelly" (015 Nuxalk Interviews, 2006).

In more recent years, some families switched to propane stoves to re-cook the grease. The premise was basically the same, but there was debate over which method produced the better grease. Out of the

fourteen cooks interviewed, 50% used the traditional method of hot rocks. Lastly, the re-cooked grease was strained through a cheesecloth material to remove any remaining fish particles.

Storage

Eulachon grease had traditionally been stored in watertight wooden boxes. After European contact, metal cans were used, followed by gallon wine jugs and more recently, sealable wide mouth jars and tin cans. The grease would keep for several years if kept in a cool storage area but it would keep even longer if kept in the fridge or in the freezer. Once sealable cans and jars came into use, the grease was said to "stay fresh" forever (017 Nuxalk Interviews, 2006). The sealable methods of storage were used only during the last few decades. Prior to the 1980s, when more grease was consumed, larger containers were needed to store the grease produced. However, by the 1990s, 79%, of those whom responded, reported that their grease consumption had decreased 'a fair bit' or 'a lot' (Table 6). As a result, smaller amounts of longer lasting grease, was preferred.

Importance of the eulachon and its grease

The eulachon have been an important part of Nuxalk society for thousands of years. The fish themselves are a source of food that is either, dried, smoked, salted or eaten fresh. The grease extracted from the fish, formed an integral part of Nuxalk culture, as it was distributed widely in potlatches, traded with neighboring communities, and relied upon for its nutritional and medicinal uses. Of those interviewed, 69% stated that the most important reason for making eulachon grease was for their diet and 14% for use as a medicine (Table 7). One eulachon grease maker described the ways in which eulachon grease was consumed, "we'd basically use eulachon grease to make [dried foods] slide down better, we used it quite a bit in our consumption of salmon, like smoked fish…[used it] like butter" (Horace Walkus Nuxalk Interviews, 2006). In addition to being a 'condiment', the eulachon had many nutritional qualities. In 1994, samples of eulachon grease and eulachon fish taken from five different British Columbian First Nations communities[14] were analyzed. The nutritional quality analysis revealed that eulachon grease was one of the best sources of vitamin A (RE 2400/100g) found in the natural foods of British Columbia, the analysis also revealed that the fish were a good source of Calcium, Iron, and Zinc (Kuhnlein *et al.*,1996).

Table 7. Most important reasons expressed by 2006 Nuxalk interview participants for making grease.

Historical importance of grease	(% ranked 1st)
1) Diet	69
2) Medicine	14
3) Social	7
4) Trade	0
5) All the above	3
No answer	7

Although the trade of grease was not ranked by the participants as highly as diet, trading was an important aspect of the Nuxalk economy. Trade has existed between the Nuxalk of Bella Coola and their neighboring tribes for thousands of years. To the east is the Ulkatcho (Anahim Lake), to the west the Heiltsuk (Bella Bella), Kitasoo (Klemtu) and the Wuikinuxv (formerly spelt Oweekeno; Rivers Inlet). The only other neighboring tribe that possessed an eulachon run was the Wuikinuxv; their runs failed to return in 1997. The common exchange items included: herring eggs, halibut and clams from the Heiltsuk and Kitasoo and moose meat, soap berries and tanned hides from the Ulkatcho. Although all trading partners valued the grease as a food source, the Heiltsuk and Kitasoo prized the grease as a medicine and the Ulkatcho for tanning hides. In the past Eleanor Schooner used to trade her old grease with the Ulkatcho people, "they say, that is the softest they can get their tan, tanning hides with eulachon grease." Prior to European contact a vast network of trails used by generations of native people existed throughout British Columbia, "this trail system was the life blood of the native culture and economy" (Birchwater, 1993). The grease trade from the coast to the interior was so important that the trails connecting the communities were known as "grease trails."

Eulachon grease was also used as a medicine if a poisoning was suspected, as a laxative, as a cure for dry skin (Edwards, 1978), and was given to anyone who was sick (011, Peter and Elenor Schooner, 034 and

[14] Nass River, Kitimaat, Bella Coola, Kingcome Inlet, Knights Inlet

050 Nuxalk Interviews, 2006). Several Nuxalk participants commented on being given eulachon grease when they were feeling ill.

"I remember long ago, the grease was more important to use it for medicine if you got a sore throat. I remember my mom used to make it little bit warm on the stove and we drink it when we got sore throat" (011 Nuxalk Interviews, 2006).

"Everytime we didn't feel good [the old people] gave us grease" (015 Nuxalk Interviews, 2006).

"In the olden days… they used to use the grease for the chest. They used to heat it on the stove, [use] cotton and put it on the chest when a person's sick… they even used it on their throat" (050 Nuxalk Interviews, 2006).

One elder Nuxalk woman described how she used eulachon grease to help treat her baby girl who had whooping cough. The infant's chest and back were wrapped in cotton clothes soaked in warm eulachon grease. "That same night she coughed and coughed and that stuff came up and she started to get better after that. I really believe that's what helped her to get better, because she was sick" (015 Nuxalk Interviews, 2006).

Since the eulachon had many aspects of value, the social importance of the eulachon fishery can sometimes be overlooked. 'Eulachon time' was an occasion when the family; grandparents, parents, children, etc. all gathered together and worked on a common activity. This was the time when the younger generations would be witness to and learn through 'hands on' experience, the grease making process. Thomas McIlwraith, an anthropologist with the National Museum of Canada, spent part of each year between 1922 and 1924 with the Nuxalk community, documenting the structure of their society and their culture. During this time he witnessed the Nuxalk eulachon fishery and described the scene at the Bella Coola River during the eulachon season of 1922:

"The men rise at dawn to start the fires on the bank, the women and children follow with food, and for several days the whole village camps, as if on a picnic…There are tasks for everyone; the fish must be carried from the pits to the furnaces, wood must be brought, the fires stoked, the kettles stirred, the grease carried away, the fireplaces repaired, food cooked and a hundred other chores. It is a scene of great activity, carried on with good humour and merriment, for the Bella Coola realize that they are storing up luxuries for the following winter" (McIlwraith Vol. II,1948).

The importance of sharing and working together was also something taught to younger generations during the eulachon season. The first catch of the year was always shared with the community, as it was used to feed those who might not have family members to fish for them or who didn't have the fishing gear to fish. Elder Hazel Hans Sr. recalled that the community always came first, "when the first eulachons come in… they don't put them away in the box. They put the eulachons in the canoe and they call all the peoples to come and just get some to eat" (Nuxalk Interviews, 2006). This seemed to be an unspoken rule throughout the Nuxalk community. "The first stuff you got you gave away. I don't know if it was tradition or if you just grew up that way" (Horace Walkus Nuxalk Interviews, 2006). There didn't seem

Figure 32. Picture of a spoon canoe, with eulachon, taken on the Bella Coola River. Source: British Columbia Central Coast Archives; Iver Fougner photo.

to be anyone who didn't follow the principle of sharing. "When we go seine it's for the people, not for your stink box… pass it around… everyone honored that" (033 Nuxalk Interviews, 2006). Although today there is no longer the urgent need to make and store large amounts of eulachon grease for winter survival, the nutritional, medicinal, economic and social value of the grease remains a very important aspect of Nuxalk culture.

Fishing methods

Vessels

Prior to contact with explorers and settlers, the Nuxalk's main mode of transportation around the Bella Coola Valley was the river and the spoon canoe (Figure 32). The canoe was also used to fish for eulachon. By the late 1970s, new vessels were introduced into the eulachon fishery and the canoe became obsolete. The aluminum punt was introduced as a result of the commercial herring roe fishery. The commercial herring fishery had previously been closed from 1967 to 1973 due to low spawning biomass, but it reopened as a small experimental roe fishery in 1971, as the stock rebuilt (DFO, 2005). The fishery expanded rapidly during the 1970s until fixed quotas were introduced in 1983. During this expansion, many Nuxalk fishers obtained commercial herring gillnet licenses and fished these licenses with aluminum punts. These punts were also used in the eulachon fishery during the late 1970s and the early 1980s. However, because these vessels were large, they needed to be powered with outboard motors. The Nuxalk elders at the time did not approve of the use of motors in the river and believed the eulachon would fail to return if motor use was not stopped. During ancient times there were certain restrictions followed during the eulachon season. Refuse was not to be thrown into the river or the eulachon were thought to remain in the ocean, women were not allowed near the river bank at certain times and at high tide, net-posts were forbidden to be driven into the river (McIlwraith Vol. I., 1948). The motors were a new intrusion to the river and were believed to disturb the fish. In addition to these motors, the lower Bella Coola River was used as an airstrip for Wilderness Airline's floatplanes until the late 1970s. Both were blamed for a few years of low eulachon returns witnessed during the early 1980s.

"That's when they really started disappearing when those guys were using punts and motors in the river…they banned them and then it seemed like the eulachons came back" (Jimmy Nelson Sr. Nuxalk Interviews, 2006).

Table 8. Gear used to catch eulachon by Nuxalk interview participants

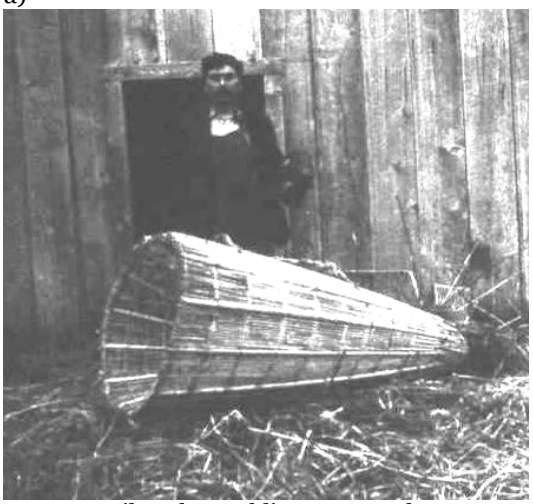
Gear used	Percent of participants
Traditional trap net	62
Seine net	83
Both trap and seine	59
Didn't fish but watched both being used	14

In May 1984, a letter sent from DFO to the Nuxalk Band Council, inquired if the Band wanted the lower part of the Bella Coola River, to be included in an application to ban the use of motor boats. The application was probably rejected although presently there has been no official motorboat ban for either the Atnarko or Bella Coola Rivers. In any case an unwritten law exists today, respected by both the Bella Coola and Nuxalk communities, to avoid use of motor boats in either of these rivers. The exact date of this self-imposed motorboat ban remains unknown but some eulachon fishers recall that punts were only used for a few years (009, 013, 029, 044, 047, 048 and 051 Nuxalk Interviews, 2006). As a result, in the late 1980s Nuxalk fishermen switched to row boats for both the eulachon and salmon food fisheries.

Gear

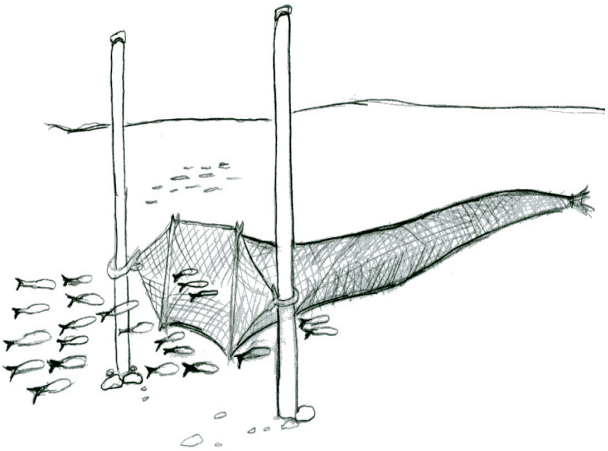
Eulachon were traditionally fished with basketry traps made of cedar bark (*Thuja plicata*), and traditional trap nets made from stinging nettle fiber (*Urtica dioica*). However, seine nets were the most common gear type used in the late 20th Century (Figure 33abc). There were no references made by the participants regarding the cedar basket traps, but 62% had previously fished with or had watched the traditional trap net being used (Table 8).

a)



Milwaukee Public Museum photo.

b)



Source: redrawn from Stewart (1977).

c)

Source: Robert Schooner photo.

Figure 33. Fishing methods used in the Nuxalk eulachon fishery a) cedar basket trap; b) the 'trap' net; c) seine net.

The traditional trap net was originally made from stinging nettle fiber. The nettle was harvested in the summer, dried and then rolled into a thin twine. The twine was interwoven to make a strong cord to construct the net. These nets were made during the winter and took several months to complete. The nets were about thirty feet long and purse-like. They were oval in cross-section, open at the wider end (eight feet in diameter) and tapered gradually towards the closed end (3 feet in diameter; McIlwraith Vol. II., 1948; Figure 33b). The nettle cord was eventually replaced with cotton twine. The mesh of these nets was larger at the opening and then got increasingly smaller towards the closed end where it was tied off (010 Nuxalk Interviews, 2006). The eulachon were removed, starting from the tied end, where sections of the net were brought into the canoe. There were four poles used to stake the net into the river bed. They were driven at least six feet into the river bed to hold the tremendous weight of the captured eulachon. One net full could consist of two to three full canoe loads, equaling thousands of fish (McIlwraith Vol. II., 1948). One Nuxalk fishers estimated that a trap net caught "a couple of tons at the most" (010 Nuxalk Interviews, 2006). When asked why trap nets were no longer used, several reasons were given. Firstly, it was harder to fish a trap net with vessels other than a canoe. Secondly, there were not many people who knew how to

construct a trap net. Finally, the seine nets were found to be more efficient at catching eulachon. According to the fishers that had used both types of gear, 71% believed seine nets were easier or faster method of catching eulachon. One Nuxalk fisher explained:

"It took longer…you only emptied your trap net once a day, left it over night, and changed it in the morning and you didn't open your trap until just before dark. That was just the way it was done in them days. Too many people in the river, if our trap was open then someone could drift inside it. Sort of a general understanding that you didn't have your trap open during the day" (047 Nuxalk Interviews, 2006).

Also, instead of three or four days of fishing with a trap net, it might take one day and just one set with a seine net (Clarence Elliot Nuxalk Interviews, 2006). The seine nets were approximately 60-70 feet long (Robert Andy Jr. Nuxalk Interviews, 2006). Once the seine net was introduced in the late 1970s the canoe and the trap nets became obsolete, "when they started going to the seine net that's when we stopped using canoes" (047 Nuxalk Interviews, 2006). By the late 1990s a few people still used the trap nets; however, they were much smaller and were essentially used to determine when the eulachon were coming. As each day passed the number of eulachon in the trap net would increase, until eventually the net was full (Peter Schooner and 010 Nuxalk Interviews, 2006). With the exception of the small trap net, the majority of fishers had switched to the seine net by the early 1980s. In spite of the efficiency of the seine net, some participants claimed that the grease tasted better when eulachon were caught with a trap net (Jimmy Nelson Sr., Anfinn Siwallace, Robert Andy Jr. and 048 Nuxalk Interviews, 2006). The trap net, using the pressure of the river, would kill the eulachon overnight, squeezing the blood out of the fish. "They were dead and their gills were almost white… when you seine them they're still alive, kicking and bleeding" (048 Nuxalk Interviews 2006). Therefore, if the blood was not properly drained, the grease would be dark, strong and more "fishy" tasting (Jimmy Nelson Sr., 047 and 048 Nuxalk Interviews, 2006). Other methods used to catch eulachon included rod and reel, dip net, hook and line, or by hand in shallow waters. These methods were more commonly used by women and children.

Run status

The Bella Coola eulachon run previously consisted of hundreds of thousands of individual fish. The strength of the run was determined by a four year cycle: three "average" years, followed by a fourth "good" year (Peter and Eleanor Schooner Nuxalk Interviews, 2006). Jimmy Nelson Sr. also commented that some years were better than others, "its weird how it [was] some years. There's just hardly any and then other years there's so much" (Nuxalk Interviews, 2006). Previously, during these good years, there were so many eulachon that people were able to fish with their hands.

There were some years, they were so plentiful that you could just go down and hand-fish them off the side of the river bank. Just walk down and grab them and put them in your bucket…there'd be a four foot black streak going up the side of the bank (Anfinn Siwallace Nuxalk Interviews, 2006).

It has also been suggested that the farther the distance the eulachon travel within a river to spawn the higher the abundance (Betts, 1994). In 1977, the DFO Fisheries Officer reported that the Bella Coola run was "not as strong as past years, and [eulachon] were only seen as far as mile 1 ½ [2.4 km]" whereas in 1980 when the run was larger, eulachon were "reported as far up as 8 mile [12.9 km]…farther than ever known to have been" (DFO, 1944-1989). In the Chilkat River of Southeastern Alaska, eulachon were commonly reported to migrate nine miles up the river. However, by the mid 1990s they spawned at or below the eight mile point, and it was suggested that the "shorter migration distance may be due to low overall run strength" (Betts, 1994).

In the late 1970s, several interview participants still reported large runs of eulachon that were easy to catch within the Bella Coola River. "In the late 70s… I remember I used to go down and sit on the bank and watch people fishing and of course you could just walk out in the river with your bucket and get your own" (Sandy Burgess, Nuxalk Interviews, 2006). However, by the early 1980s, several of the eulachon fishers reported low returns to the Bella Coola River. As a result, eight of the fishers interviewed, traveled to other rivers in Nuxalk territory to fish for eulachon.

"There was nothing in the Bella Coola River. No eulachon. One year there were no eulachon here. They don't like that when I say that but it was the truth, we had to go to South Bentinck looking for eulachon" (Andy Siwallace, Nuxalk Interviews, 2006).

One participant specifically recalled the year he traveled to South Bentinck, "I think it was '83 we just made up our mind to go and explore. Go down to South Bentinck, the Aseek. There's a good run there for a small system" (048 Nuxalk Interviews, 2006). However, Harvey Mack maintained that the eulachon were always present and that some guys just missed the run:

"We've always, as far as I can remember, we never had to move out of Bella Coola to get our eulachon. We didn't have to go to South Bentinck. The guys were just too late or not ready for the run" (Nuxalk Interviews, 2006).

Figure 34. Eulachon spawning in the Bella Coola River, April 1996. Source: Robert Schooner photo.

The bulk of the Bella Coola eulachon run usually arrive in late March or in early April, coinciding with the commercial herring fishing season in the Central Coast. Many of the men that had traveled to South Bentinck were also commercial herring fishers. Thus, it is possible that some may have missed the peak of the Bella Coola run. Nevertheless, there was growing concern for the eulachon run during this time. Horace Walkus, a grease maker, whose house is located alongside the Bella Coola River, noticed the decline, "I had a feeling that they were diminishing, like we're not getting much this year and each year it was going down and down" (Nuxalk Interviews, 2006). The most noticeable decline came in the last few years before the collapse, as the eulachon were getting much harder to catch (006 and 051 Nuxalk Interviews 2006). From the interview information, it appears that 1996 was the last large run of eulachon to the Bella Coola River (Figure 34).

Table 9. Status scale used to depict eulachon run size for the Bella Coola River

Run size status (1-10)	Meaning
1-2	Low
3-4	Medium-low
5-6	Medium
7-8	Medium-high
9-10	High

The 1996 run was described by an elder Nuxalk lady as "so thick that they were coming on the beach…we were able to just put them in buckets and bring them home" (015 Nuxalk Interviews, 2006). By 1997, the eulachon were getting harder to catch. Wally Webber, a Nuxalk eulachon fisher, remembered trying to catch eulachon in 1997:

"We had a really hard time that year, a really hard time. We couldn't get anything for the longest time and then finally one day…we got about 3 tons…and that's what we had to make grease with. That was it" (Nuxalk Interviews, 2006).

By 1998 there were still enough eulachon to make grease but several interview participants described the run size as "average" (Jimmy Nelson Sr., Wally Webber and 047 Nuxalk Interviews, 2006) and approximately eighteen tonnes of eulachon were caught (Tallio and Webber, 1998).

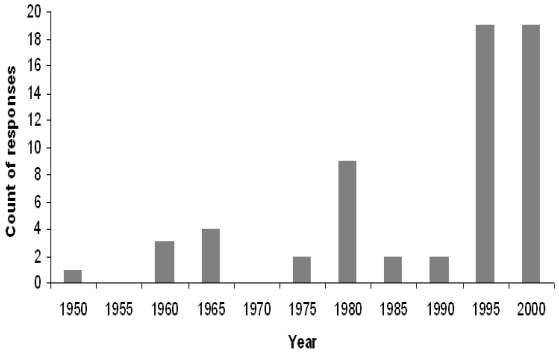


Figure 35. Number of respondents commenting on Bella Coola eulachon run status from 2006 Nuxalk

Examining past and present run status

A one to ten ranking scale was developed to describe the Bella Coola eulachon run status for a given time period (Table 9). Run size comments made during the 2006 interviews and those made in DFO Fisheries Officer's weekly reports and annual narrative reports (1944-1989) were ranked separately on the status scale. Comments made during the interviews were of a broader time frame than the DFO comments. The interview participants could only describe the stock status of specific decades or the early/late parts of a decade, such as the 'early '60s', but not individual year run sizes, that is, except for the last few years of eulachon fishing (1996-1998). This was expected, as the participants didn't keep written records and relied entirely on memory for their comments. On the other hand, the DFO comments were recorded in weekly typed reports, usually made by one officer, but not necessarily every year. There were stretches of time, such as in the early 1980s, where no comments were recorded in the DFO reports. Initially the interview comments were divided into fifteen categories, each consisting of five years, except for the late 1990s, where each year was a separate category (e.g., early 1960s, late 1960s, 1996, 1997, etc.). The number of participants that made comments for each category varied, with more comments being made for the more recent decades (Figure 35). Finally, the years for the early and late nineties were combined and a total of twelve categories were used for the results. These categories consisted of five year periods from 1945-2005. To get the final status value for each corresponding 5-year time category, the DFO individual year rankings (e.g., 1945-1949) and the multiple rankings from the interview responses were averaged. The result was twelve possible status data points for each of the DFO and the interview data sets.

The range of ranked values for each time period is shown with error bars on the interview time series (Figure 35). There was usually only one DFO comment per year, thus no range of values existed. The DFO time series depicts a downward trend in run size status, starting from 1945, with the most drastic decline seen after the early 1990s. The interview comments illustrate a sharp decline in the early 1980s, with a slight increase in run size in the late 1980s and early 1990s. Both sets of data display an overall declining trend in run size with a complete absence by the late 1990s (Figure 35). There is a significant correlation between the two different sets of run status data ($r^2 = 0.823$), shown in Figure 37.

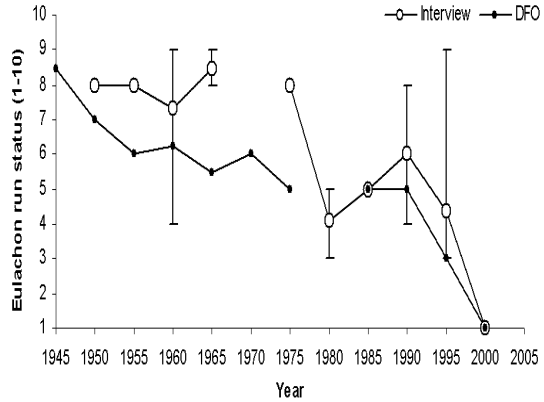


Figure 36. Eulachon run status, derived from 2006 interview responses and DFO Fisheries Officer comments, from 1945-2005

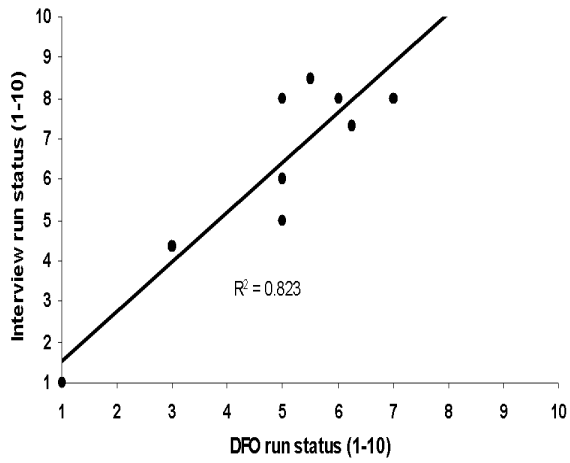


Figure 37. Comparison of Interview and DFO run size status data ($r^2 = 0.823$).

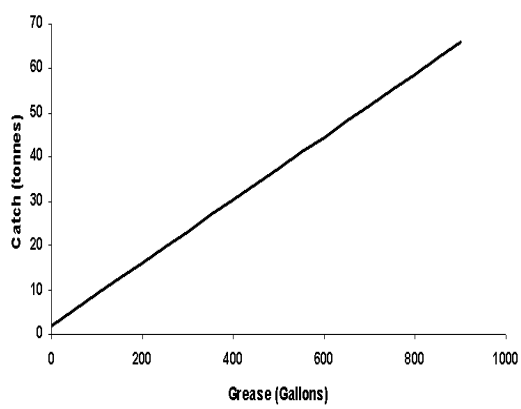


Figure 38. Gallons of grease produced vs. the total amount of eulachon caught for grease making.

Estimating eulachon catch from grease production

Calculating past eulachon catch from grease production is based on the relationship between the total eulachon grease produced and the total catch of fresh eulachon. If the amount of grease produced for each year can be determined and if some eulachon catch data already exists, catch can be estimated for years where no data exists.

Grease model

The grease model is based on the linear relationship (Figure 38):

$$\text{Catch} = (TG/\ gt) + fc$$

where 'TG' equals total grease produced by the community in one season, 'gt' equals the amount of grease produced from one tonne of fresh eulachon and 'fc' is the estimated portion of fresh eulachon caught, not used for grease making but used for smoking, salting, etc.

Grease production from family group

The Nuxalk eulachon fishery consists of several 'grease camps'. In order to produce grease, a camp must possess a cooking box and usually there is only one box per camp. Each camp is a family group and consists of several generations, married relations and close friends. The owner of the cooking box is usually the head of the camp or the 'head cook'. The head cook makes most of the decisions, such as when to start cooking, who can cook at the camp and who cooks first. Several cookings are usually completed at each camp during one season:

"Depends on how much we put in the box… maybe three or four cookings, depends on how many guys you got helping too, because if there's more guys, there'll be more eulachon in [the stink box]. Fill it right up" (043 Nuxalk Interviews, 2006).

Most of the families make between fifty and one hundred gallons of grease per year unless there was a special event, such as a potlatch, or an upcoming trade with a neighboring community. Then, approximately one hundred gallons or more might be made for that year. In order to calculate the amount of grease produced by the Nuxalk community for a specific year, the number of eulachon grease camps operating needed to be determined. Using the information provided by the interview participants, a time-series of each grease camp and its grease production, was constructed for the years 1980-1998. These years were chosen because the cooks interviewed, during this period, first became head cooks of their family's camp. Each head cook was first asked if he could recall the total amount of grease he produced for any specific year. If he could not recall a specific year, the years that his camp made grease were determined by how often his camp made grease. For example, if the head cook said his camp made grease every year, his camp was recorded for every year in the time-series. If he said grease was made every other year, his camp was recorded every two years and if grease was made only when grease supply was gone, his camp was recorded every four years. When the exact amount of grease was also not known for a specific year, the head cook gave an estimated range of grease produced by his camp. This provided high and low estimates for his camp's production. A best estimate was also made which took into account the number of cooks per camp and thus the total amount of grease one camp produced. These additional cooks did not have their own camp but helped to fish and helped to prepare the camp, thus were

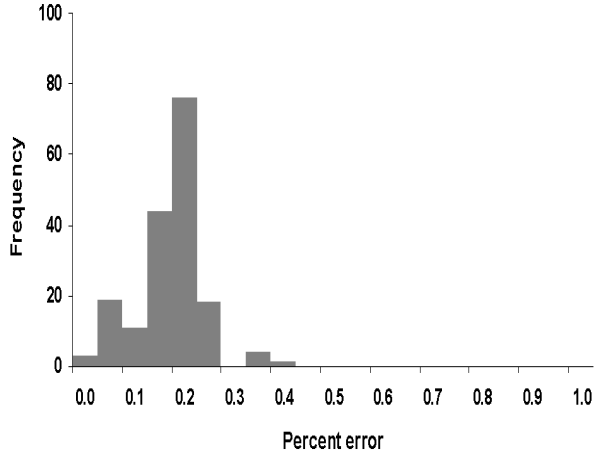


Figure 39. Frequency histogram of the absolute percent error surrounding the best estimate.

permitted to do their own cooking.

"They'd share the cooking box, like my dad shared his with his brother but he wouldn't help him make it. He'd just leave it there... he'd leave so much eulachon in [the] stink box and say "okay I've done enough, I've made enough grease. If you want to make some, there's eulachons over there... you just have to go make it"" (Carl Siwallace Nuxalk Interviews, 2006)

Also factored into these best estimates were bits of information gathered from old newspaper articles or journals that recorded the Nuxalk eulachon grease making for a specific year. For example, an article in Beautiful British Columbia magazine, titled "Oil of Oolichan" reported in 1980, "450 liters oolichan oil" was produced at one camp (Kopas, 1980). Also Kuhnlein *et al.* (1982) reported that in 1982, four camps were operating and in 1981 five camps were operating. This additional information helped to determine the number of camps and helped to decide on the best estimate for each year.

Error in raw data

A normal distribution was determined for the error in the raw data sets (i.e., grease estimates and the DFO catch data). The distribution was determined by examining two plots, a frequency histogram and a normal probability plot of the absolute error values. These plots are visual graphing techniques used to 'see' if a data set exhibits the properties of a normal distribution. The idea of the normal probability plot is to rank the data set and change the ranks into percentiles that can then be converted into z-scores (Hesse, 1998). If the data are normally distributed, they will lie in a straight line with the line crossing the x-axis at about the mean of the data.

Grease estimates

There were a total of 87 grease camps and 87 best estimates of grease production determined for the 19 year time series. The percent (+/-) error of these best estimates was calculated using

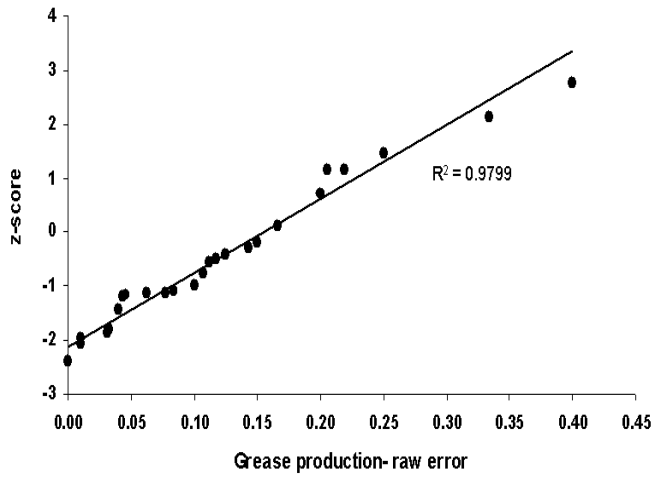


Figure 40. Normal probability plot of the absolute percent error surrounding the grease production best estimate (r2 = 0.98).

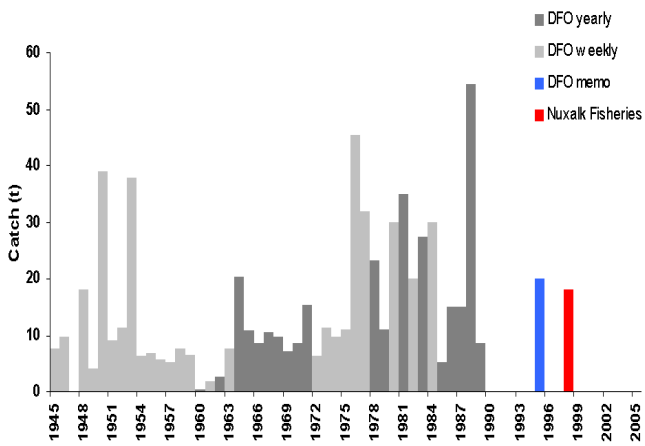


Figure 41. Bella Coola First Nation eulachon catches as reported by DFO and the Nuxalk Fisheries Department (1945-1998).

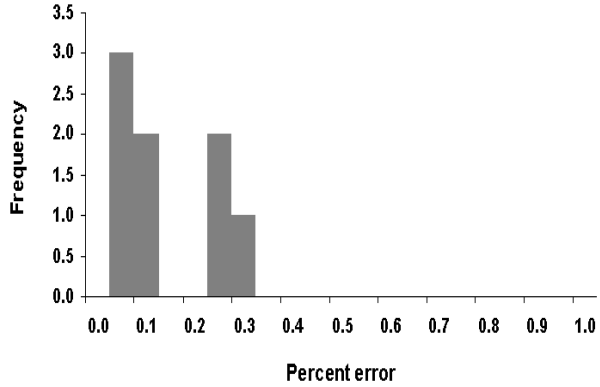


Figure 42. Frequency histogram of the absolute % error surrounding DFO reported catch.

the high and low range given by the head cooks as a percent of the best estimate. The average percent (+) error of the 87 high values totaled 15.3% and the average percent (-) error for the 87 low values totaled 15.7%, thus a coefficient of variance of 15.5% was used. The grease error frequency histogram appeared to be normally distributed (Figure 39) and the normality plot exhibited a straight line with an r^2 value of 0.98 (Figure 40) thus a normal distribution was assumed.

Department of Fisheries and Oceans (DFO) catch data

DFO eulachon yearly catch totals for the Bella Coola River Nuxalk fishery were recorded in Fisheries Officer's weekly reports and annual narrative reports, and memos from 1944-1989 and 1995 (Figure 41). The weekly reports recorded catches for each day of the week whereas the yearly reports only summarized the catches for the season or gave an annual catch total. One year of catch data was also included from the Nuxalk Fisheries Department, as the fisheries manager observed and recorded the catch daily during the 1998 season (Figure 41; Tallio and Webber 1998). Prior to 1997, there was no regularly functioning fisheries department for the Nuxalk Nation. The annual average eulachon catch for the Bella Coola River using these two data sources equaled approximately 15 t.

The DFO eulachon catch totals for the years 1980-1989 were used in the analysis. Since no error or range of catch was recorded for the DFO data, another source of recorded eulachon catch was used to determine the possible error. A report titled, "The socio-economic importance of fishery resources to the Bella Coola Valley," by Environment Canada, recorded the annual catch of eulachon in the Nuxalk fishery from 1965-1973 (excluding 1972; Boland, 1974). For these same years, the percent difference (+/-) between the Boland catch and the DFO catch was calculated. The following percent error was determined: (+) average of 9% and (-) average of 16%, thus a coefficient of variance of 11.7% was used. The DFO error frequency histogram appeared to be normally distributed (Figure 42) and the normal probability plot strongly suggested a normal distribution (r^2=0.89; Figure 43); thus a normal distribution was assumed.

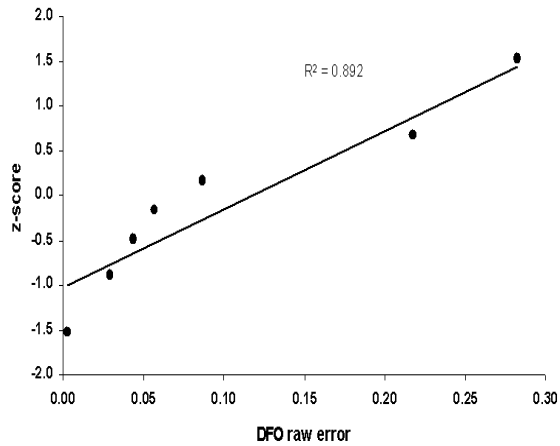


Figure 43. Normal probability plot of the absolute % error surrounding DFO reported catch (r2 = 0.89).

Fresh catch (fc)

The fresh catch consisted of the portion of the catch used for smoking, salting, freezing, or for eating fresh; independent of the catch used for grease production. According to several of the eulachon fishers it was common for the community to take between two and four boat loads of fresh eulachon (Horace Walkus, Peter Schooner, Andy Siwallace, 010, 033 and 047 Nuxalk Interviews 2006). These boat loads were wooden skiffs that varied in size and in the amount filled by a fisher. Thus fisher's estimations of weight per skiff ranged from 500 lbs (0.23 t) to over 2000 lbs (0.91 t). However, those who estimated lower weights per skiff estimated more boat loads to the community and those who estimated higher weight per skiff, estimated fewer boat loads. As a result, the total estimation of fresh catch

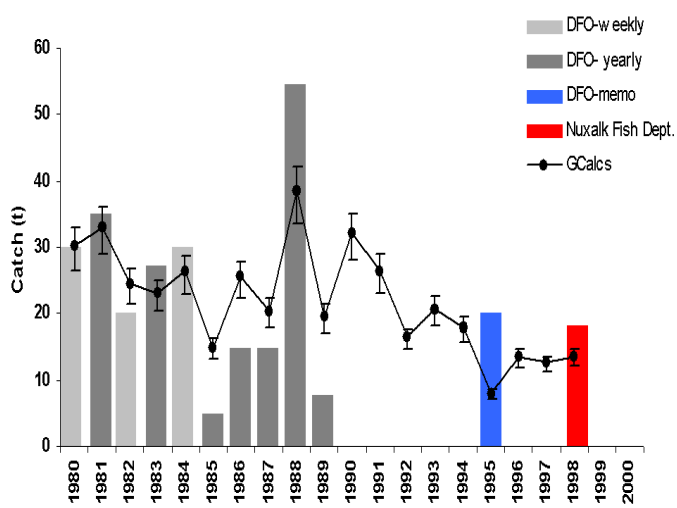


Figure 44. Estimated eulachon catch (black line) with confidence intervals, from the grease model (1980 to 1998), plotted with the original eulachon catch data (DFO dark grey-weekly, light grey-yearly, checkered grey-memo; Nuxalk Fisheries- diagonal lines).

was narrowed to a range between 1.5 and 3.0 t. In the model, a random number from a normal distribution was generated between these amounts and used as an estimate for each year's fresh catch.

Confidence intervals and estimating catch

Confidence intervals on the estimated catch were estimated using a Monte Carlo routine developed using Excel, Visual Basic for Applications and the Grease Model. Five hundred simulations were run, each generating a replicate data set of grease values and catch values based on the original 'best estimate' grease data and the recorded DFO catch data. Each new grease and catch data set, was determined using random values that had the same statistical properties as the original data (i.e., from a normal distribution and the same variance and mean as the original data). For each simulation the solver routine in Excel attempted to minimize the sum of squares between the randomly generated DFO catch data and the new catch estimated from the relationship: [Catch = (total grease produced/gt) + fc] by altering the model parameter, gt. Each time the process was repeated, the estimated catch data set was changed when different sets of random numbers were selected. The fitted gt parameter was used to estimate a new catch time-series (Figure 44). Confidence limits for the catch were calculated using the 95th percentile of parameter gt. In addition catch estimates were made for the years (1990-1998) where previously no eulachon records had been kept. Refer to Appendix 6 for a summary of the results.

Setting limits for parameter 'gt'

To prevent unreasonable estimates of parameter 'gt', high and low constraints were added to the solver routine, to limit its value. The constraint values were determined from two reports, the Nuxalk Nutrition Food Project (Kuhnlein *et al.*, 1982) and a report on Knight Inlet grease production (Common Resources Consulting Ltd., 1998). The 1982 Nuxalk Nutrition Food Project calculated that each stink box held approximately 6300 kilograms of fresh eulachon and yielded an estimated 280 litres of grease. The project also reported that five stink boxes could yield upwards of 2000 litres of oil (Table 10). For comparison, the gt, for Knight Inlet, ranged from 10.0-13.3 (Common Resources Consulting Ltd., 1998). The constraints for gt were set at 9 and 16 gallons/t of fresh eulachon. The model estimated the parameter gt at: 14.07 gal/t with confidence intervals calculated using the 95th percentile (high = 15.6 gal/t and low = 12.4 gal/t; Figure 45).

Table 10. Previous studies calculations of grease produced (gallons), per metric tonne (t) of fresh eulachon. Source: Knight Inlet- Common Resources Consulting Ltd., 1998; Bella Coola – Kuhnlein *et al.*, 1982

Location	Year	(t) of fresh fish	Litres (L) of grease	Gallons (G) of grease	gt (G/t)	gt (L/t)
Bella Coola (1 stink box)	1981	6.3	280	61.6	9.8	44.4
Bella Coola (5 stink boxes)	1981	31.5	2000	440	4.0	63.5
Knight Inlet (average)	1998	1	55.0	11.0*	10.0*	45.3
Knight Inlet (max)	1998	1	60.2	14.6*	13.3*	60.2

*Converted from reported gallons/ton.

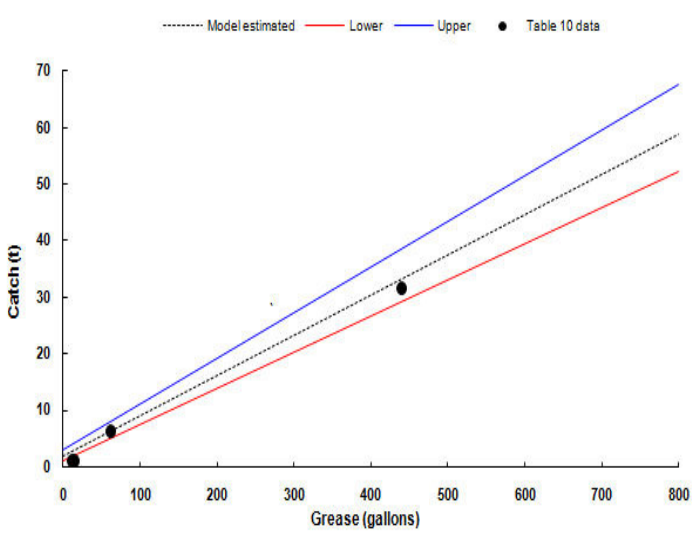


Figure 45. Confidence intervals calculated using Monte Carlo limits (95%tiles) of parameter gt (gallons/t) and comparison data from Table 10.

There are several reasons for the range seen in gt values. Firstly, female eulachon were said to produce more grease than males (009, Horace Walkus, 048, 051 Nuxalk

Interviews, 2006), with the first run consisting of mostly females, followed by a run of males, and then a mixture of both (Hazel Hans Sr., Kitty Moody, Eleanor Schooner, Horace Walkus, 033, 048 Nuxalk Interviews, 2006). Studies conducted on other rivers have also reported the dominance of females in the first part of the run, followed by a wave of males: the Kemano River (Lewis *et al.*, 2002), the Nass River (Langer *et al.*, 1977) and generally in Northwest Coast rivers (Stewart, 1977). Rogers *et al.* (1990) also found that the lipid content of whole females was greater than that found in male eulachons. Although females were preferred for making grease, the Nuxalk's principle was to allow the first run to go through without any fishing. One Nuxalk fisher described the logic behind this principle:

"The females had the most oil so it was tempting to [go fishing] but there was a hard law that said "no, we don't touch it", that [was] our way of managing, that [was] our conservation method" (048 Nuxalk Interviews, 2006).

In 1998, it was reported that Knights Inlet grease camps could produce 26 gallons of grease from 2.04 t of fresh eulachon if only females were used (Common Resources Consulting Ltd., 1998). Secondly, the amount of time that the eulachon were aged also contributed to the difference in the amount of grease produced per tonne. If fish were aged too long they would produce less grease. However, if the cooking was started too early, the fish were said to release less oil (030 Nuxalk Interviews, 2006). Finally, if the eulachon were caught too late in the run, less oil was also produced (048 Nuxalk Interviews, 2006). This was probably due to eulachon fat resources being consumed during the maturation process. For the Nuxalk eulachon fishery it was common practice to use a mixture of both females and males and to catch the eulachon before they reached the spawning grounds.

Effort

The effort in this fishery was difficult to determine quantitatively. The only recorded fishing effort data found was in DFO reports and only described by the number of nets used during the season. And this was only for three years (1949 to 1951), where 5, 20 and 9 trap nets were recorded. Thus, the only way to describe the effort in the fishery was to combine the catch and the TEK/LEK information. Some of the older participants (born during the 1920s) discussed how there were more stink boxes when they were younger and lived in "Old town" (015 and Andy Siwallace Nuxalk Interviews, 2006). Old town was the town site of Bella Coola that was previously located on the north side of the river. There were large floods in 1924 and 1932 that caused much destruction. It was the 1936 flood that tore out the footbridge connecting the north and south sides of the river that persuaded the Nuxalk people in 1938 to relocate to the south side of the river. Thus it would have been during the 1930s when the older participants recalled "lots" of operating stink boxes.

When examining the DFO records, the catch for the early 1960s appeared to be quite low (Figure 41). It is difficult to determine if this was due to low effort or poor catch recording. However, from 1960-1963, comments in DFO Fisheries Officer reports are minimal or non-existent, as the officer took annual leave during the eulachon season. One Nuxalk fisher stated that during this period, a dam had been built in the river and the estuary was used as a booming ground for logging companies (048 Nuxalk Interviews, 2006). He reports that these activities resulted in low returns which forced the Nuxalk to conserve the run for the next few years so it could rebuild itself. Thus this may have accounted for the low catches in the early 1960s.

Table 11. Perception of the number of people involved in the Bella Coola eulachon fishery, prior to the 1999 collapse, compared to 20 or 30 years before (i.e., 1970s and 1980s).

Did the number of people in the fishery decrease? (Results from 18/29 participants)	% of participants	# of participants
No answer	38	(11/29)
Some cause stated	62	(18/29)
No or less than 10%	11	(2/18)
Yes a little (20-30%)	11	(2/18)
A fair bit (30-40%)	22	(4/18)
A lot (<50%)	56	(10/18)
Total	89	(16/18)

Effort in the 1970s may have been higher as the catches appear to have increased. "When I first started [making grease] in the 70s there were at least ten maybe twelve eulachon camps, the last year [1998] there were only five" (Russ Hilland, Nuxalk Interviews, 2006). It is difficult to determine if the number of participants decreased or if it was just the number of operating camps that decreased. Interview

participant views varied, when asked if the number of people involved in the fishery had decreased. Fifty-six percent of the respondents stated that the number of participants decreased by "a lot" or by "more than 50%" and 89 % believed that participation had decreased by some amount (Table 11).

Those participants that thought the number of people involved remained the same or decreased "a little" also believed the members from several different family groups were working together rather than running their own camp. The "[number of people] probably stayed the same … [as] everybody started ganging together" (Wally Webber, Nuxalk Interviews, 2006). Thus the same numbers of individuals were producing grease but not as much grease was being made.

"In the later years, we didn't do as much" (Peter Schooner, Nuxalk Interviews, 2006).

"I never really made much anyways. When you have eulachon grease you like to have it fresh, like having smoked eulachons, you don't want to keep them from year to year" (047 Nuxalk Interviews, 2006).

"Back in the day, 30 years ago, everybody had their own eulachon camp because they were making lots [of grease]…four or five cookings…later there might have been almost as many people involved, but they weren't doing as much grease" (Russ Hilland, Nuxalk Interviews, 2006).

The only catch per unit effort information that may reveal declining abundance was from comments made by participants regarding the fishery during the last decade of the fishery (the late 1990s).

"As time went on, there seemed to be less eulachon in the river, smaller schools, and not as much were caught in each seine set" (009 Nuxalk Interviews, 2006).

"The runs seemed to get shorter…then they'd come early, then they'd be gone" (Anfinn Siwallace, Nuxalk Interviews 2006).

"The amounts of sets you'd have to do and stuff was increasing" (Carl Siwallace, Nuxalk Interviews, 2006).

"People were starting to get low amounts of eulachon. They were working hard to get them" (Wally Webber, Nuxalk Interviews, 2006).

The Bella Coola eulachon run collapse

In 1999 the eulachon failed to return to the Bella Coola River. Jacinda Mack, a member of the Nuxalk Nation, described the atmosphere in Bella Coola at the time:

"[The] arrival of the eulachon is always a big event in the Nuxalk valley. In the days preceding their appearance, throngs of birds and people line the shores of the river, watching and waiting for the eulachons to return. Families ready their smoke houses, inspect their nets and prepare the stink boxes. However, in the spring of 1999, after weeks of waiting- anticipation turned into anxiety and finally into confusion and despair" (Mack, 2000).

Today, the Nuxalk people are still waiting in anticipation for the return of the eulachon. It has been nine years since the last eulachon fishery occurred on the Bella Coola River and the impact of the collapsed run can still be felt today.

"I seen a big difference, like right now everybody would be working, getting ready…everybody would be happy…getting ready for a good feast. Now everybody is walking around in a daze, seems like to me" (Harvey Mack, Nuxalk Interviews, 2006)

"I think it depressed people. It kind of broke the social atmosphere in the spring time. People used to look forward to it in the winter, it was a favorite occasion. It was like a festival, eulachon grease making. All the families would be busy…making grease, you'd see them up and down the river working around the cooking camps. You'd hear them laughing, joking around, telling stories. It used to be a good place where you could go listen to stories" (048 Nuxalk Interviews, 2006).

The most frequent questions participants asked during the interviews were "are they coming back?" and "why did it happen?" Some Nuxalk fishers believe that they are being blamed for overfishing the Bella Coola run. However, if overfishing was the main reason for their decline, why are they not returning to the other rivers in Nuxalk territory? "Kimsquit and Kwatna.... South Bentinck, why are they diminishing there too? Nobody's fishing them. So what's happened?" (Horace Walkus Nuxalk Interviews, 2006). Since the collapse several people have traveled to South Bentinck in search of the eulachon, but without success (Robert Andy Jr. and 010 Nuxalk Interviews, 2006). One interview participant, a camp watchman for a logging camp on the Kimsquit River (Upper Dean Channel) from 1998-2000, caught eulachon in 1998 but the following year, 1999, the Kimsquit run also failed to return. From the discussion during the interviews, it appears that all ten eulachon river systems in Nuxalk territory collapsed around the same time, the spring of 1999. The many hypotheses regarding the collapse of the Bella Coola eulachon will be discussed in the final section of this report ("Discussion and Conclusions").

CONCLUSION

The Nuxalk Nation has experienced enormous change in the past two hundred years since contact with non-First Nations, from population decimation by infectious diseases to today's loss of the eulachon. The absence of the Bella Coola eulachon has made the Nuxalk eulachon fishery and eulachon grease making a part of the past.

"There's no gathering down the river any more, number one. There's no hustle bustle, there's no smoke houses going, our kids don't know what eulachons are, our elders have suffered from not having it... a way of life has changed, our way of life" (Anfinn Siwallace, Nuxalk Interviews, 2006).

Despite the loss, the Nuxalk interview participants spoke of the eulachon and grease making with pride. Although the fishery saw changes in fishing and processing techniques, the Nuxalk people strove to protect the resource by introducing new regulations. Motor boats were banned and the first run of females was allowed to pass through without fishing. Despite these efforts, the Nuxalk elders remained concerned, as if the decline seen in the early 1980s was a forewarning of the 1999 collapse. The eulachon fishery of the late twentieth century may not have been the salvation fishery of the past but it was still a vital component in the teaching and guiding of the younger generations. In general, the interview participants were keen to participate and document the Nuxalk eulachon fishery. The quantity of the grease produced and the estimated eulachon catch was only possible to calculate because of the information shared by the Nuxalk fishers and elders. Their knowledge of the eulachon, the fishery, the river, and all the changes that occurred, have helped to guide this study and have helped to encourage the search for an explanation to the eulachon's disappearance.

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RECONSTRUCTING ABUNDANCE OF EULACHON THROUGHOUT ITS GEOGRAPHIC RANGE USING A FUZZY EXPERT SYSTEM

INTRODUCTION

Eulachon in-river relative abundance has been roughly assessed in the past by analyzing commercial catch statistics (Ricker *et al.*, 1954; Washington and Oregon Departments of Fish and Wildlife [WDFW/ODFW], 2005). More recently, additional relative abundance indicators have become available to assess eulachon run strength for specific rivers (i.e., Fraser and Columbia Rivers). In the Fraser River, three pre-season indicators (egg and larval surveys, offshore eulachon biomass estimates from shrimp trawl surveys and Columbia River catch data) and one in-season indicator (the Fraser River eulachon test fishery) are used to determine the relative strength of the current year's run (DFO, 2006). The Columbia River management plan also uses test fishery catches, larval density estimates and DFO offshore eulachon biomass estimates to predict relative run strength and guide management decisions (WDFW/ODFW, 2005). However, these relative abundance indicators have short time-series and can only be applied to these two rivers. Thus far, in-river egg and larval surveys, used to calculate spawning biomass, are the most effective method to determine a river's run strength.

Historically in British Columbia (BC), these surveys were only conducted sporadically, for example, Skeena River, BC (Lewis, 1997), Nass River, BC (Orr, 1984), Klinaklini River, BC (Berry, 1996), Kitimat River, BC (Penderson *et al.*, 1993) and the Kingcome River, BC and Wannock River, BC (Berry and Jacob, 1998). More recently, consistent annual estimates have been conducted on the Fraser River by DFO from 1995-2006 (DFO, 2007) and the Bella Coola River by the Nuxalk Fisheries Department from 2001-2006 (Lewis and O'Connor, 2002; Winbourne and Dow, 2002; Moody, 2005, 2006; Nuxalk Fisheries, 2005-06). Extreme declines of some eulachon populations have been observed, for example, in 1994 the Fraser River run noticeably declined (Hay and McCarter, 2000), in 1999 the Bella Coola River failed to return and since 1998, the run on the Kitimat River has had very low returns (EcoMetrix, 2006). In the absence of data on absolute stock abundance, two types of information are commonly used to assess fisheries status: a history of catches and an index of abundance (Hilborn and Mangel, 1997).

Although it is unlikely that the fishing of eulachon has caused the extreme declines of the Bella Coola River and Kitimat River eulachon populations, catches are the most readily available data. Catch time-series data were available for some of the more well-known eulachon rivers. However, catch information can often be a misleading trend indicator. A "healthy" increase in catch could be the result of three possible scenarios: (1) the stock is healthy, (2) the fishing effort has increased or (3) the range occupied by the species has decreased (Walters and Martell, 2004). In the late 1800s, when commercial eulachon fisheries first began, catches were likely affected by economic factors and market demand and not the abundance of the stock. This is shown by a quote from Clemons and Wilby (1946):

"As the knowledge of other species increased and fishing improved, the eulachon market deteriorated… demands of the small local markets rather than the supply of fish, have dictated the size of catch at the peak of the run."

McHugh (1941) also reported that on the Fraser River:

"The total catch [of eulachon] in any area is governed to a considerable extent by the demand. In the year of a heavy run, an abundance of fish may be caught in a short time, and no advantage is gained by fishing long hours if the extra catch cannot be sold. In the case of a light run, by fishing longer hours it may still be possible to keep up with the requirements of the market. The total catch in such cases would give no idea of the relative abundance of fish."

The commercial catch from the Columbia River was also known to be affected by consumer demand and changes in regulations e.g., from 1960-1977. With the exception of 1965 and 1966, the commercial fishery was open year-round 3 1/2 days per week, but in 1978 this was expanded to 7 days per week (WDFW/ODFW, 2005). Thus commercial eulachon landings, summed for the whole fishing season are not reliable indices of abundance for the Columbia and Fraser Rivers. Consequently, a need has arisen to develop an alternate method to evaluate eulachon relative abundance.

Mackinson and Nottestad (1998) refer to detailed information collected by scientists, in the desired format, as "hard data", and the applied knowledge of fishers and fisheries managers, as "practical data"; the latter collected by the review of literature and interviews with experts. The combination of the hard and practical data can reduce the uncertainty surrounding past eulachon abundance assumptions, which have been based primarily on past catch records, and be used to build a more complete understanding of these populations. Hence, it should be possible to combine eulachon catch data and other scientific data (e.g., CPUE and larval surveys) with experts' knowledge of the fishery and infer a relative abundance index for eulachon for different rivers.

As eulachon abundance estimates are rare and catch data by themselves can be a poor representation of relative abundance, fuzzy set theory may provide an alternate method for obtaining reliable estimates of relative abundance. Fuzzy set theory or fuzzy logic was first introduced by Lotfi Zadeh (1965). Basically the idea of fuzzy logic is that a proposition is not just true or false but may be partly true or false to any degree (Nogita, 1985). Fuzzy sets are terms that define general categories so the transition from one category to another is gradual with some states having greater or lesser membership than others (Cox, 1999). Thus fuzzy logic uses an imprecise but very descriptive language to deal with input data, more like a human expert would.

Study objectives

Eulachon were of only "marginal interest or concern to Fisheries and Oceans Canada (DFO) prior to 1990" (Hay and McCarter, 2000), thus there has been limited documentation on past catches and only recently any examination of annual abundance. The purpose of this study was to use fuzzy logic to describe past and present eulachon abundance trends for fifteen eulachon systems in seven geographical areas across the entire geographical range of the fish. Each of these eulachon systems represents a geographical area comprised of either one or more than one eulachon river(s). Because of limited data only rivers where data sets could be located have been used. These geographical areas are: Alaska South Central, Alaska Southeast, BC North, BC Central, BC South, Washington/Oregon and California (see *Review of historical eulachon fisheries* for detail). The final results from this chapter will display four coast-wide, colour-coded eulachon abundance status tables.

METHODS

Fifteen eulachon systems were analyzed (Table 12). They are referred to as eulachon 'systems' and not rivers because one of the systems is an inlet (Cook Inlet, Alaska) and includes three rivers. The other fourteen systems are individual rivers and include: the Alaskan Rivers (Copper, Chilkat, and Unuk); the BC Rivers (Nass, Skeena, Kitimat, Kemano, Bella Coola, Wannock, Kingcome, Klinaklini, and Fraser), the Columbia River from the States of Washington and Oregon; and the Klamath River from the State of California. Using similar methods developed by Cheung *et al.* (2007) an index of annual eulachon abundance is estimated for each of these systems. Cheung *et al.* (2007) use catch time-series data to determine the exploitation status of several fisheries and combine this information to estimate the depletion risk index of a species. The exploitation status of a fishery is based on the relative position of the annual catch in the time-series and its ratio to the maximum catch. However, instead of using only the exploitation status of a fishery to determine an index of eulachon abundance, this fuzzy expert system also includes seven other types of data.

Types of data

In each system a maximum of eight types of data were available to assess the relative abundance of these eulachon populations: (1) First Nation/recreational/commercial catches (CA); (2) Catch-per-unit-effort (CPUE) data; (3) spawning stock biomass estimates (SSB); (4) test fishery catches (TF); (5) larval survey data (LS); or (6) annual run size report comments (RC); (7) fishing effort comments (LE); and (8) interview and local comments (ILC) (Table 12). The report and low effort comments were obtained from specific comments made in scientific or fisheries officer reports during or after a fishing season, while interview and local comments were obtained from specific comments made by local experts. See Appendix 7 for a detailed description of where each data source used for each eulachon system were found.

Catch data (CA)

Table 12. Data sources available for 15 eulachon systems used in the expert system, including the number of data sources for each system and the number of systems that have a specific data source.

RIVER		CA	LE	CPUE	SSB	LS	TF	RC	ILC	TOTAL # data sources
Klamath	R1								✓	1
Columbia	R2	✓	✓	✓		✓		✓		5
Fraser	R3	✓	✓	✓	✓		✓	✓		6
Knights	R4	✓	✓					✓	✓	4
Kingcome	R5	✓	✓					✓	✓	4
Wannock	R6	✓						✓	✓	4
Bella Coola	R7	✓	✓		✓			✓	✓	4
Kemano	R8	✓	✓	✓				✓	✓	5
Kitimat	R9	✓	✓	✓	✓			✓		5
Skeena	R10							✓	✓	2
Nass	R11	✓	✓	✓				✓		4
Unuk	R12	✓						✓	✓	3
Chilkat	R13	✓						✓		1
Copper	R14	✓	✓					✓		3
Cook Inlet	R15	✓	✓						✓	3
TOTAL # systems		13	10	5	3	1	1	13	9	
Total data sources										54

Catch time-series was the most widely available of the eight data sources and so it was the most commonly used. It can be useful when attempting to understand the overall status of a population (Grainger and Garcia, 1996). But eulachon catch data can be a poor indicator of abundance when market demand influences the level of catch. The relationship between catch and population status also becomes less reliable when catch is influenced by stricter management policies, environmental factors or by changes in fishing effort. The expert system was designed to minimize these effects by incorporating other data sets. However, when only catch data were available, the expert system was limited to estimating the abundance status based on the relative position of the annual catch, before or after the maximum catch and the ratio of the annual catch to the maximum catch.

Low effort information (LE)

LE information was taken directly from comments made in reports describing the effort of a specific eulachon fishery. The LE information was only used in the algorithm when it existed with catch data. Thus if an LE comment existed, a (1) was assigned for that year in the river's data base. If no information existed or no fishery took place or fishing effort was normal, no data was entered. Examples of comments describing low effort are:

"There was a heavy run of oulachons fishermen were not very active on account of lack of demand [1940 Fraser River]" (DFO, 1940-1979).

"The eulachon harvest was quite a bit lower than normal this year mainly because a high [water level] occurred at their peak of migration making catch success poor [1985 Bella Coola]" (DFO, 1944-1989).

"The oulichan run to the Nass River was considered to be moderately good this year, judging from reports received from local Natives, however catches for food purposes were fairly light in comparison with some past years due to the quantity of ice moving downstream in the Nass River which hampered fishing activities [1965 Nass River]" (DFO, 1941-1973).

Thus it was assumed that catch time-series data underestimated the abundance of the population when LE information existed.

Catch-per-unit Effort (CPUE)

Only five of the fifteen eulachon systems had CPUE data: the Columbia River (1988-2006), the Fraser River (1941-1953, and 1982-1996), the Kemano River (1988-2004), the Kitimat River (1994-2006) and the Nass River (1995-2005, excluding 1997). As the CPUE data sources all had different units, each data point was expressed as a ratio of its maximum value in its time-series. It has been suggested that CPUE may overestimate eulachon abundance (WDFG & ODFG, 2001). For example, eulachon are known to exhibit shoaling behaviour when entering the river, and therefore catchability may remain high even when overall abundance has declined substantially, making CPUE a poor index of abundance (WDFG & ODFG, 2001). However, this might be compensated to some extent since eulachon were caught in-river with a limited area to escape fishing activities. Moreover, the data were averaged over the entire season. Two other problems have been identified in the Columbia River commercial fishery regarding using CPUE to assess run strength: 1) during high periods of abundance nets may be saturated with fish and CPUE may not reflect true abundance; 2) during high abundance markets may not be able to process and sell all the available catch so fishers deliberately reduce their catch rate (WDFG & ODFG, 2001).

Apparently, the Columbia River CPUE data were collected weekly (pounds of eulachon per delivery) and averaged at the end of each season (WDFG & ODFG, 2005). The Fraser River CPUE data included two separate time-series. The first time series (1941-1953) was calculated by dividing the total catch in pounds by every 100 square fathoms of net used per hour of fishing (Ricker *et al.*, 1954). The second time series (1982-1996) was calculated in tonnes of eulachon caught per day averaged for the season (DFO, 2008). Kemano River CPUE data was calculated in t/set averaged for the season (Lewis and Ganshorn, 2004). The Kitimat River CPUE data was expressed in terms of fish caught per 24-hour gill net set (7.6 m x 1.8 m, 3.8 cm mesh; EcoMetrix, 2006). Nass River CPUE data was expressed in terms of total catch for the season per total hours fished for the season (Nisga'a Fisheries, 2007).

Spawning Stock Biomass (SSB)

SSB data were limited and only three rivers had 5 or more years of consecutive time-series data: the Fraser River 1996-2006 (DFO, 2007), the Bella Coola 2001-2006 (Lewis and O'Connor, 2002; Winbourne and Dow, 2002; Moody, 2005, 2006; Nuxalk Fisheries, 2005-06) and the Kitimat River 1993-2006 (Penderson *et al.*, 1995; EcoMetrix, 2006). The Fraser and Bella Coola surveys calculated the relative spawning biomass of eulachon from the capture of eggs and larval caught during in-river plankton tows. The Kitimat River surveys roughly estimate the total number of spawners from gill netting and split beam hydro-acoustics (Stevens, 2001). The Fraser and Bella Coola population assessment studies were initiated after major declines had occurred in the populations. As these SSB estimates may have only calculated the biomass of the depressed population and each data point is expressed as the ratio of its maximum value in the time-series, these estimates may overestimate eulachon abundance when no other data source exists to contribute to the final abundance status prediction. Fortunately, for these systems there are other data sources available.

Larval Surveys (LS)

Larval survey data only existed for the Columbia River. The larval surveys began in the Columbia River tributaries in the early 1990s and expanded to the mainstem of the river in 1996. They were used to measure the brood-year strength of the run by measuring larval densities that were averaged across stations and depths at selected index sites (WDFG/ODFG, 2005). In past years, the sampling techniques did not include the same sampling areas or were not conducted over the same time periods. Thus the data may not "accurately reflect the overall abundance" (WDFG/ODFG, 2005). In addition, these surveys were not initiated until after the run had a noticeable decline in abundance (1994), thus "it is difficult to correlate larval catches to relative run strength" (WDFG/ODFG, 2005). For consistency between data sources, each larval survey data point was expressed as a ratio of its maximum value in the time-series.

Test Fishery (TF)

Test fishery data only existed for the Fraser River: it operated during the eulachon spawning seasons between 1995 and 2004, with the exception of 1999 and used a standardized gillnet deployed for 15

minutes during slack tide (Therriault and McCarter, 2005). The total catch was counted and each individual fish reported. TF data generally corresponded with the SSB estimates in the Fraser River, however, in the years where it did not, the test fishery predicted greater abundance than the SSB estimate. Therriault and McCarter (2005) suggest that this is perhaps due to "the limited (daily) and unreplicated (one time) sampling method employed by the test fishery… as eulachon can be highly schooled (but not necessarily abundant) during the 15 minute fishing window." As with other data, for consistency between data sources each TF data point was expressed as a ratio of its maximum value in the time-series.

Report Comments (RC)

Report comments were obtained from specific written comments made in scientific reports or fisheries officer reports during or after the eulachon fishing season. To assign a numerical value, the comment was interpreted and ranked on a scale from one to ten. A score of one meant that abundance was extremely low and a score of ten meant abundance was very high. For example:

"There was a good run of eulachons in the Fraser River this week and although it was fished quite intensively, escapement appeared good [Fraser River - Chilliwack-Hope district 1954]" (DFO, 1940-1979). Score: 8

"Oulichan run to Bella Coola less than half of total run according to catch with heavy fishing [Bella Coola 1956]" (DFO, 1944-1989). Score: 4

"The run of eulachons into the Nass River this year is one of earliest and largest since 1904 [Nass River 1958]" (DFO, 1941-1973). Score: 10

Interview and local expert comments (ILC)

These comments were obtained from local experts during interviews, personal conversations, from e-mails, or from local knowledge recorded in published or unpublished reports. They were based on a person's recollection of an event, years after it had occurred, whereas report comment data were recorded and based on an expert's knowledge during the time of the actual event. To assign a numerical value to the comment, the comment was either, interpreted and ranked on a scale from one to ten by the researcher, or a local expert assigned a specific value for the year. A score of one meant that abundance was extremely low and a score of ten meant abundance was very high.

Operating the eulachon fuzzy expert system

The expert system was developed using Microsoft Excel and Visual Basics for Applications (see Appendix 8 for the complete code). The expert system was designed to combine the 8 data types above to derive an annual index of eulachon abundance status (Figure 46). In order to estimate the annual abundance status for an eulachon system, one or more of the data series had to have at least five years of consecutive data. However, once this data requirement was met, data sources with sporadic years of data were also used, as for example in an individual report comment (RC) from 1977. A conventional fuzzy model has three basic steps: (1) fuzzification (2) inference process (3) defuzzification (Kandel, 1994). These are described below.

Fuzzification

The fuzzification process determines the degree of membership to the fuzzy set using membership functions and input parameters (e.g., smoothed catch).

Exploitation status

The catch time-series data were categorized into exploitation status categories. Since fluctuations in catch can be caused by changes other than those due to fishing (e.g., primary productivity in the environment) each catch time-series was smoothed with a 3-year running average (Figure 47a and b). A 3-year running average was chosen because three years is thought to be the most common age of maturity for most eulachon populations (Hay and McCarter, 2000) and thus thought to be sufficient to smooth any major catch fluctuations that may have been caused by environmental variability.

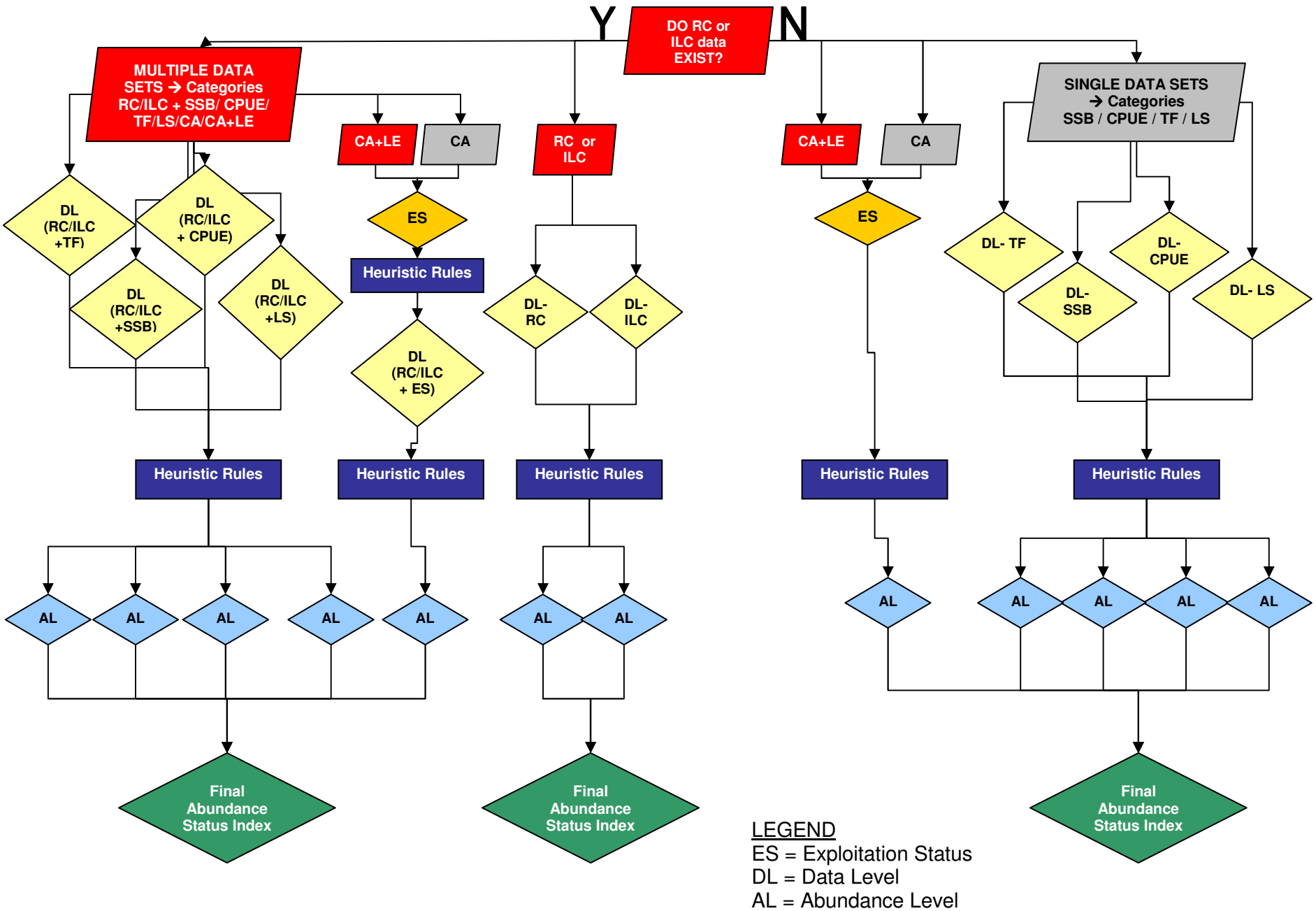


Figure 46. Schematic diagram of the structure of the fuzzy expert system used to predict eulachon abundance.

To make catch values comparable between rivers, each catch data point was expressed as a ratio of its maximum value in its catch time-series. These values were then classified by their position relative to the maximum smoothed catch in their time-series (i.e., before or after the maximum catch was reached). The state of a fishing resource is classified by the UN Food and Agricultural Organization (FAO) as under-exploited when there is significant potential for expansion. As a fishery approaches maximum productivity the population becomes fully-exploited (Alverson and Dunlop, 1998). As the productivity declines the population becomes over-exploited, reduced and depleted as catches continue to decrease below historical levels. If fishing effort is curtailed or reduced to a low level, a recovery stage may occur.

Thus each smoothed catch data point was sorted into the exploitation status categories: (1) under-exploited, (2) fully exploited, (3) over-exploited, (4) reduced, (5) depleted and (6) recovering (Figure 48) based on its position and ratio to the maximum catch (Table 13). These categories were based loosely on those developed by Grainger and Garcia (1996) in demonstrating the usefulness of catch time-series data when trying to interpret the developments in world's fisheries.

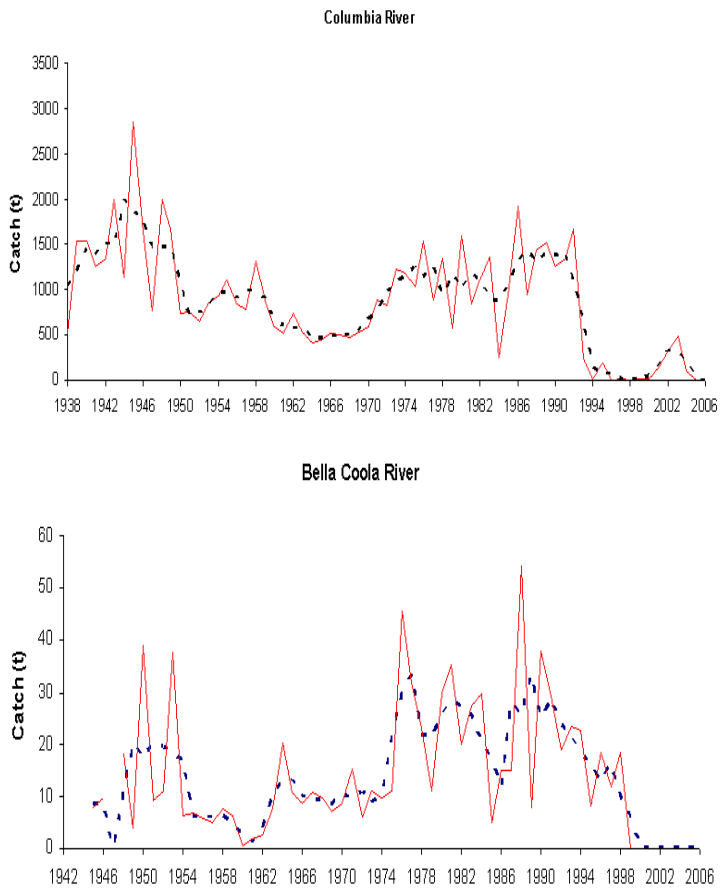


Figure 47. Columbia River catch time-series (a) and Bella Coola catch time-series (b) Source: Columbia- WDFG & ODFG, 2005; Bella Coola-previous chapter.

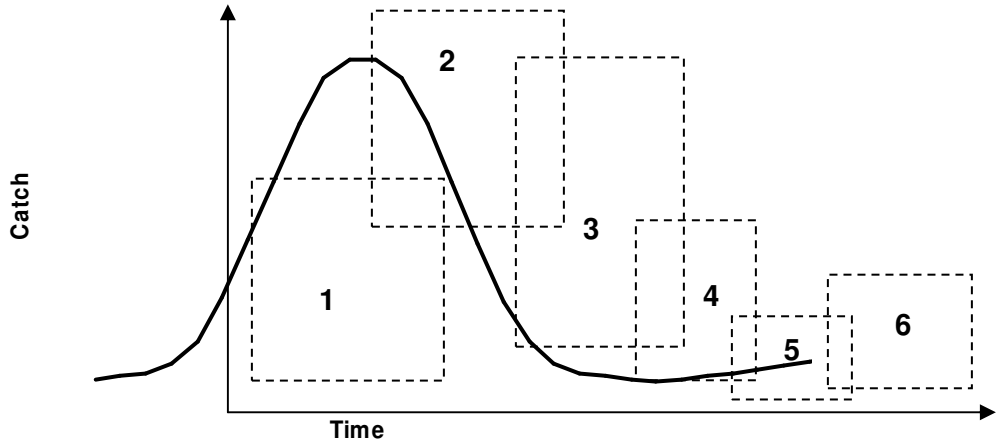


Figure 48. Diagram showing the classification of exploitation status of a population based on a catch time-series: (1) under-exploited; (2) fully-exploited; (3) over-exploited; (4) reduced; (5) depleted; (6) recovering.

Table 13. Categorization of a population's exploitation status based on fisheries catch time-series data.

Exploitation status (premise)	Domain of fuzzy sets[a] Catch relative to maximum in Time-series[b]		Position of data point in time series (before or after the maximum catch)	Fuzzy membership function
(1) Under-exploited	0 – 0.7	(0-0.4)	Before maximum	Trapezoidal
(2) Fully-exploited	0.4 – 1	(0.7-1)	Before maximum	Trapezoidal
(2) Fully-exploited	0.5 – 1	(0.7-1)	After maximum	Trapezoidal
(3) Over-exploited	0.3 – 0.7	(0.5)	After maximum	Triangle
(4) Reduced	0.1 – 0.5	(0.3)	After maximum	Triangle
(5) Depleted	0 – 0.3	(0-0.1)	After maximum	Trapezoidal
(6) Recovering	3-<3	(8-<8)	After maximum and after conditions of low fishing effort and 'depleted' status occurred for at least 3 years	Trapezoidal

[a]Domain of a set represents all possible values of an independent variable of a function. Values in parentheses represent the value or range of an independent variable with full membership to the set;
[b]Estimated from the ratio of catch at year t to the maximum catch (using catch time-series smoothed running average).

The domain, or range of possible values used for the fuzzy sets were based loosely on the "moderate" scenario categories developed by Cheung (2007). He used three scenarios (i.e., liberal, moderate and conservative) and determined that the moderate scenario was robust and performed the best.

Each data value could belong to multiple categories (e.g., fully and over-exploited) with degree(s) of membership calculated from predefined membership functions for the categories (Figure 49a, b and c). Since prior knowledge about the shape of the fuzzy membership function was unavailable, the expert system used the simplest fuzzy membership functions, trapezoidal and triangular:

$$\text{Membership} = 0 \qquad \text{if } x \le a$$

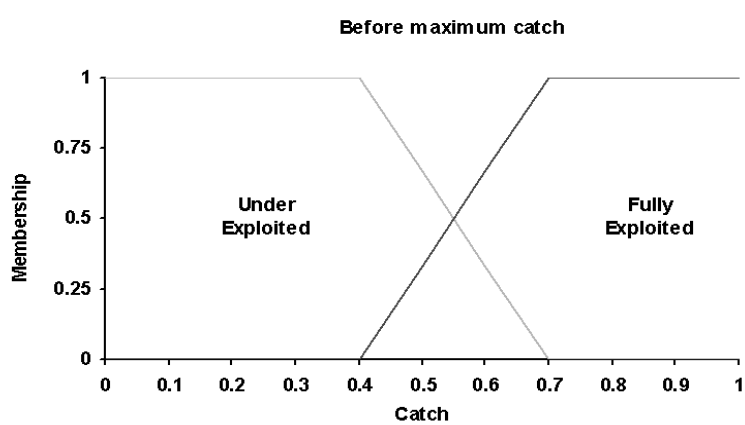
$$\text{Membership} = \frac{x - a}{b - a} \qquad \text{if } a<x<b$$

$$\text{Membership} = 1 \qquad \text{if } b \le x \le c$$

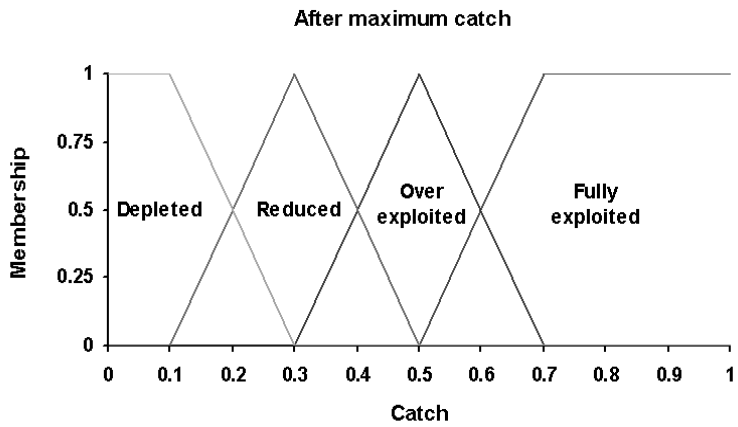
$$\text{Membership} = \frac{d - a}{d - c} \qquad \text{if } c \le x \le d$$

where x is the standardized value of the data series. The base of a triangular and trapezoidal fuzzy membership function is determined by 'a' and 'c' and 'a' and 'd', respectively. Values of 'x' between 'b' and 'c' have minimum membership and for the triangular membership function, 'b' and 'c' were equal.

a)



b)



c)

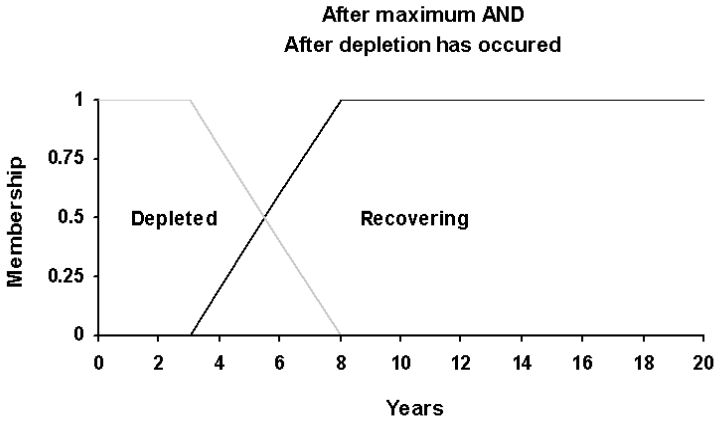


Figure 49. Fuzzy sets defining the catch input data used for determining exploitation status: (a) exploitation status before maximum catch (b) exploitation status after maximum catch (c) exploitation status after depletion status has been reached and fishing effort is low.

For example, the First Nation smoothed eulachon catch from the Bella Coola River in 1973 was 8.97 t, approximately 27% of the maximum smoothed catch in 1977 (33.4 t). Based on the fuzzy membership functions, the Bella Coola fishery in 1973 was classified as underexploited with full membership. On the other hand, the smoothed Columbia River commercial catch in 1973 was 1,073.3 t or approximately 54% of maximum smoothed catch of 1944 (1,994.2 t), thus was classified as fully exploited and overfished with memberships of 0.19 and 0.81 (full membership = 1), respectively.

Table 14. Categorization of data levels based on data sets (CPUE/ SSB/ TF/ LS/ RC/ ILC).

Domain of fuzzy sets[a]	Data relative to max. in time series[b]	Data level	Fuzzy membership function
0.7 – 1.0	(0.9-1.0)	High	Trapezoidal
0.5 – 0.9	(0.7)	Medium-high	Triangle
0.3 – 0.7	(0.5)	Medium	Triangle
0.1 – 0.5	(0.3)	Medium-low	Triangle
0.0 – 0.3	(0.0-0.1)	Low	Trapezoidal

[a]Domain of a set represents all possible values of an independent variable of a function. Values in parentheses represent the value or range of an independent variable with full membership to the set; [b]Estimated from the ratio of the data value at year t to the maximum data value (excluding RC and ILC data which use their original data value and not a ratio value).

Data levels (DL)

The following data sources report comments (RC), inteveiw/local comments (ILC), CPUE, SSB, larval surveys (LS) and test fishery (TF) data were categorized into data levels (DL). As with catch data, each individual data point was expressed as a ratio of its maximum value in its time-series and based on this value, each data point was categorized into the following data level categories: (1) high, (2) medium-high, (3) medium, (4) medium-low, (5) low (Table 14 and Figure 50). The domain or range of possible values used for these fuzzy sets were based on the assumption that as a data value increases from 0 to 1, the concluding data level will increase from low to high. The particular domains were arbitrarily divided into five fuzzy sets. The trapezoidal sets were assigned a total range of 0.3 and the triangular fuzzy sets were assigned a total range of 0.4. The medium-low to medium-high categories were assigned a greater range because it was assumed that they may have a larger range of overlap than the low and high categories.

For example, in 1943 CPUE for the Fraser River was calculated at 154.79 lbs/100 fathoms^2/hour (0.62 t/183 m^2/hr) approximately 0.67% of the maximum CPUE in the time-series from 1941-1953. Based on the fuzzy membership functions (Figure 50) the data level was classified as medium-high and medium with memberships of 0.85 and 0.15, respectively.

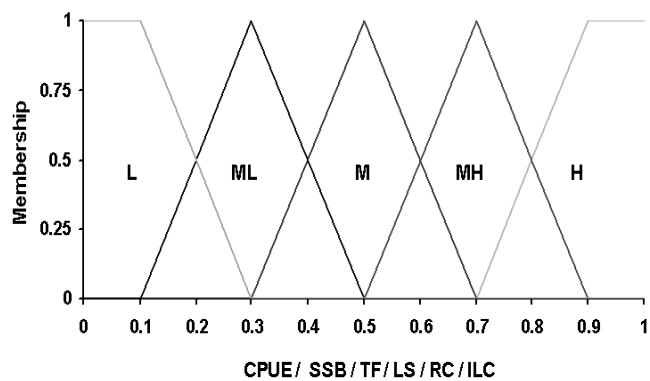


Figure 50. Fuzzy sets defining the input data CPUE or SSB or TF or LS or RC or ILC data, for determining data levels.

Inference process

Inferring abundance level (AL)

Three sets of heuristic rules were used in the expert system. The first rule set (A) inferred abundance levels from exploitation status and low effort information; (B) inferred abundance levels from the data levels derived from CPUE, SSB, test fishery (TF), larval survey (LS), report comment (RC), and interview/local comment (ILC) data and (C) inferred abundance levels from a combination of qualitative data (RC and ILC data) and quantitative data (CPUE, SSB, TF, LS and catch; Table 15). The weights (CF) of each rule and the reasoning behind the assigned weights are explained in the next section.

Table 15. Heuristic rule sets, the data for each set and the certainty factor assigned to each set.

Rule Set	Data Types	Weight (CF)	Importance/Rationale[a]
B	LS	0.25	Med-Low: poor sampling techniques
B	TF	0.25	Med-Low: vulnerable to overestimating the run
A	Catch	0.25	Med-low: poor indicator of abundance
B	CPUE	0.25	Med-low: possible effect of schooling fish
B	SSB	0.25	Med-low: conducted after a major decline
B	ILC	0.30	Medium-low: direct indicator of run size but based on memory so lower than RC
B	RC	0.40	Medium-low: direct indicator of run size
A	Catch; LE	0.50	Medium: increases CA certainty with LE data
C	LS; RC or ILC	0.50	Medium: increases LS certainty with RC/ILC data
C	TF; RC or ILC	0.50	Medium: increases TF certainty with RC/ILC data
C	Catch; RC or ILC	0.50	Medium: increases CA certainty with RC/ILC data
C	SSB; RC or ILC	0.50	Medium: increases SSB certainty with RC/ILC data
C	CPUE; RC or ILC	0.50	Medium: increases CPUE certainty with RC/ILC data
C	Catch; LE; RC or ILC	0.75	Med-high: three data sources to increase certainty of catch data

[a]See section on 'types of data' for a more detailed explanation and references.

The first rule set used exploitation status to predict the abundance level (AL) of each eulachon fishery. These heuristic rules were developed from three assumptions: (1) the AL of an exploited eulachon fishery decreases as the population becomes fully exploited, over exploited, reduced and depleted (Table 16). For example, in 1950, the Columbia River had

a smoothed catch of 1,055.5 t or approximately 53% of the maximum smoothed catch (1,994 t in 1944) and thus, the population was classified as fully-exploited and over-exploited with memberships of 0.15 and 0.85, respectively. Thus the following rules were applied:

IF the population is fully-exploited THEN the abundance level is medium and medium-high.

IF the population is over-exploited THEN the abundance level is medium.
The second assumption (2), is that the abundance level (AL) of depleted, reduced and over-exploited fisheries is higher in years of low fishing effort than in years when effort is normal or unknown (Table 16).

Table 16. Heuristic rule conclusions that relate exploitation status to abundance level (AL) when (1) low effort does not exist and (2) when low effort does exist.

Exploitation status (premise)	Conclusions (1) (AL)		Conclusions (2) (AL) with *low effort*	
Under-exploited	High		High	
Fully-exploited	Medium	Medium-high	Medium-high	
Over-exploited	Medium		Medium-high	
Reduced	Medium-low	Medium	Medium	
Depleted	Low	Medium-low	Medium	
Recovering	-		Medium-low	Medium

For example the Columbia River in 1960 had a smoothed catch of 663.4 t or approximately 0.33% of the maximum smoothed catch (1,994.2 t in 1944) and was classified as over-exploited and reduced with memberships of 0.16 and 0.84. However, fishing effort was low thus the following rules applied:

IF the population is over-exploited AND the fishing effort is low THEN the abundance level is medium-high.

IF the population is reduced AND the fishing effort is low THEN the abundance level is medium.

The third assumption applies only after three criteria for the population have been met (1) it has reached a depleted stage, (2) it has remained depleted for at least three years, and (3) low fishing effort has been reported in all depleted stages; hence the third assumption reads "if a population has been depleted for more than 3 years and the fishing effort has also been low, the population is presumed to be recovering." Fishing is known to reduce the abundance of targeted stocks. Thus under this assumption, it is assumed that the population is depleted because of fishing, consequently, if fishing effort is decreased or ceased, the population is assumed to have recovered to a medium-low or a medium abundance level. The onset of a recovering population is 3 years, as this is the average age of maturity of an eulachon (Clarke *et al.*, 2007). Therefore, once these three criteria have been met, the population is considered to be recovering until catch surpasses the recovering membership category and thus moves into reduced, over-exploited, etc. (Table 16).

For example:

IF the population is recovering THEN the abundance level is medium-low and medium.

The second set of heuristic rules uses the data levels (DL) derived from Report Comments (RC), Interview/Local Comments (ILC), CPUE, SSB, Larval Surveys (LS) and Test Fishery (TF) data to predict the abundance level (AL) for each year. These heuristic rules were developed from the assumption that "the abundance level will improve as the data level increases from low to high" (Table 17).

Table 17. Heuristic rule conclusions (abundance level) that relate the data level (DL) of RC/ ILC/ CPUE/ SSB/ TF/ LS to abundance level (AL).

Data level (DL) (premise)	Conclusions (AL)
High	
Medium-high	Medium-high
Medium	Medium
Medium-low	Medium-low
Low	Low

For example:

IF the data level is low THEN the abundance level is low.

Combining heuristic rules

The third set of heuristic rules combines the qualitative data levels from report comment (RC) and interview/local comment (ILC) data sets with quantitative data levels derived from either exploitation status, CPUE, SSB, larval surveys (LS) or test fishery (TF). These heuristic rules were developed based on three assumptions; (1) qualitative data describes the abundance level of the eulachon system better than quantitative data because they provide information that specifically describes the run size (the limitations of each quantitative data type at inferring abundance were discussed in section 4.2.1). The second assumption, (2) the presence of an RC or ILC data level will influence the abundance level derived from CPUE, SSB, LS, TF or exploitation status (Table 18, 19a and 19b). Thus, under this assumption, the combination of data levels from quantitative and qualitative data will better represent the true abundance level than when only one type of data is used. Fishers or local experts are in a unique position to construct plausible hypotheses about observations that may not be available to research scientists (Pinkerton and Weinstein, 1995). Thus qualitative data may provide unique information when combined with other research observations (e.g., catch), and hence a more plausible conclusion may be reached.

Table 18. Conclusions (abundance level) to heuristic rules that combine CPUE/SSB/TF/LS data levels with RC/ILC data levels (DL).

	CPUE or SSB or TF or LS Data level (DL) (premise)				
RC or ILC Data level (premise)	Low	Med-Low	Medium	Med-High	High
Low (L)	L – AL	L – AL	L – AL	ML – AL	ML – AL
Med-Low (ML)	ML – AL	ML – AL	ML – AL	M – AL	M – AL
Medium (M)	ML – AL	M – AL	M – AL	M – AL	M – AL
Med-High (MH)	M – AL	M – AL	MH – AL	MH – AL	MH – AL
High (H)	M – AL	M – AL	MH – AL	MH – AL	H – AL

Table 19a. Heuristic rules conclusions (abundance level) when the exploitation status of an eulachon population is combined with RC/ILC data levels when effort is normal/unknown.

	Exploitation status (premise)				
RC or ILC Data level (premise)	Depleted	Reduced	Over-exploited	Fully-exploited	Under-exploited
Low (L)	L - AL	L - AL	ML – AL	ML – AL	M – AL
Med-Low (ML)	ML – AL	ML – AL	ML – AL	M – AL	M – AL
Medium (M)	M – AL	M – AL	M – AL	M – AL	MH – AL
Med-High (MH)	M – AL	M – AL	MH – AL	MH – AL	MH – AL
High (H)	M – AL	MH – AL	MH – AL	H - AL	H – AL

Table 19b. Heuristic rules conclusions (abundance level) when the exploitation status of an eulachon population is combined with RC/ILC data levels when effort is low.

	Exploitation status with *low effort* (premise)				
RC or ILC Data level (premise)	Recovering	Reduced	Over-exploited	Fully-exploited	Under-exploited
Low (L)	ML – AL	L – AL	ML – AL	M – AL	M – AL
Med-Low (ML)	ML – AL	ML – AL	ML – AL	M – AL	M – AL
Medium (M)	M – AL	M – AL	M – AL	M – AL	MH – AL
Med-High (MH)	M – AL	M – AL	MH – AL	MH – AL	MH – AL
High (H)	M – AL	MH – AL	MH – AL	H - AL	H – AL

For example:

IF the CPUE data level is low and the RC data level is medium THEN the abundance level is medium-low. For example, in 1962 the Fraser River had a smoothed catch of 184.8 t or approximately 88.6% of the smoothed maximum catch in 1955 (208.6 t). Based on the catch fuzzy membership functions, the Fraser River fishery in 1962 was classified as fully-exploited with full membership (full membership = 1). However, there was also report comment (RC) information available for that year (0.5 data value) from a DFO Fisheries Officer weekly report (DFO, 1940-1979), which indicated a medium abundance level with full membership. Thus the fully exploited exploitation status and the RC abundance level were combined using the following rule:

IF the population is fully exploited AND RC abundance level is medium THEN abundance is medium.

When different rules result in the same conclusion, memberships to the conclusion are accumulated using the MYCIN method (Buchanan and Shortliffe 1984).

$$\text{Membership}_e = \text{Membership}_{e-1} + \text{Membership}_i \cdot (1 - \text{Membership}_{e-1})$$

where Membership_e is the degree of membership of the conclusion after combining the conclusions from e number of rules, and Membership_i is the degree of membership of the conclusion from rule i. For example, this method would be used when a 'medium-high' abundance level is derived from both exploitation status and CPUE data level.

Sensitivity of rules

The sensitivity of the final abundance status to the heuristic rules was tested by systematically 'turning off' each rule. This degraded the system in steps so that the impact of losing information could be assessed by examining the resulting effect to the output results. To test the sensitivity, the Fraser River and the Columbia River's 'base' abundance status results were compared to results with each of the 14 rules turned off. The base results were derived using all applicable rules and a certainty factor (CF) of 1.0 (100%). The Fraser River data set was chosen because it had the highest number of data sources (six), followed by the Columbia River (five). The rules were turned off one at a time and the final abundance status calculated. The sum of the squared differences (SSD) between the base results and each of the fourteen final abundance status results, minus a rule, were calculated to determine the sensitivity of the final abundance status to each rule. The log of SSD was plotted to display this sensitivity.

Defuzzification

The process of defuzzification converts the final range of conclusions (i.e., abundance levels [AL]) with different memberships or fuzzy values, to a single number (i.e., final abundance status). The most widely used defuzzification technique is the "centroid" method. This method finds the "balance" point of the solution fuzzy region by calculating the weighted mean of the region (Cox, 1999). Thus the evidence (i.e., abundance level) from all rules yields an answer that is weighted by the importance of the rule by assigning a weight multiplier (Cox, 1999) or a certainty factor (CF; Buchanan and Shortliffe, 1984). For example, the truth of a premise is multiplied by a certainty factor that has been assigned to the rule e.g., a CF value

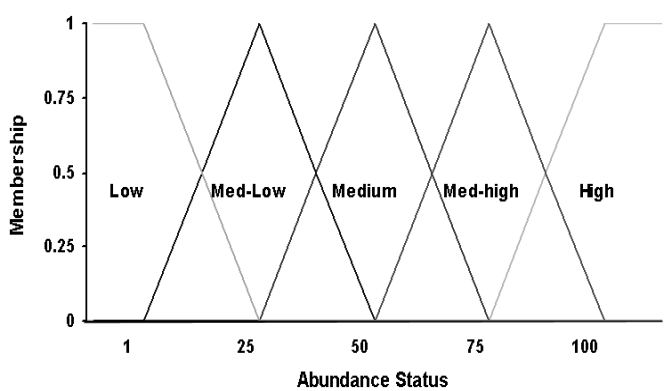


Figure 51. Output fuzzy sets for the abundance status of an eulachon population. The "Low" and "High" abundance status levels are defined by trapezoid membership functions while the "Med-low", "Medium" and "Med-high" abundance status levels are defined by triangle membership functions. The final abundance statuses were scaled arbitrarily from 1 to 100.

of 0.75 reduces the force of the rule by 25% (the default weight is 1.0).

$$\text{Membership}_{\text{conclusion}} = \text{Membership}_{\text{premise}} \cdot \text{CF}$$

The expert system used a total of four different CF values for each of its rules (0.75 for med-high, 0.5 for medium, 0.4-0.25 for med-low, and 0.1 for low) (Table 15). The statements with higher confidence carry more weight and have greater effect, i.e., the data sets by themselves (larval survey, test fishery, catch, CPUE, SSB, report comments (RC) and interview/local comments (ILC)) were assigned weights between 0.25 and 0.4. RC and ILC were assigned higher weights because they were assumed to be a direct indicator of relative run strength, whereas the other data types may misrepresent relative run strength (refer to section 4.2.1 on types of data for an explanation on the limitations of each data type). The combination of two data sets, e.g. RC + CPUE data, increases the CF value assigned to the rule from medium-low (0.25) certainty to medium certainty (0.5). Thus a higher confidence is associated with the combination of two data sources. In addition, when three data sources are combined (i.e., catch + low effort + RC or ILC), the CF value is increased to medium-high certainty (0.75).

The final abundance statuses were expressed on an arbitrary scale of increasing abundance from 1 to 100 and were categorized into five status levels: low, medium-low, medium, medium-high and high (Figure 51). For example, the Klamath River eulachon run of 1972 was classified as 'high' with a membership of 1.0 and a final abundance status of 100.

Coast wide eulachon abundance status

To illustrate the overall coast-wide past and present eulachon abundance status, 15 eulachon systems were chosen and their estimated abundance status indices plotted on four tables using a ten-point colour scale (reds signifying low abundance, yellows and light blues signifying medium abundance and darker blues signifying medium-high to high abundance) (Table 20). Four, 20-year time periods were displayed between the years 1927 and 2006. The white squares indicate no information available for the year. The 15 systems were arranged from north to south, from Cook Inlet, Alaska, to the Klamath River, California.

Table 13. Colour scale used to represent coast-wide eulachon estimated abundance status indices (1-100) and the final abundance level (e.g. low).

10<	10<20	20<30	30<40	40<50	50<60	60<70	70<80	80<90	90<100
Low	Low	Med-low	Med-low	Medium	Medium	Medium	High	Med-high	High

RESULTS

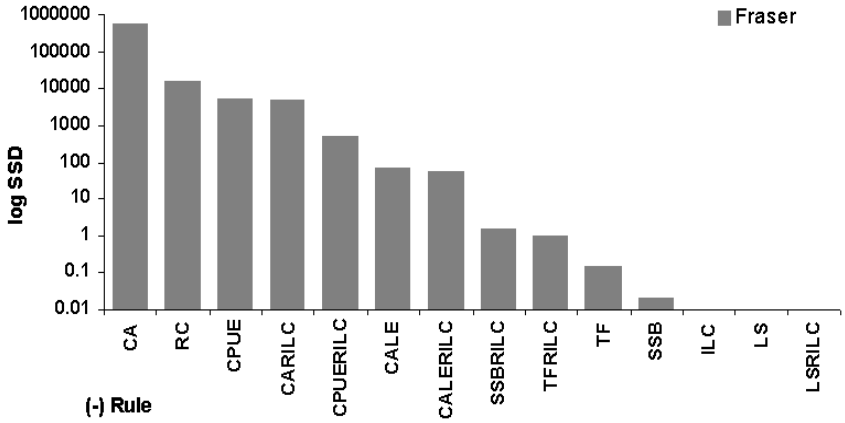
Sensitivity analysis

Both final abundance status time-series were most sensitive to the catch rules. The Fraser River final abundance status was also sensitive to the report comment and CPUE rules in addition to the combination rules: catch and CPUE plus report or interview/local comments (Figure 52a). The Columbia River final abundance status was also sensitive to the combination rule catch + low effort and the report comment rules (Figure 52b). The rules which had no effect on the final abundance either did not have applicable data (e.g., interview/local comments) or were not applicable because the combination of the data sources did not exist (e.g. SSB with report or interview/local comments for the Columbia River). The Fraser River data set was again used to test the sensitivity of the results to each data source. Each data type was removed from the expert system and the final results compared to the base results. Not surprisingly, the results were most sensitive to the catch data, followed by the report comment data and CPUE data (Figure 52c).

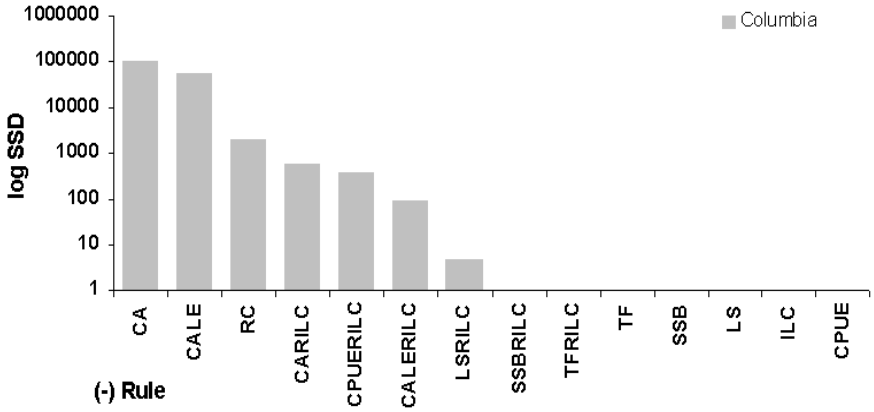
Figure 53 (a, b and c) illustrates the differences in the final Fraser River base results minus each of the three most sensitive rules, where generally without the report comment rules, the abundance status was lower, and without the catch rules the abundance status was higher. The range of abundance status results (i.e., the maximum and minimum values estimated when each of the rules are subtracted) for the Fraser

River (1940-2006) are shown in Figure 54. Only these years were used because prior to 1940, the only source of data was catch data. Thus only catch rules would be applicable to these data and only one value generated, it being both the minimum and maximum value.

a)



b)



c)

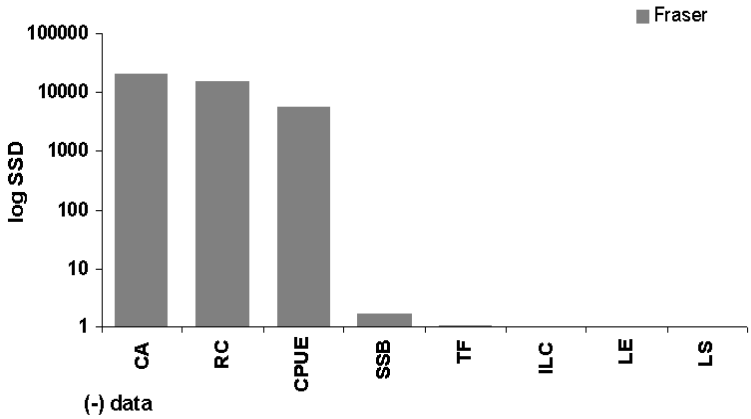


Figure 52. Sensitivity of the final abundance status results (a) Fraser River and (b) Columbia River, minus the applicable heuristic rules and (c) Fraser River minus each data set. All results calculated using the sum of squared differences (SSD).

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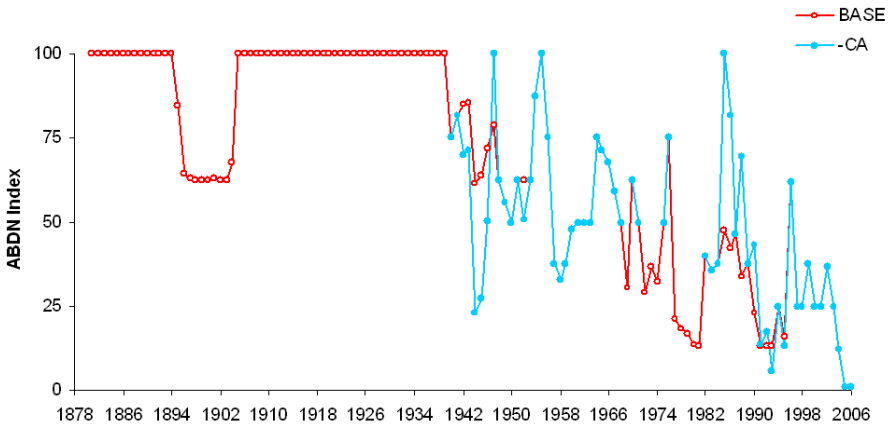

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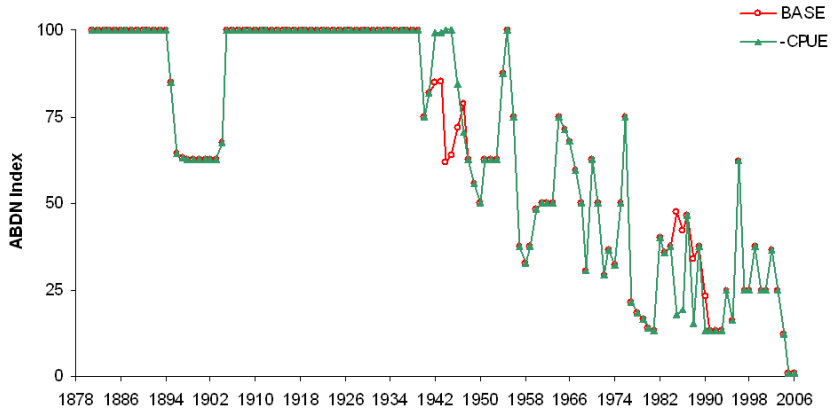


c)

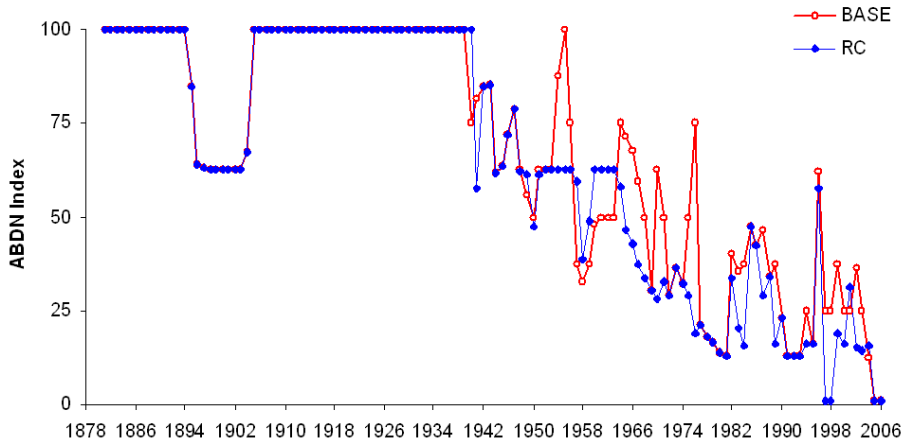


Figure 53. Comparison of the 'base' results of the Fraser River eulachon final abundance indices and results minus a) catch rules and CPUE + RC/ILC rules c) RC rules.

Abundance status (ABDN) index estimations

Based on the combination of eight possible sources of data, the expert system estimated the annual abundance status (ABDN) of fifteen eulachon systems. The number of annual ABDN index estimations for each system depended on the available data. The Fraser River had the longest final ABDN index time-series with 125 years estimations. The Unuk River, Alaska, had the shortest final ABDN index time-series with only nine years of estimations.

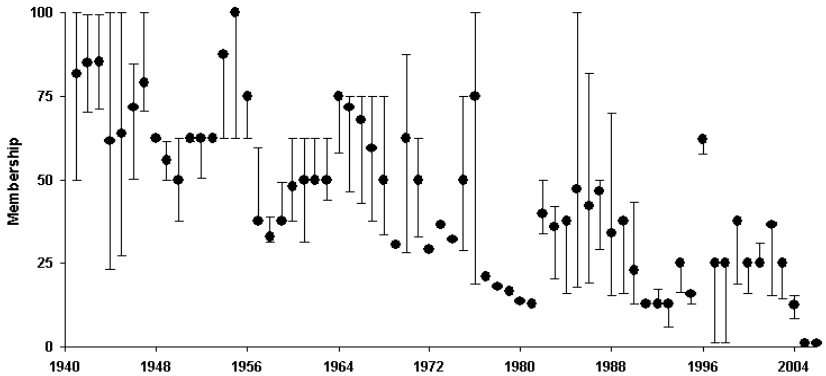


Figure 54. Fraser River 1940-2006 base final eulachon abundance results with minimum and maximum abundance values shown with error bars. Ranges calculated by subtracting each rule.

Cook Inlet, Alaska

The estimated annual eulachon ABDN index for this area has remained consistently above 75 or at medium-high or high abundance levels for the past fifteen years (Figure 55). In the most recent years a decline to medium-abundance level is estimated but the overall abundance remains well above a medium abundance level (ABDN index=50). The total catch from this area appears to be low with only a few years of significant commercial catches (>45 t), which have occurred only in the past few seasons (2006-2007).

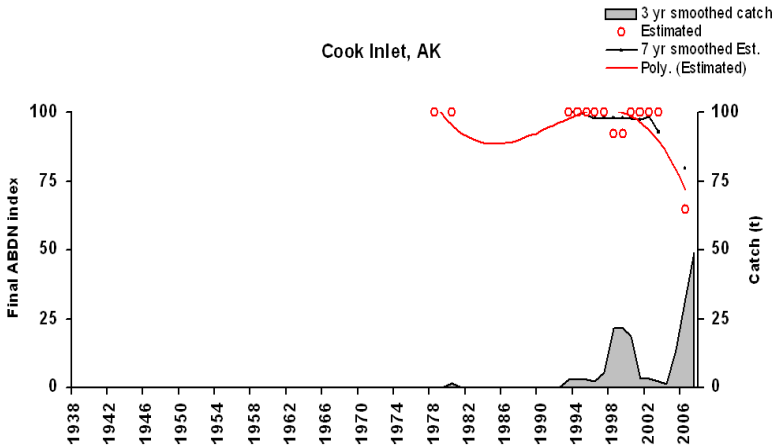


Figure 55. Cook Inlet, Alaska, estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 year smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Copper River, Prince William Sound, Alaska

The estimated annual eulachon ABDN index for the Copper River has remained consistently above 50 or above the medium abundance level for the majority of the time-series with few exceptions (Figure 56). Up to date ABDN index estimations could be made if the most recent catch data (2004-06) was known and/or local expert knowledge was acquired.

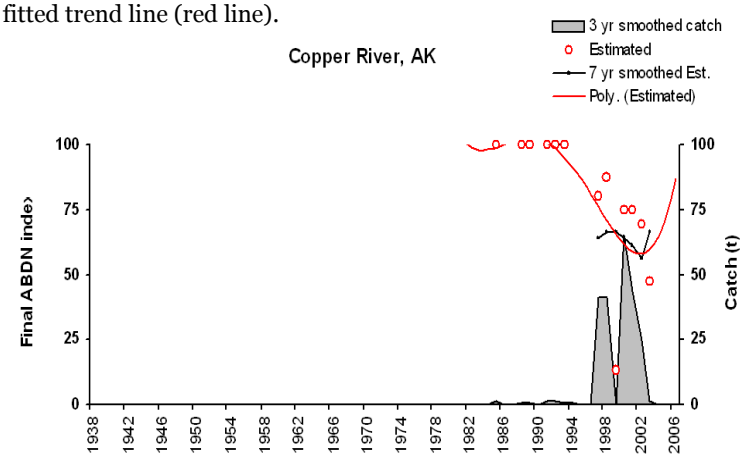


Figure 56. Copper River, Alaska, estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 year smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Southeastern Alaska, Chilkat River and Unuk River

The estimated annual eulachon ABDN index for the Chilkat River fluctuated around 50 or around the medium abundance level for the past two decades (Figure 57a). Most recently, the Chilkat River's eulachon ABDN index has remained around 75 or at the medium-high abundance level with an increasing trend estimated. The eulachon ABDN estimations for the Unuk River were limited to the past two decades. The ABDN index dropped below the medium-low abundance level in the most recent years, 2004-2006 (Figure 57b). Data for both of these systems are very limited and new data or information should be added to improve and add to these abundance status estimations.

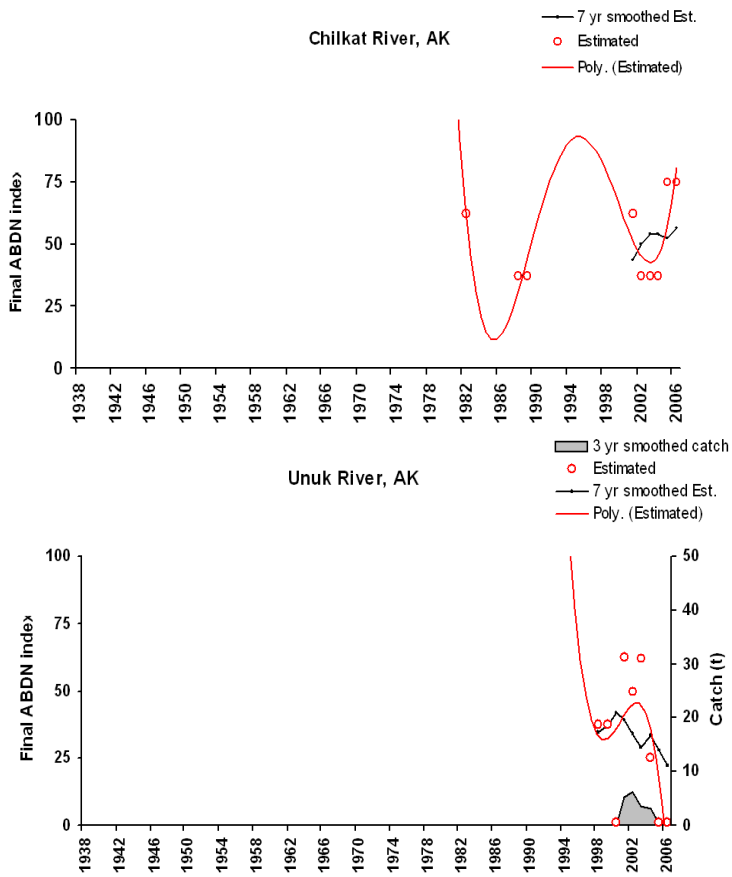
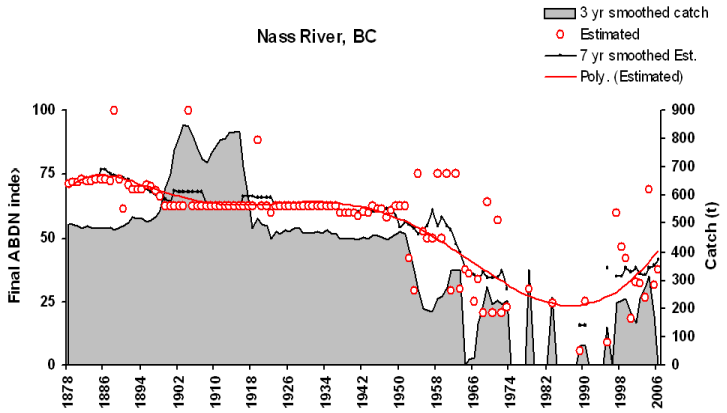


Figure 57. (a) Chilkat River, Alaska and (b) Unuk River, Alaska estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 yr. smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Nass River, Northern BC

Two time-series of smoothed catch data were used for the Nass River abundance status estimations. The first estimated abundance time-series (a) was based on the reconstructed smoothed total catch (the commercial catch plus First Nations reconstructed catch calculated in *A review of historical eulachon fisheries*, from 1878-1952). The second time series (b) was based on the total recorded catch from all data sources from 1929-2006 (Appendix 1) excluding estimated catches. Overall, the second time-series (b) estimated a higher average ABDN index than (a) (Figure 58a and b). Time-series (a) had an average ABDN index of 57 whereas time-series (b) had an average ABDN index of 65. The higher abundance status estimations for time-series (b) occurred because the majority of the abundance status estimations were based solely on catch data and time-series (a) had a higher maximum catch (851 t vs. 478 t) than time-series (b); thus lower catch ratios would indicate lower abundance. The addition of other data sources such as, report comment data may confirm or change these results. Time-series (a) predicts a slow decline in ABDN that begins around 1950 and then a slow increase in ABDN during the early 1990s. However, data for this time period was very limited. Time-series (b) predicts a gradual decline in abundance that starts at the beginning the time-series and ends around 1950 when the ABDN index averages approximately 50 or a medium abundance level. Both time-series indicate an increasing ABDN trend in the most recent decade beginning around 1998. Other data sources could add support to these estimations, for example, run status information collected from First Nations elders and fishers and a reconstruction of past catches using grease production (methods from *Estimating historical catches of the Nuxalk Nation eulachon fishery*) for the twenty-years between 1974 and 1994 when data are most limited for the Nass River. For the final coast-wide ABDN table, estimations using time-series (a) will be utilized.

a)



b)

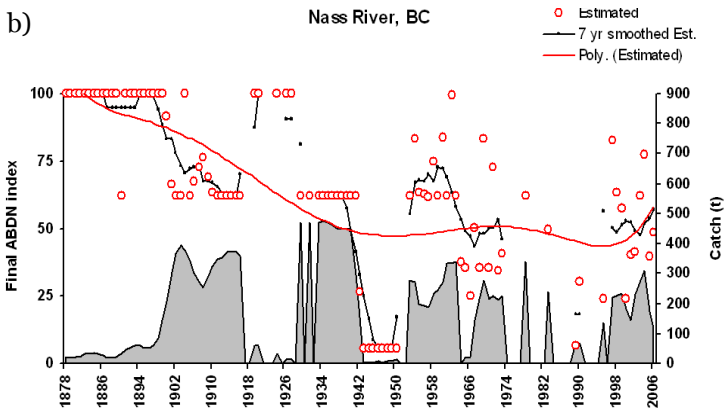


Figure 58. Nass River estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 yr. smoothed catch (grey fill) and a polynomial fitted trend line (red line) using (a) estimated catch time-series and (b) using 'reported' catch.

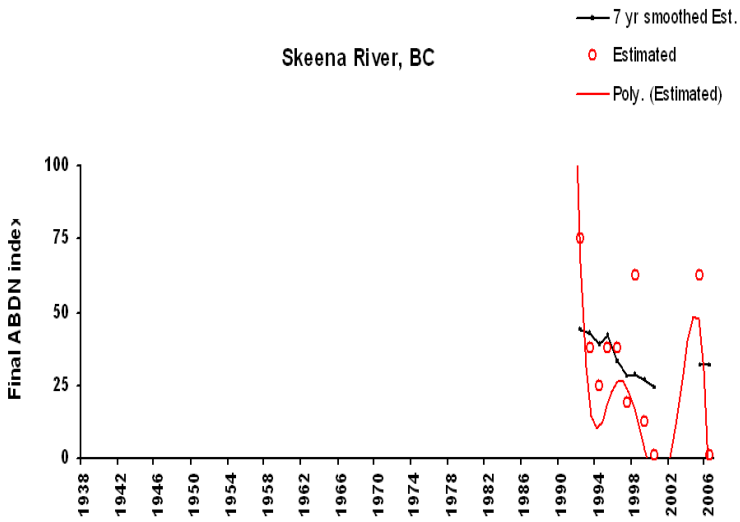


Figure 59. Skeena River, BC estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 year smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Skeena River, Northern BC

The estimated eulachon ABDN index for the Skeena River has fluctuated between 1, a low abundance level, and 75, a medium-high abundance level, during the past two decades (Figure 59). Throughout the time-series, there have also been extreme lows, for example, in the years 2000 and 2006. The ABDN index estimations for this river were based solely on report and interview/local comment information. Additional run status information or catch data from past DFO records or from interviews with First Nations elders and fishers would help to improve these estimations.

Kitimat River, Douglas Channel and Kemano River, Gardner Canal, BC

The estimated annual eulachon ABDN index for the Kitimat River drastically dropped during the mid 1990s and has remained low since 1998 (Figure 60a). This time-series could be improved if additional abundance information was collected from First Nations elders and fishers because information from the 1970s and 1980s is limited.

The estimated annual eulachon ABDN index for the Kemano River remained above a medium abundance level (ABDN index = 50) until the late 1990s (Figure 60b). A low to medium-low abundance level period occurred between 1999 and 2001 followed by a short three-year recovery and more recently a low ABDN index estimation of 1 for 2005 and 2006.

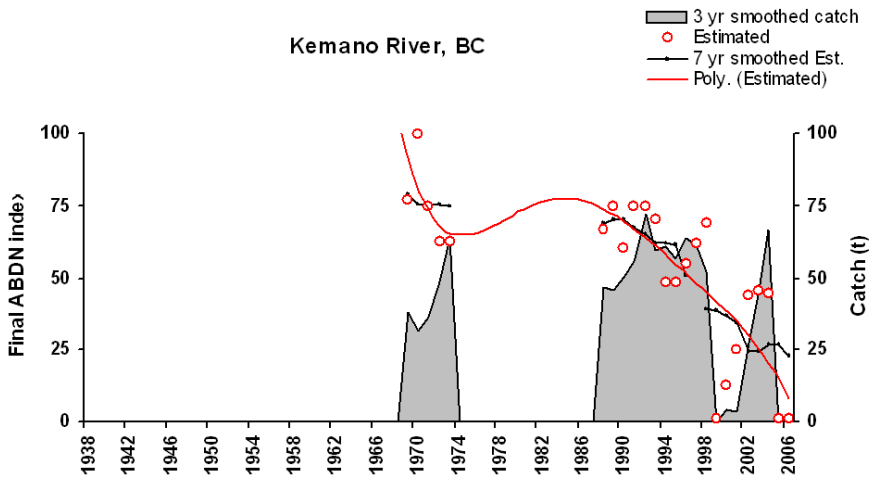


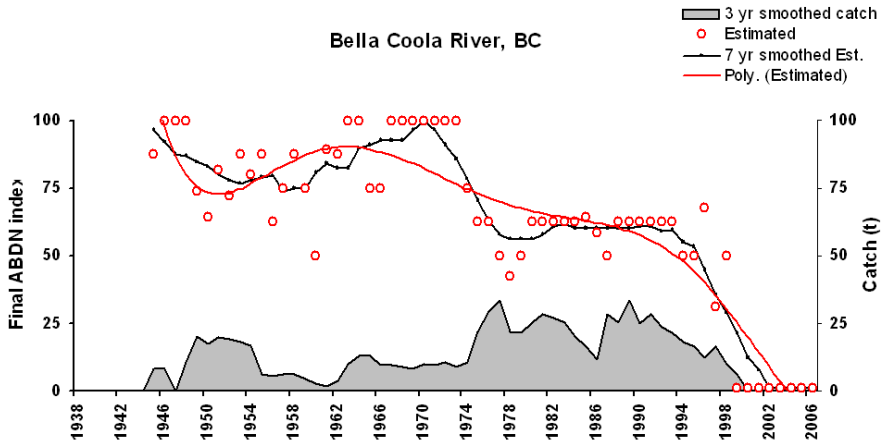
Figure 60. Kitimat River, BC (a) and Kemano River (b) estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 yr. smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Bella Coola River, North Bentinck Arm and Wannock River, Rivers Inlet Central Coast, BC

The estimated annual eulachon ABDN index for the Bella Coola River has fluctuated over its 61 year time-series but appears to have begun a slow decline during the mid-1970s (Figure 61a). The ABDN index remained consistently above 50 or a medium abundance level, until the mid 1990s where it declined sharply below a medium abundance level. Since 1999 the abundance status has remained at a very low level (ABDN index = 1).

The estimated annual eulachon ABDN index for the Wannock River began to decline in the mid 1970s and since 1997, has dropped and remained at a low abundance level (ABDN index = 1; Figure 61b).

a)



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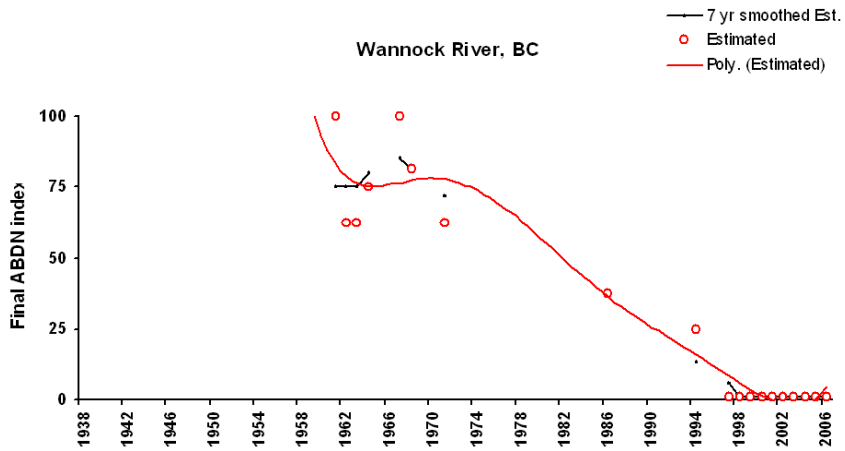


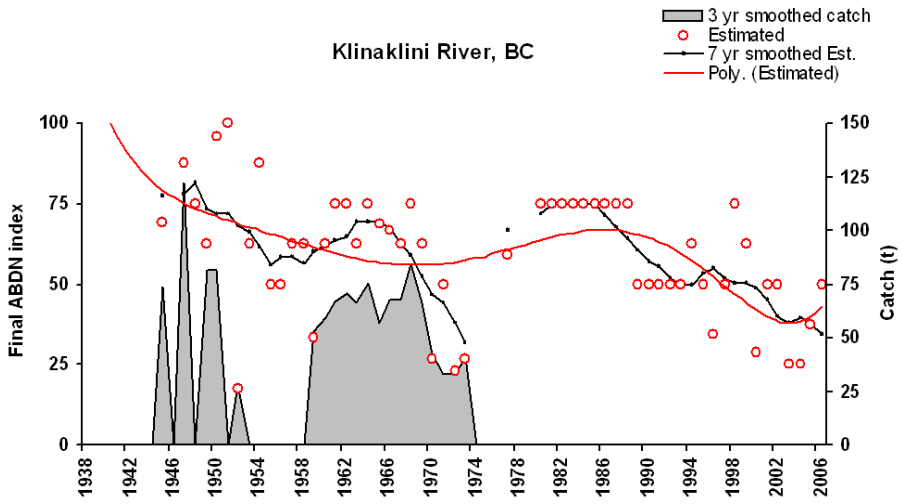
Figure 61. Bella Coola River, BC (a) and Wannock River (b) estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 yr. smoothed catch (grey fill) and a polynomial fitted trend line (red line).

<u>Klinaklini River, Knight Inlet and Kingcome River, Kingcome Inlet, BC</u>

The estimated annual eulachon ABDN index for the Klinaklini River has fluctuated between a medium-high and medium-low abundance level over its estimated time-series (Figure 62a). There appears to be a small decline in abundance level during the early 1970s and a larger decline, more recently, during the mid 1990s. The abundance level trend appears to be improving and has been estimated at medium abundance (ABDN index = 50) for 2006.

The Kingcome River's estimated annual eulachon ABDN index appears to have had more extreme fluctuations than the Klinaklini River (Figure 62b). Over the past 14 years this system has had periods of low abundance levels (ABDN index =1) followed by years of medium abundance levels.

a)



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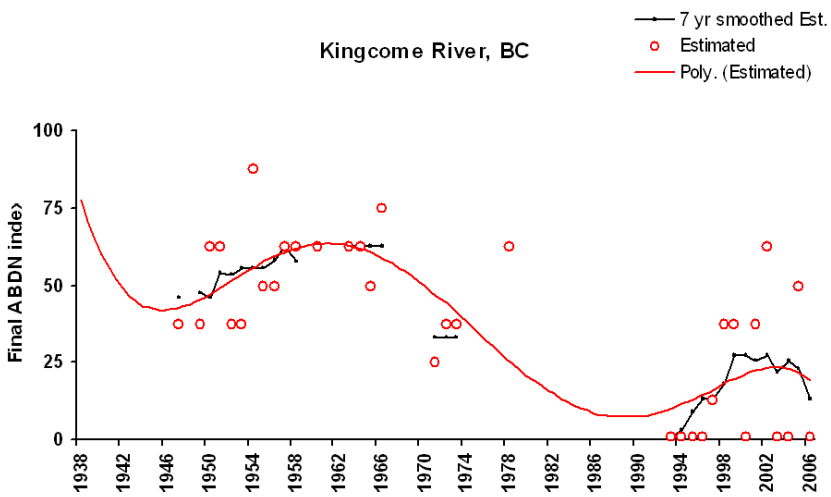


Figure 62. Klinaklini River, BC (a) and Kingcome River (b) estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 year smoothed catch (grey fill) and a polynomial fitted trend line (red line).

<u>Fraser River, Southern BC</u>

Of the 15 eulachon systems the Fraser River has the longest estimated eulachon ABDN index time-series (125 years). The ABDN index began to show a noticeable decline during the mid 1940s followed by a steady decrease in abundance level for the rest of the time-series (Figure 63). Over the past 15 years there has been a more significant decline with a small increase estimated in 1996 (ABDN index = 61). Since then the abundance level has remained between low and medium-low (ABDN index between 1 and 37).

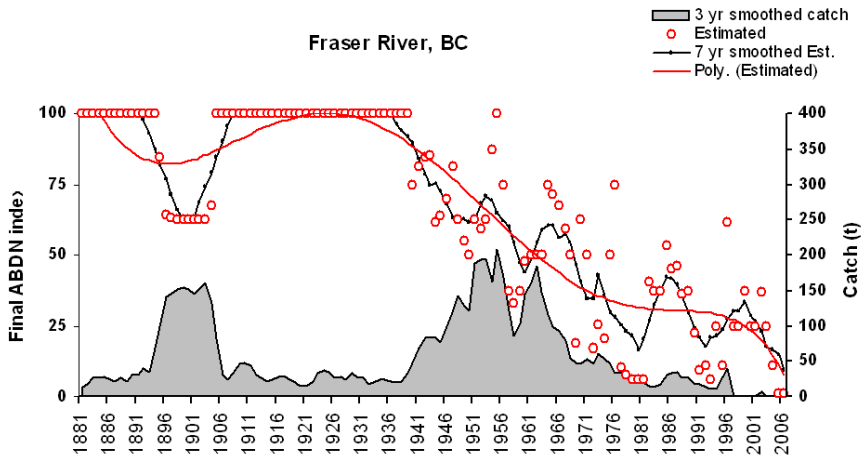


Figure 63. Fraser River, BC estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 yr. smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Columbia River, Washington/Oregon

The estimated eulachon ABDN index for the Columbia River has remained consistently below a medium-high abundance level (ABDN index = 75) for the entire time-series. The abundance level fluctuated between the medium and medium-high abundance levels until the mid 1990s. From 1994 to 1999 ABDN index dropped to a medium-low abundance level (ABDN index = ~13; Figure 64). It improved slightly from 2000-2003 (ABDN index range: 31-49); however, the ABDN index dropped and remained below 12 after 2003.

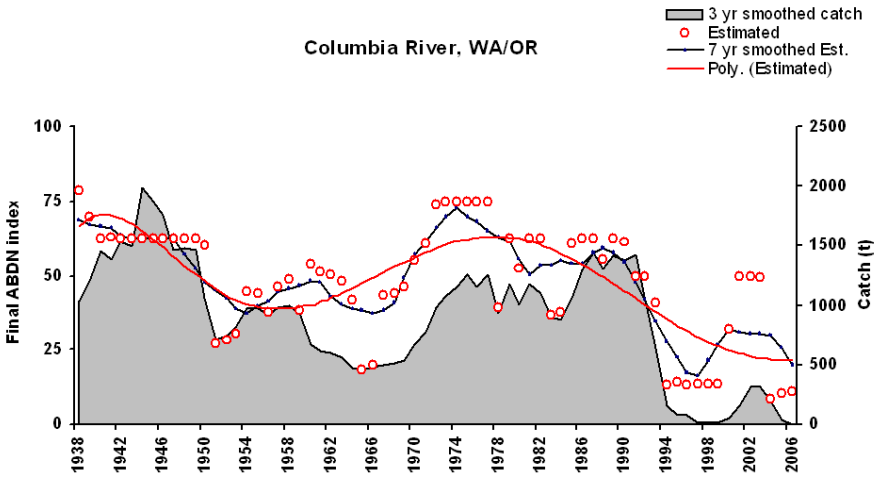


Figure 64. Columbia River, BC estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 year smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Klamath River, Northern California

The estimated eulachon ABDN index for the Klamath River dropped drastically in the early 1990s and has remained low for the past 15 years (Figure 65). The last decade the Klamath ABDN index was above 75 was during the late 1980s. Additional run status information or catch data from past government records or from interviews with First Nations elders and fishers would help to improve the estimations for this river.

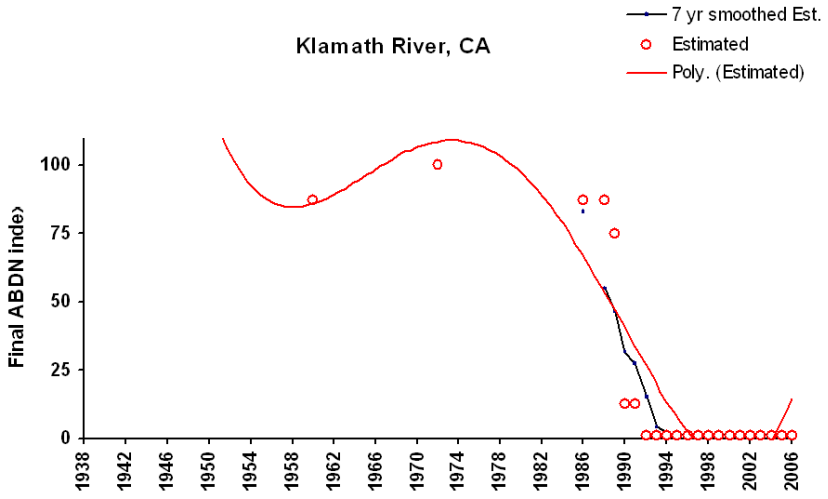


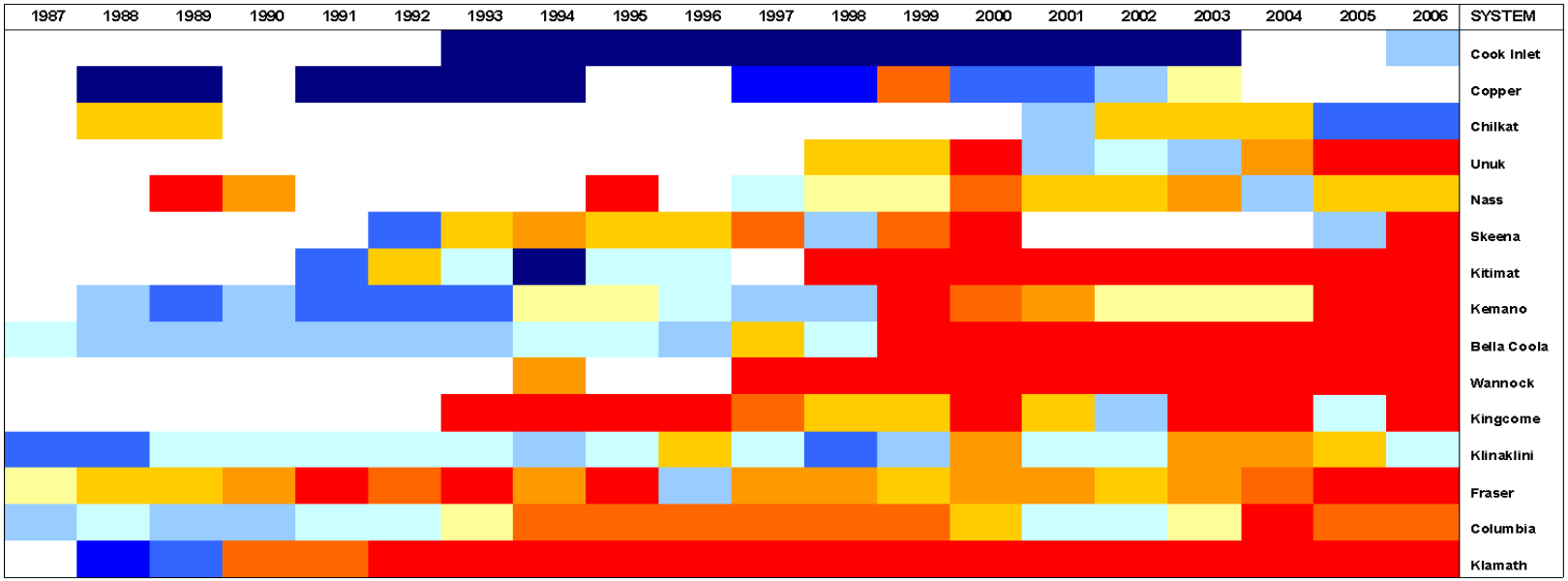
Figure 65. Klamath River, CA, estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 year smoothed catch (grey fill) and a polynomial fitted trend line (red line).

Over the last 20 years, a large proportion of the systems have had multiple years of low abundance (Table 21a). The most recent coast-wide table has noticeably more red squares (low years of abundance) compared to the earlier coast-wide tables. One important factor to note regarding Table 21a is that the rivers located farther north generally have higher abundance indices (blues) than those located farther south. There are a few exceptions, for example the Klinaklini River located in the Central Coast, BC, had higher abundance in 2006 than the Unuk River located in Southeastern Alaska (Table 21a).

Table 21. Fifteen Pacific North Coast eulachon system's abundance status estimations for four separate 20 year time periods. a) 1987-2006; b) 1967-1986; c) 1947-1966; and d) 1927-1946. Abundance status indices (1-100) and relative abundance level (low-high).

10<	10<20	20<30	30<40	40<50	50<60	60<70	70<80	80<90	90<100
Low	Low	Med-low	Med-low	Medium	Medium	Medium	High	Med-high	High

a)



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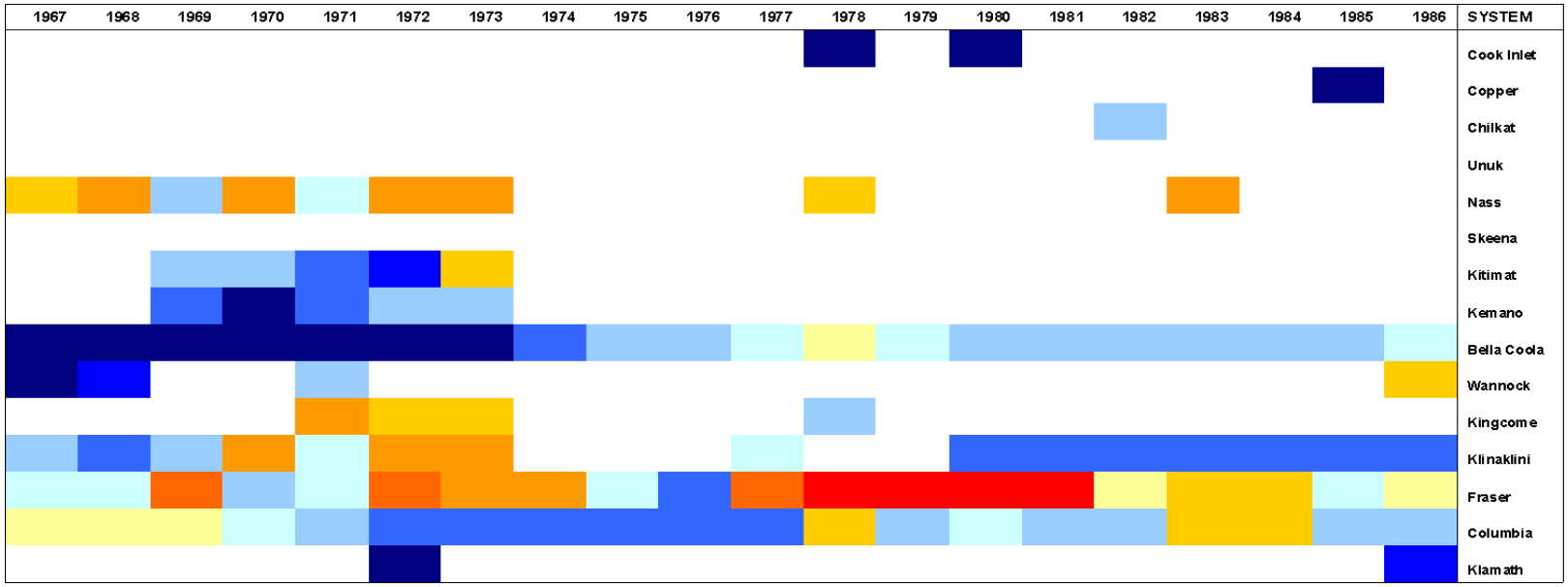
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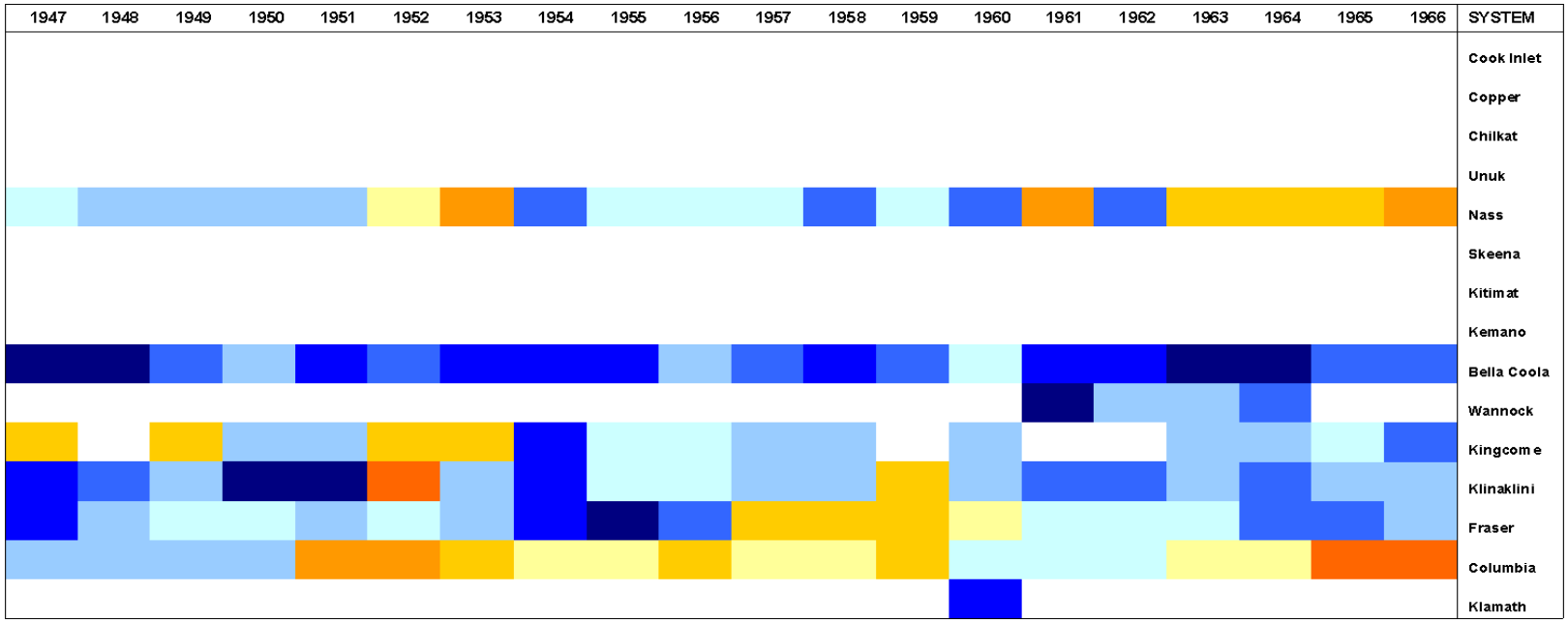
Kingcome
Klinaklini
Fraser
Columbia
Klamath

c)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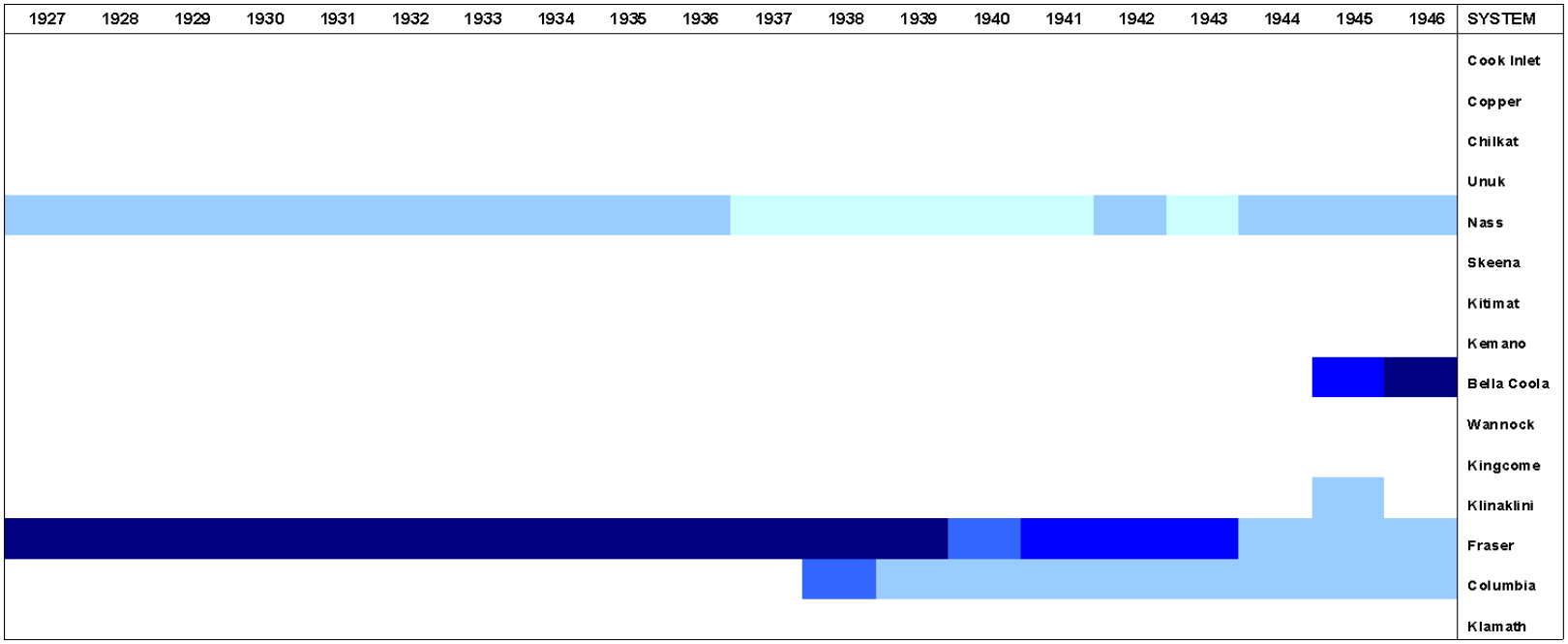
Bella Coola
Wannock
Kingcome
Klinaklini
Fraser
Columbia
Klamath

d)


1927
1928
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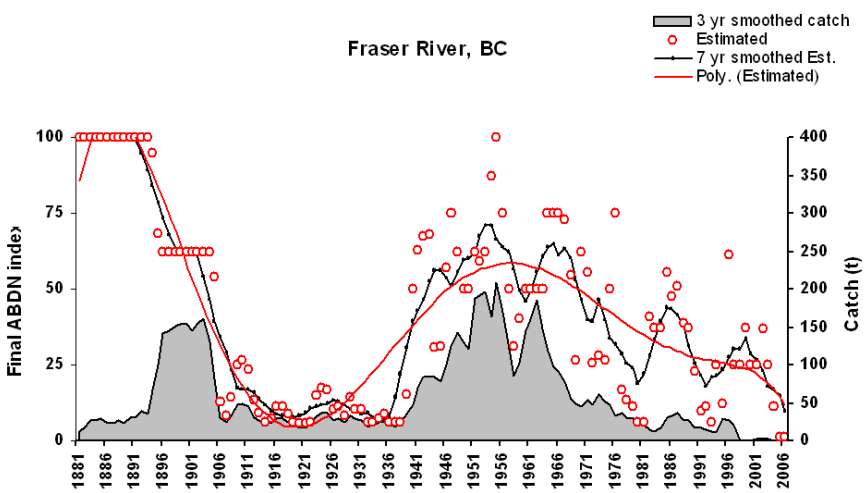
1944
1945
1946
SYSTEM
Cook Inlet
Copper
Chilkat
Unuk
Nass
Skeena
Kitimat
Kemano
Bella Coola
Wannock
Kingcome
Klinaklini
Fraser
Columbia
Klamath

DISCUSSION

The numerous white squares in Table 21 (a, b, c and d) dramatically illustrate the lack of data for most eulachon bearing systems across the entire North Pacific range of this species. This study summarized existing information to construct a representation of the past and present eulachon abundance of selected rivers. With the exception of some of the more northern rivers, for example, Cook Inlet and the Chilkat, River, Alaska, there has been a noticeable decline in abundance in most eulachon systems over the past 20 years (Table 21a). The eulachon systems that have had very low abundance status for an extended time period are those located in the most southern part of the range, for example, the Klamath River, California, the Columbia River, Washington/Oregon and the Fraser River, BC. Smaller northern rivers such as the Wannock River, the Bella Coola River and the Kitimat River, have suffered a more dramatic and long standing period of low abundance.

The benefit in using the fuzzy logic expert system, which was designed to estimate the relative abundance of eulachons in fifteen eulachon systems using a combination of data sources, is that estimations of abundance status can be made for a species that has limited data. The system incorporates all existing data, whether it is qualitative or traditional quantitative data (i.e., catch time-series data) to make its prediction. However, when only catch data is available the results rely heavily on the placement and the size of the maximum catch. This system has tried to minimize this problem by smoothing the catch data with a three-year running average. This tends to dampen out extreme values, which may or may not be erroneous, and highlights the movement of the data with time. For example, there has been some speculation as to the accuracy of the Fraser River catch data from the early 1950s as the reported catch may include all commercially caught smelts, even though the catch has been reported as eulachon (Doug Hay, pers. comm., 2007). Thus the maximum catch of this time series (337.5 t) in 1952 may misrepresent the true maximum catch. When the data are smoothed, the maximum catch equals 208.6 t and occurs in 1955. However, if the smoothed maximum catch is taken from the peak in the early 1900s (161.4 t in 1903) the estimations look much different for the first half of the estimated time-series (Figure 66a and b). Time-series (a) estimates a collapse in the early 1900s, whereas time-series (b) estimates a high abundance status level during the same time period. Even so, the second halves of both time-series are similar, and the depletion trends in the most recent years are basically the same, regardless of the position and value of the maximum catch.

a)



b)

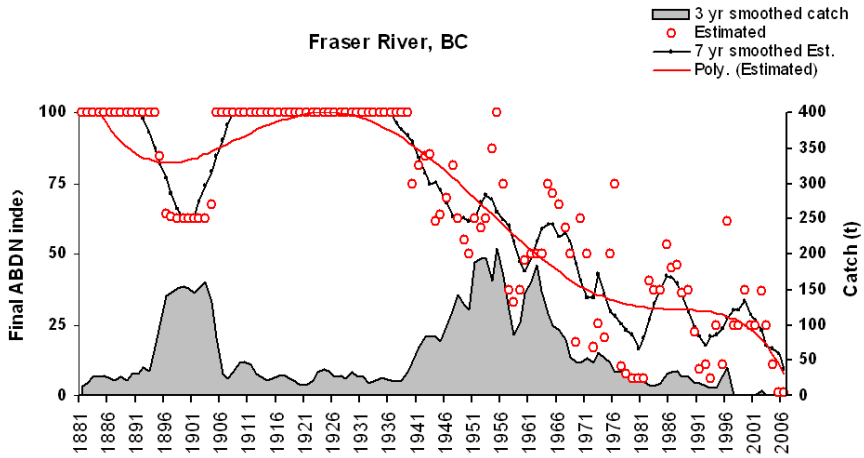


Figure 66. Fraser River, BC estimated eulachon abundance status (circles), 7 year smoothed abundance status estimations (black line), 3 yr. smoothed catch (grey fill) and a polynomial fitted trend line (red line) with (a) catch ratios calculated using the maximum catch from catch peak (1903) and (b) from the reported smoothed maximum catch (1955).

The risk of false estimations from an over-reliance on catch data can be reduced by incorporating other sources of information. For example, information about why there were low commercial eulachon catches between the early 1900s and the early 1940s makes the estimations from time-series (b) more plausible. The document that reported these early catches also stated that eulachon markets had deteriorated during this time because knowledge of other species increased, thus the demands of small local markets, not the abundance, dictated the size of the catch during this time (Clemens and Wilby, 1946).

The use of this expert system is an admission that knowledge of each eulachon system is incomplete and uncertain, yet by applying to the system a reasonable abundance status trend can be estimated. There will be deviations in the final results depending on the data available and the applicable rules, however, these appear to be relatively small in most cases (Figure 53a, b and c). Needless to say, the rules of the expert system and the weighting of the rules are based on the researcher's expert opinion and could be adjusted after collaboration with other scientists.

CONCLUSION

In conclusion, it is suggested that the fuzzy expert system approach described here is a useful tool to estimate eulachon relative abundance status. Many of these abundance index estimations could be improved with the gathering of more information within each local region. Ideally, each system would have a continuous 80+ year time-series for each of the eight data sources. However, this would never be possible as SSB estimates and CPUE were not measured in the past. Nevertheless additional historic catch records or qualitative information on run size may be buried in archives of government offices or museums and could be looked for.

First Nations have accumulated detailed knowledge regarding past eulachon abundance patterns and run sizes from their own experiences and from those of their elders. Information has been passed down through generations and is critical for a species, like eulachon, that is lacking 'hard' data. Interviews with First Nations and local experts should be conducted in all areas, using the methods developed in the section on *Estimating historical catches of the Nuxalk Nation eulachon fishery*, so that information on past run sizes and grease production can be obtained and applied to the expert system. This expert system was built with the assumption that more information would, or could be added, to its existing database so that future estimations could be made and past estimations improved.

To conclude this project, a small number of the eulachon impact hypotheses will be explored to determine the relationship between the estimated abundance indices and the impact hypotheses suggested in the section, *Assessing the impacts on eulachon populations*.

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ASSESSING THE IMPACTS ON EULACHON POPULATIONS

INTRODUCTION

Nearly all eulachon populations, from California to southeastern Alaska, have shown recent, sharp declines in their spawning runs, especially since the mid 1990s (Hay and McCarter, 2000), but the reasons remain uncertain. In February 2007, the Department of Fisheries and Oceans (DFO) held a workshop in Richmond, British Columbia (BC), to determine research priorities for eulachon using an impact hypothesis approach (hereafter referred to as the 2007 Workshop). The goal was to identify "key uncertainties affecting science advice for eulachon management" (Pickard and Marmorek, 2007). This section will summarize the available evidence, for and against, the main hypotheses (Table 22) suggested during this workshop.

There have been numerous reductions in eulachon spawning habitat and larval rearing areas (estuarine environments) caused by forest related operations, in-river dredging operations, industrial pollution (Hay and McCarter, 2000), shoreline development and river flow management practices (Eulachon Research Council, 1998). Changes in the global climate have also affected, firstly, the freshwater environment due to the erosion of glaciers, thus altering the timing and the size of spring freshets (Barry, 2006), and secondly the marine environment, reducing the availability of food, increasing the northward migration of warm water predators such as adult hake (*Merluccius productus*), or increasing the number of eulachon competitors such as juvenile hake (Hay and McCarter, 2000). There have also been impacts from the capture of eulachon, whether it is eulachon caught in off-shore in shrimp trawl fisheries (Hay *et al.*, 1999) or eulachon caught in targeted, in-river fisheries (see *A review of historical eulachon fisheries*). Finally, increases in the bird and mammal populations may have contributed to increased predation of eulachon within estuaries (Hay *et al.*, 1997). It remains unknown if the drastic decline of some eulachon populations was a result of a single event or a combination of events. It would be beyond the scope of this study to do a complex analysis on all possible causes for the decline of the eulachon and further complicating this task is the limited amount of data available to test any one hypothesis. Whatever the cause(s), the largest obstacle(s) preventing the recovery of some populations need(s) to be identified, "you know we've got all these things that we think might [have happened]. To me, find out so that you can do something about it, get them back somehow" (015 Nuxalk Interviews, 2006). Hence, this chapter examines the effects of changes in shrimp catch, hake biomass, hake catch, ocean conditions and seal (*Phoca vitulina*) and sea lion (*Eumetopias jubatus*) abundance on the changing abundance of seven eulachon populations estimated in *Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system*.

The Nuxalk perspective

It was a widespread belief of the Nuxalk respondents (86%) during my 2006 Nuxalk interviews that the shrimp trawl fishery was by far the most likely reason for the collapse of the British Columbia (BC) Central Coast eulachon. It has been well publicized in the Central Coast region that eulachon are captured as bycatch in the shrimp trawl fishery, for example, the *Coast Mountain News* article on March 16, 2000 was titled, "Shrimp fishery on Central Coast threatens oolichan run" (Kuhn, 2000). Some of the participants have also had personal experiences involving eulachon bycatch.

"In Namu, the first years we worked out there [1970s], trawlers came in…shrimp trawlers. My dad, I was wondering, why he always went out back…he'd go pick out the eulachons that were dumped on the floor. The trawler would dump the shrimp into the big holding tanks…we had to grade [the shrimp]. The eulachons would get thrown on the floor with everything else that wasn't needed. My dad would pick up the eulachons and then he'd take them home and cook them. Tubs and tubs of eulachon they'd dump off the edge" (044 Nuxalk Interviews, 2006).

In addition, one Nuxalk commercial salmon fisher recalled a conversation he had with a shrimp trawler deckhand a few years ago. The deckhand claimed that he was told by his boss to "keep quiet about the catches of eulachon they were getting" alluding to the fact that there were lots of eulachon being caught as bycatch (010 Nuxalk Interviews, 2006).

Table 22. Impact hypotheses developed at the "2007 workshop to determine research priorities for eulachon." Those investigated here are marked (*).

Hypothesis #	Description of hypothesis
H1	Land and water management impacts led to the recent coast-wide decline in eulachon
H2	Pollution (industrial effluents, sewage and agricultural runoff) has reduced spawning success on some rivers.
H3	Pollution (industrial effluents, sewage and agricultural runoff) has reduced egg and larvae survival on some rivers.
H4	Dredging activity results in spawner and egg entrainment as well as the smothering of eggs.
H5	Dredging activity negatively impacts eulachon freshwater habitat.
H6	Changes in the volume and discharge patterns of rivers draining forested areas change the availability of suitable spawning sediments and reduce the success of eulachon spawning and the survival of eggs.
H7	Debris from log handling and booming in rivers has direct deleterious impacts on egg survival.
H8	Log booms in marine and estuarine areas affect the survival of eulachon larvae and juveniles.
H9	Shoreline construction (e.g., roads, dykes) reduces the amount and quality of eulachon spawning habitat resulting in decrease in spawning success and egg / larvae survival.
H10	Diversions/dams affect water volume, temperature and sediment levels reducing the quality and quantity of eulachon spawning habitat.
H11	Climate-driven changes in freshwater hydrology (glacier / snow melt) are causing the decline in eulachon.
H12	Climate-driven changes in the estuary (ocean currents / run timing) have caused a reduction in larvae growth and survival.
H13*	Climate-driven changes in ocean conditions (Increase in sea surface temperatures (SST), freshwater runoff, salinity, pH and sea levels) directly impact juvenile / adult eulachon survival.
H14	Climate-driven changes in near-shore ocean / continental shelf conditions (increase in sea surface temperatures, freshwater runoff, salinity and sea levels) have reduced the availability of food, reducing the survival of eulachon.
H15*	Increase in predation of eulachon by warm water species such as hake as their distributions move northward has reduced the survival of juvenile (1+) eulachon.
H16*	Increase in competition from warm water species such as hake as their distribution moves northward has reduced the survival of juvenile and adult eulachon.
H17	Eulachon are caught as bycatch in the offshore shrimp trawl fishery.
H18	Bycatch reduction devices used in the shrimp trawl fishery are effective at reducing the amount of eulachon caught.
H19*	Shrimp trawler harvest has made a significant contribution to the recent decline in eulachon.
H20	Shrimp trawler harvest is a significant factor preventing the recovery of eulachon.
H21	First Nations harvest has made a significant contribution to the recent decline in eulachon
H22	First Nations harvest is a significant factor preventing the recovery of eulachon.
H23	Commercial fishing has made a significant contribution to the recent decline in eulachon.
H24	Commercial fishing may be a significant factor slowing the recovery of eulachon.
H25*	Mammal / bird / fish predation of spawners has been a significant factor contributing to the recent decline in eulachon.
H26	The decline in eulachon is harming dependent populations of mammals, birds and fish.

Source: Pickard and Marmorek, 2007.

Additional explanations for the decline given by the participants included: over fishing of the female eulachon; seine fishing in eulachon spawning grounds; overly efficient fishing methods (seine nets); booming of logs in the estuary; increased silt in the river from logging practices; global warming causing

increases in predators (seals, porpoises (*Phocoena vomerina*), hake and chub mackerel (*Scomber japonicus*); and increases in river temperatures (Table 23).

Table 23. Possible causes for the decline of the Bella Coola eulachon given by Nuxalk community participants during the 2006 Nuxalk interviews

Possible causes	% of participants	Number of responses*
No answer given	14%	(4/29)
Some cause stated	86%	(25/29)
Shrimp trawl bycatch	83%	(24/29)
Fishing related (fishing females; in spawning areas; using seine nets)	17%	(5/29)
Anthropogenic changes to river/estuary (dams; dykes; log booms; inc. silt from logging operations)	14%	(4/29)
Climate change- inc. predators	10%	(3/29)
Climate change- inc. river temp	7%	(2/29)

*More than one cause given per person

METHODS

The first part of this study will summarize and provide background information on each hypothesis described in Table 22. The second part will examine some of the impact hypotheses using data from seven of the fifteen eulachon systems (i.e., the Nass River, BC; the Kemano River, BC; the Bella Coola River, BC; the Klinaklini River, BC; the Fraser River, BC; the Columbia River, Washington/Oregon, USA) whose annual abundance statuses were estimated in *Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system*. These rivers were chosen because they had the longest time-series of abundance estimations over the eulachon geographic range. Each eulachon abundance data set was compared with (1) offshore BC shrimp trawl catch data (DFO 1972-2006); (2) hake (age 3+) biomass data (1966-2006; Helser *et al*., 2006); (3) hake catch data (1966-2005; Helser *et al*., 2006); (4) climate data including: the Southern Oscillation Index (SOI; DFO, 1951-2006), the Northern Oscillation Index (NOI; 1948-2006; Schwing *et al*., 2000), the Upwelling Index (UI; National Oceanic and Atmospheric Administration [NOAA], 1946-2006), and Sea Surface Temperature (SST) data from the lighthouse at Amphitrite Point, near Barkley Sound, on the West Coast of Vancouver Island (DFO, 1940-2006); and finally (6) northern harbour seal (*Phoca vitulina*) and Steller sea lion (*Eumetopias jubatus*) data prepared by Ainsworth (2006). For each data set, Spearman's rank correlation coefficient and the coefficient of determination (r^2 value) were calculated[15]. Each of the eulachon abundance time-series were also time lagged by two and three years and also compared with the six data sets. The final results from the correlation analyses can be found in Appendix 9.

RESULTS AND DISCUSSION

Land and water management

At the 2007 Workshop, the first hypothesis (H1), "land and water management impacts led to the recent coast wide decline in eulachon" included nine sub-hypotheses (H2-H10) which discussed forestry operations, industrial pollution, dredging operations, shoreline developments and water flow operations

[15] A free on-line statistics software (calculator) was used (Wessa 2008) to calculate the rank correlation coefficient, corrected for the ties in the ranked data, and also gave the 2-sided t-value for 95% confidence.

(dykes/dams) (Pickard and Marmorek, 2007). All of these activities occur in the freshwater environment and thus they may be (1) contributing to the in-river mortality of returning eulachon adults and their deposited eggs and hatched larvae; (2) limit or cause damage to eulachon spawning habitat; and (3) provide barriers to eulachon spawning migration.

Forestry operations

The forestry operations that may impact eulachon populations include the removal of trees and log handling processes, such as log transfer, log sorting and log storage. The removal of trees from a watershed can have many effects on a river system, for example, it may increase fine sediment (Beschta, 1978), increase sediment production (Hartman *et al.*, 1996), change the composition of spawning gravel (Scrivener and Brownlee, 1989) and increase the temperature of the river (Holtby, 1988). Log handling operations may also impact the rivers by damaging shoreline and underwater substrate during construction or operation or by depositing wood waste that may smother habitat and its inhabitants (G3 Consulting Ltd., 2003).

The primary spawning habitat of eulachon occurs over small pebbles in moderate water velocities where the eggs can attach to pea-sized gravel (Smith and Saalfeld, 1955). Increased flows may diminish the preferred spawning substrate as well as increase the chance of eggs being flushed into the marine environment prior to hatching. Eulachon eggs appear to tolerate low- to mid-range salinities during incubation but higher salinities (>16 ppt) can cause mortality (Lewis *et al.*, 2002). Increased egg mortality has also been found in areas with higher silt and organic accumulations (Langer *et al.*, 1977). Increased water flow may also hamper the migration of returning adults as eulachon are weak swimmers and thus commonly enter rivers during high tides.

It is likely that eulachon performance would be even poorer than that of herring, as the herring's body is deeper and presumably more muscular. This may be why the Nass River eulachon migration is timed so as to coincide with minimum river discharge and maximum flood tides (Langer *et al.*, 1977).

Several local eulachon experts have reported increased flooding in logged eulachon river systems. Historically, the flooding period of the Klinaklini River, Knight Inlet, used to take approximately a week to reach the flooding stage but in the past 15 years the flood stage is reached in as little as three hours (Ryan, 2002). Flooding has also been observed in the Kingcome River, "it has become a problem, [the river] rises very quickly, within three to six hours, [and] lots of silt [is produced]" (Nicholson, 2002). The logging activities in the Skeena watershed are also suspected to have increased flooding in its watershed, however, the larger size of the Skeena River may mask direct flooding effects (Ryan, 2002).

Log handling operations are activities where logs are transferred from land to the water, transported to sorting and booming grounds, towed in booms or barges to storage areas and eventually transported to processing facilities (G3 Consulting Ltd., 2003). Two studies have examined the effects of log handling activities on the eulachon (Langer *et al.*, 1977; Orr, 1984). A study from 1969-1971 specifically focused on log driving operations and identified three possible impacts: the blasting of obstructions, silt and organic inputs and log accumulations (Langer *et al.*, 1977). The results were immediately used to assess and minimize the impacts of the log drive on the eulachon population. Fisheries officers were instructed to minimize these impacts by using stricter restrictions to delay the timing of blasting, enforcing the mandatory removal of limbs from logs, and removing log jams. Log driving also occurred on the Columbia River until the practice was eliminated in 1914; however, other logging practices such as the reduction of riparian buffers continue to negatively affect fish species in this river (Lower Columbia Fish Recovery Board [LCFRB], 2004). Log booms may also have a harmful affect if they are located in-river or in the estuary, as accumulated debris may produce anoxic water, reducing eulachon egg and larvae survival (Hay and McCarter, 2000).

Although there are several harmful effects caused by forestry operations, few feel that these effects are solely responsible for the extreme decline of some eulachon populations.

"I couldn't understand…if it had to be the logging, you know? People have been logging in the valley for a hundred years and we still had a good run until they started shrimp fishing. I can't really believe it was

logging on account we've had a good run when they were clear cutting up here" (Harvey Mack Nuxalk Interviews, 2006).

At the Eulachon Research Council (ERC) meeting held in Terrace, BC, in 2000, the British Columbia Forest Services stated that given the current knowledge on eulachon, they felt that ocean conditions were probably the main cause of the eulachon decline and past forest practices were probably not a significant contributor to the decline (ERC, 2000). The impacts of forestry operations on eulachon survival are difficult to separate from other land use activities. Each eulachon system has a different type of forestry operation that occurs in its watershed, the timing and the duration of these operations also vary between watersheds. This makes it difficult to compare the impacts of forestry operations between eulachon systems. As a result the impacts from forestry operations have not been thoroughly investigated (Hay *et al.*, 1997). The conclusions from the 2007 Workshop highlighted two impacts from logging operations that may potentially have an important effect on eulachon but are of an uncertain magnitude: (1) the changes of volume and discharge patterns in smaller rivers that decrease the availability of suitable spawning sediments; and (2) the debris from log handling operations that impact eulachon egg and larval survival. These two conclusions need further investigation to demonstrate the magnitude of impact they may have on eulachon survival.

Pollution

The overall hypothesis, "the pollution of spawning rivers contributed to a decline in eulachon" in rivers affected, or "contributed to a decline in the resilience of eulachon", included sub-hypotheses H2 and H3 at the 2007 Workshop (Pickard and Marmorek, 2007). It is probable that in-river pollution reduces the spawning success of returning adults and the survival of eggs and larvae (Rogers *et al.*, 1990). Pollutants enter a river from either point sources, such as sewage treatment plants and direct industrial discharges, or from, non-point sources, for example runoff from urban and agricultural areas (Dorcey, 1976).

The effects of such pollution on eulachon have been studied on the Fraser River (Rogers *et al.*, 1990) and the Kitimat River (Mikkelson *et al.*, 1996) although other eulachon systems have also been impacted e.g. the Columbia River, Washington/Oregon (Smith and Saafeld, 1955; LCFRB, 2004). During the spring of 1986 and 1988 Fraser River eulachon were captured between the river mouth and 31 km upstream and studied for selected contaminants (Rogers *et al.*, 1990). The fish were analyzed for several contaminants: chlorophenols (source: wood preservation operations), chloroguaiacols (source: pulp bleaching), DDT-related compounds (synthetic pesticide) and polychlorinated biphenyls (PCBs). Chlorophenols and chloroguaiacols contaminants were found in water and tissue samples and whole fish; and some fish gonads were found to contain DDT-related compounds and PCBs. Most of the whole body, liver and gonad tests contained chlorophenols, chloroguaiacols and DDT-related compounds, all of which increased in concentration with the distance of capture from the mouth of the river. This study demonstrated that eulachon could potentially be used as an integrator of trace contaminants in the Fraser River as they do not feed in fresh water. Thus, any contaminants must come directly from the environment. The authors also suggested that these pollutants may impact eulachon spawning success if eulachon egg fertility was affected in the same fashion as Baltic flounder (*Platichthys flesus*) and herring (*Clupea harengus*; fertility decreased when PCBs >120 ng g^{-1}).

Pollution impacts on eulachon have been extensively studied on the Kitimat River. The river once supported a large eulachon fishery conducted by the Haisla First Nation. In 1969, Eurocan Pulp and Paper Company (Eurocan) completed construction of a pulp and paper mill located on the Kitimat River. One of the Haisla's reserves is located along the shoreline approximately 1.5 km downstream of the mill's discharge (BEAK, 1991). The mill discharges its final effluent into the Kitimat River approximately 3.2 km upstream of the Kitimat estuary (BEAK, 1991). In 1972, the Haisla eulachon catch was significantly lower than the previous season (~23 t compared to ~82 t in 1971) as there were complaints about the fish being "tainted" (DFO, 1969-1973). Eulachon are believed to be more susceptible to tainting than other fish because off their high fat content and because they commonly return to spawn during low river flow periods when river effluent concentrations are highest (BEAK, 1994). Since 1972, there has been no eulachon caught for food consumption from the Kitimat River (Tirrul-Jones, 1985). Eurocan's effluent was first studied for "tainting" on exposed sockeye salmon in 1972 (Geiger) and then on exposed eulachon in 1973 by Fisheries and Marine Service and in 1975 by the Environmental Protection Service. All studies

concluded that the Eurocan effluent was capable of causing off-flavours in the fish tested, which increased with effluent concentration (Derksen, 1981). However, it wasn't until 1991 that Eurocan, under the direction of Waste Management Branch of the British Columbia Ministry of Environment, evaluated the potential of the effluent to affect the flavour of exposed eulachons (BEAK, 1991). The 1991 testing results demonstrated that fish exposed to 10% effluent after 27 hours were "tainted" and those exposed to 5% effluent were "marginally tainted". Similar studies continued from 1992 to 1995 on both eulachon and eulachon grease. These studies demonstrated that eulachon and the grease were equally affected (BEAK, 1996).

After the 1992 study, Eurocan installed a turpentine recovery system and made improvements in pulp washing in an attempt to reduce the tainting effects (BEAK, 1994). However, during the 1996 study, tainting was still found to occur and similar taint detection thresholds were obtained for eulachon and rainbow trout (BEAK, 1996). No studies were conducted in 1997, but they were continued in 1998. In 1999, there were very few spawning eulachon that returned to the Kitimat River and fish had to be obtained from the nearby Skeena River for testing. They were found to still be tainted but only during March and not during April (BEAK, 2000). By 2001, significant changes had been made by Eurocan to stop the tainting of eulachon and the effluent quality parameters were found to be significantly better than those measured in 2000 (Stevens, 2001). In 2004, the Haisla and Eurocan entered into a long-term agreement to develop a sensory evaluation test method over four years. This method would be used in future studies to determine if the final effluent impaired the Haisla's use of the Kitimat eulachon. The 2005 study suggested that the eulachon were still being tainted but conflicting results were found in 2006 (EcoMetrix, 2006). Nass River eulachon were obtained for the 2006 study as both the Kemano and Kitimat River eulachon runs were poor. The eight eulachon that were captured from the Kitimat River in 2006 were tested for tainting and were found to not be tainted, whereas the caged fish captured from the Nass River and exposed downstream of Eurocan's discharge were found to be tainted in 2006 (EcoMetrix, 2006). A reason suggested for the contradicting results was exposure time to the effluent. The fish from the Nass River were exposed for a measured 48 hours whereas the exposure time of the Kitimat River eulachon was unknown. On a positive note, the final effluent in 2006 was the lowest measured during an eulachon tainting study. Nevertheless, there is also the issue of effects to human health, resulting from anything that can be tasted as a taint.

Although there are major concerns over the uptake of contaminants by eulachon, their exposure to pollution preceded the recent major decline of the three known polluted eulachon systems: the Kitimat River, the Fraser River and the Columbia River. In contrast, rivers with minimal pollution have also suffered major declines, for example, the Kemano River, Bella Coola River and the Wannock River. Thus pollution may be an important contributing factor, but probably is not the sole reason for these declines. The only study that tested the effect of pollutants on egg survival and hatching was conducted in 1994 using Eurocan effluent and Kitimat River eulachon eggs (BEAK, 1994). The results indicated that there appeared to be no detrimental effect. However, there were logistical difficulties that may have affected the final results. For instance, a poor return of adults occurred in 1994, thus there was a shortage of females with eggs at the same stage of development. To fully understand the impacts of pollution to eulachon survival, further investigations on egg survival and hatching are suggested.

Dredging

Hypothesis 4 and 5 at the 2007 Workshop, suggested that dredging activities might negatively impact the eulachon by entraining adult spawners and deposited eggs; smothering downstream eggs with suspended sediments produced; and altering eulachon spawning habitat (Pickard and Marmorek, 2007). It has also been suggested that dredging activity in the vicinity of eulachon spawning areas can make the substrate unstable for egg incubation (LCFRB, 2004).

The function of dredging is to remove sediment from an aqueous environment and dispose of it at a different location (Lasalle, 1990). The main purposes of dredging are usually to increase or maintain the depth of water in a navigation channel, for flood and erosion control or to harvest sand for sale. Dredging in estuaries can have many environmental effects. Some of these include impaired light penetration from increased turbidity; altered tidal exchange, mixing and circulation; increased saltwater intrusion and creating an environment that is highly susceptible to low dissolved oxygen levels (Johnston, 1981).

Annual dredging occurs in some eulachon rivers, but most commonly in rivers with higher human populations, such as the Fraser River (Naito, 1998) and the Columbia River (LCFRB, 2004). Shipping and port activity continues to increase on the Fraser River and channel deepening has occurred between 2001 and 2005 to accommodate larger ships (Fraser River Estuary Management Program, 2006). More than half of the sand dredged from the Fraser River is removed, and thus is not deposited in the intertidal region. The major consequence is that the river bed level is lowered and the tidal range is increased (McLaren and Ren, 1995). This may effect the survival of incubating eulachon eggs if the salinity of the river is increased; salinities (>16 ppt) cause egg mortality (Lewis *et al.*, 2002). The annual maintenance dredging for the Columbia River's estuary has averaged 3.5 million cubic yards per year since 1976 and has concentrated the flow into one deep main navigation channel reducing the flow to side channels and peripheral bays (LCFRB, 2004).

The entrainment of adult eulachon spawners by dredges was documented in 1976 on the Fraser River (Tutty and Morrison, 1976) and at the mouth of the Columbia River between 1985 and 1988 (Larson and Moehl, 1990). In the Fraser River, an estimated 17,417 spawning eulachon, or approximately 0.9 t, were captured between the months of March and June (Tutty and Morrison, 1976). Eulachon entrained by hopper dredges in the Columbia River (mean entrainment: 0.002 individuals per cubic yard) was found to be minimal. However, it was cautioned that in river channels where the river may be more constricted, there would be a greater chance of eulachon entrainment, especially during peak migration (Larson and Moehl, 1990).

Entrainment of out migrating salmon and returning eulachon has been recognized on the Fraser River and as a result the timing of dredging operations has been prohibited during the months of March and June (Naito, 1998). Consequently on the Fraser River, the entrainment of eulachon eggs and adults has been minimized. Impacts to eulachon spawning habitat is likely still occurring in all rivers where dredging occurs and the impact to eulachon survival should be further investigated.

Shoreline development/flow management

Hypothesis 9 and 10 at the 2007 Workshop suggested that shoreline construction such as roads and dykes may reduce the quality of spawning habitat thus resulting in decreased spawning success and egg/larval survival. Also, diversions, such as dams, were suggested to affect the quality and quantity of spawning habitat by changing water volume, temperature and sediment levels during eulachon spawning (Pickard and Marmorek, 2007). At the 2002 Eulachon Conservation Society Workshop held in Prince Rupert BC, increased water velocity due to diking was identified as a concern. After a river has been diked the velocity at the thalweg increases because the current is forced into the middle of the channel (Sandheinrich and Atchinson, 1986). This is of particular concern for eulachon spawning success, as eulachon prefer to spawn in moderate water velocities (Smith and Saalfeld, 1955). Many eulachon rivers are located close to major cities or towns, thus have dikes built along them to control flooding (e.g., Fraser River). After the 1948 flood of the Fraser River, an extensive diking program was initiated and resulted in the river being confined to a relatively narrow strip (Northwest Hydraulic Consultants, 2006). It appears that eulachon may use the very shallow margins along the banks for spawning (Eulachon Conservation Society, 2002) thus reduced quantities of shallow sandy areas may be limiting eulachon spawning habitat. Increased water velocities may also be why eulachon, in some rivers, are not migrating as far upstream as they once did (Eulachon Conservation Society, 2002).

Some eulachon systems have also had dams built within their watersheds, for example the Columbia River and the Kemano River. The Columbia River Basin has a very complex system of dams and reservoirs used for power generation, navigation and flood control. These have greatly reduced historical water levels during the spring freshet, as water is stored for power generation and irrigation, while the rest of the year the water flow has increased as water is released during the winter drawdown of the reservoirs (LCFRB, 2004). The higher flows during the winter may negatively affect spawning eulachon and eggs/larvae as they usually enter and spawn in the Columbia River during the winter months. The Bonneville dam on the Columbia River also impedes the migration of spawning eulachon to their historical upriver spawning grounds as the fish are "often unable or unwilling to migrate through fish ladders" (LCFRB, 2004). This does not explaint the present decline of eulachon, as most dams were built during the 1930s and 1940s (Bargmann, 2000).

Land and water management practices have changed the freshwater habitat of most eulachon systems and thus have likely contributed to their declines. However, these impacts are probably not the sole cause of the recent coast-wide eulachon declines (Pickard and Marmorek, 2007). At the 2007 workshop, three initial steps were recommended to help determine the land and water management practices that have impacted the eulachon: (1) the past and present impacts for each eulachon system need to be identified; (2) monitoring and yearly abundance estimates need to be conducted for index systems; and (3) the areas of critical freshwater habitat used for spawning and egg incubation need to be identified and mapped so that they can be protected. In 1976, a submersible pump was used to determine the presence or absence of eulachon eggs in the Fraser River to gain further knowledge of spawning areas (Samis, 2007). A more recent study used radio telemetry on the Twentymile River, Alaska, (Spangler, 2002) and acoustic trawls on the Fraser River (Stables *et al.*, 2005). These studies have shed some light on eulachon migration patterns and spawning locations. However, similar studies need to be conducted in other impacted eulachon rivers.

Fisheries

The fisheries that capture eulachon are: (1) in-river fisheries targeted at catching eulachon which include commercial, First Nation and sport fisheries; and (2) offshore trawl fisheries that capture eulachon incidental bycatch. The in-river fisheries reduce the numbers of spawning adults whereas the marine trawl fisheries reduce the numbers of the pre-spawning adults and juveniles.

In-river eulachon catches: First Nation and commercial

Fishing diminished stocks

Hypotheses 21 to 24 from the 2007 Workshop suggested that First Nations and commercial catches have "made a significant contribution" to the recent decline of the eulachon and may be a "significant factor in preventing the recovery of eulachon" (Pickard and Marmorek, 2007). Thus any modest declines during the 1990s may not have been noticed initially and fishing effort may have been increased in order to obtain sufficient resources resulting in a larger number of available spawners being caught. To a certain extent these hypotheses were supported by a few of the 2006 Nuxalk interview participants.

"People started fishing higher up in the river and we never read the signs that they were diminishing, we just kept fishing them" (Anfinn Siwallace Nuxalk Interviews, 2006).

"You think about it now, we should have let those guys go and spawn. When it starts getting tough to catch them, whatever is there, we should have let spawn and we didn't we just went after them" (Wally Webber Nuxalk Interviews, 2006).

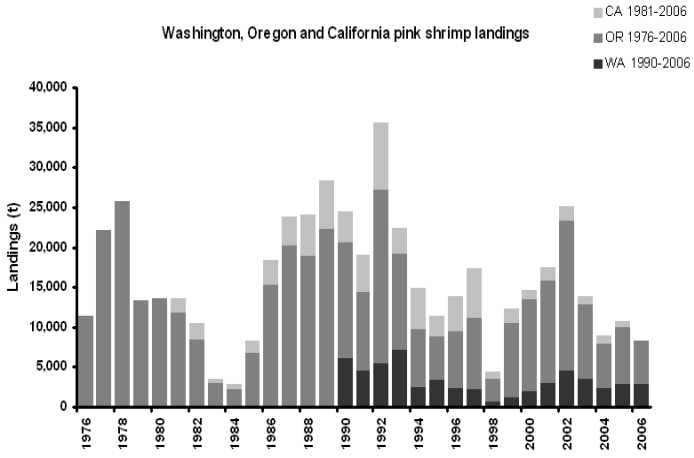

Figure 67. Washington (grey), Oregon (dark blue) and California (light blue) shrimp landings. Source: WDFG, 2008; ODFG, 2006; National Marine Service, 2008.

The conclusion for these hypotheses at the end of the workshop were that over fishing was "likely not an important link" (Pickard and Marmorek, 2007) as catches by First Nations or directed commercial fisheries were usually small and did not increase in recent years (see *Estimating historical catches of the Nuxalk Nation eulachon fishery* for catch records). In fact, in most cases, catches have probably decreased (e.g., Nass River). In 1996, the Fraser River eulachon spawning stock biomass was estimated at 1,916 t with a total catch of 62.3 t, a catch rate of approximately 3%, yet three and four years later there were still poor returns (420 t in 1999 and 120 t in 2000).

Although the signs of declining runs may have been missed, it was unlikely that increased effort alone caused the simultaneous collapse of several eulachon runs in the BC Central Coast. For example, the Kimsquit River in the Dean Channel and the Kilbella River in Rivers Inlet both had annual runs that were not fished regularly and both collapsed during the late 1990s. Today, eulachon abundance of these rivers remains low.

Methods of fishing

Several First Nations have witnessed major declines in their eulachon runs and some have expressed concerns regarding the use of newer fishing technologies. For example, a few of the 2006 Nuxalk interview participants expressed concerns regarding the seine net which was introduced to the Bella Coola eulachon fishery during the 1970s. The seine net operates by dragging a large, fine-meshed net across the bottom of the river, whereas the traditional trap net hangs suspended in the water column capturing eulachon with the lowering of the tide (see *Estimating historical catches of the Nuxalk Nation eulachon fishery* for details). The seine net also replaced the traditional conical net in the Klinaklini River and Knight Inlet during the mid-1950s (McNair, 1970). Today, however, some families of Knight Inlet have returned to the traditional conical net, as this gear is thought to capture eulachon less destructively (Fred Glendale, pers. comm., 2007). Some Nuxalk fishers believe the lead line of the seine net scrapes and kills recently deposited eggs when it is dragged across the river bottom (002 Nuxalk Interviews, 2006). The seine net was also described as "too easy" and "too efficient" when capturing eulachon (Wally Webber and Anfinn Siwallace, Nuxalk Interviews, 2006). In the past, during an abundant run, a conical net may take 3 to 4 days to fill up a stink box but when using a seine net, a box could be filled with one set (Clarence Elliot, Nuxalk Interviews, 2006).

Another concern in recent years was that traditional rules were no longer being followed; one such rule was to allow the first run or wave of fish, primarily made up of females, to pass through without any fishing. "The females were such a treasure and everybody would go after them. What would naturally happen if the females are over fished? And they weren't in big numbers to start with…if you get rid of one side of the species you're unbalancing that whole system" (Horace Walkus, Nuxalk Interviews, 2006). The section, *Estimating historical catches of the Nuxalk Nation eulachon fishery* discusses in more detail the dominance of females in the first run and the amount of grease female eulachon produce compared to that of male eulachon. Although these practices may have contributed to the decline in eulachon returns, it is unlikely that these methods of fishing caused the simultaneous collapse of the BC Central Coast eulachon runs.

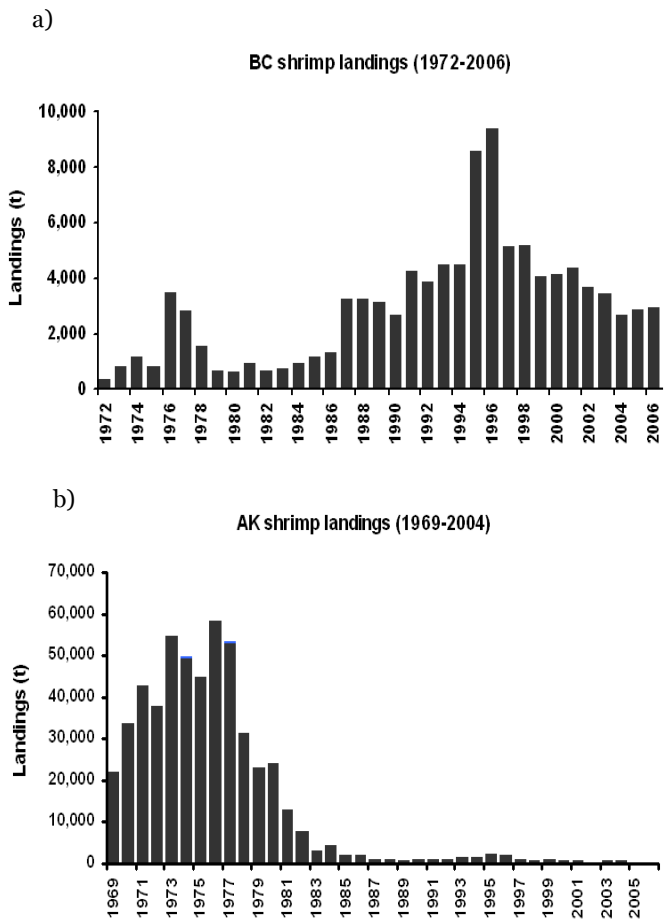

Figure 68. Shrimp trawl landings from (a) BC and (b) Alaska. Source: DFO 2007 & ADFG 2006.

Ocean fisheries

At the 2007 Workshop, impact hypotheses 17-20, suggest that shrimp trawl catch has contributed to the recent decline in eulachon (Pickard and Marmorek, 2007). These hypotheses considered the significance of eulachon bycatch by the shrimp trawl fishery and the effectiveness of bycatch reduction devices (BRDs). Shrimp trawling occurs in the marine environment and captures predominantly age 1+ (60-130 mm) and age 2+ (90-180 mm) eulachon but may also include some age 3+ (140-200 mm) as determined by eulachon caught in DFO shrimp trawl surveys (DFO, 2007a). Thus the incidental capture of eulachon in marine waters will affect the number of returning adults, one or two years later, assuming that the majority of eulachon mature between 2 and 3 years of age. It was determined by Clarke *et al.* (2007) that the Columbia River eulachon mature after 2 years and the more northern rivers, including the Fraser, generally mature after 3 years.

Background

The earliest records of trawling for shrimp in BC waters are from 1895 (Clark and Huston, 1998; Harbo, 1997). However, the demand for shrimp on the Pacific Northwest Coast rapidly developed during the late 1950s with the development of automated peelers (Clark and Huston, 1998). The majority of shrimp catch on the Pacific Northwest is taken by Oregon shrimp fisheries (Figure 67); the BC shrimp trawl fishery is relatively small in comparison (Figure 68a), averaging ~3,250 t since 1976, whereas Oregon averaged 11,750 t during the same period. Alaska once supported large commercial shrimp fisheries between the late 1950s and 1980s, which occurred predominantly in the Gulf of Alaska (GOA), but the shrimp population crashed during the late 1970s and early 1980s (Figure 68b). Most of the historic shrimp fishing areas in the GOA are now closed to shrimp trawling (e.g., Cook Inlet) and in more recent years the shrimp landings have been much smaller and predominantly come from Southeastern Alaska (ADFG, 2006).

Shrimp trawling is a method of fishing in which a vessel drags a cone-shaped net with a rectangular opening through the water to catch shrimp. The two types of trawling systems that are used in the BC shrimp fishery are the otter trawl and the beam trawl. Beam trawls use a net attached to a rigid beam, where the beam is used to hold the mouth of the net open regardless of the speed of towing (Jennings *et al.*, 2001). The otter trawls use otter boards or doors, hydrodynamically designed so that as they are pulled through the water the wings of the net are held open, requiring a certain tow speed to achieve an opened net. The size of the otter trawl is much larger than that of a beam trawl because it has no rigid structure (i.e., the beam) to limit its size or maneuverability.

History of the BC shrimp industry

Before 1996, the BC shrimp trawl fishery occurred in three major areas of the BC Coast: the inshore waters of the Strait of Georgia, the coastal areas off the North Coast inlets, and the West Coast of Vancouver Island (DFO, 1998). And up until 1996, the shrimp trawl fishery was generally open year-round with no catch limitations. The majority of landings were a mix of smooth pink shrimp (*Pandalus jordani*; >90%) and sidestripe shrimp (*Pandalopsis dispar*; Rutherford *et al.*, 2004). However, after 1996, the fishery expanded into areas previously not fished, such as the shrimp management area, Queen Charlotte Sound (QCSnd; Figure 69) and landings increased dramatically. The total catch of shrimp in 1995 (8557 t) almost doubled the 1994 landings (4502 t; Figure 68a). The suggested reasons for this shift in fishing area and effort were: reduced fishing opportunities in the groundfish and salmon fisheries, higher prices of shrimp, a decline in Washington and Oregon shrimp catches and abundant shrimp stocks on the BC Coast (DFO, 1999a; Clayton, 2001). According to Dale Gueret, North Coast Fisheries Coordinator in charge of the Central Coast shrimp trawl fishery for 2000, the increased fishing effort occured after DFO instigated a Pacific salmon license buy back in 1997. As a result many fishers began utilizing their shrimp licenses resulting in more shrimp licenses being issued (Kuhn, 2000). As a result of this increased effort and a concern for the shrimp resource, DFO announced the closure of the shrimp trawl fishery on March 21, 1997 until an acceptable management and assessment plan for the fishery was reached (DFO, 1997). The fishery was eventually reopened, approximately a month later (April 8, 1997) and an agreement-in-principle to continue the development of a management plan to ensure the conservation of the resource between DFO and the Shrimp Trawl Sectoral Committee (STSC) was made. The first elected STSC was

formed in 1995 and consisted of industry and DFO representatives. The focus at this time was the conservation of the shrimp resource and not bycatch.

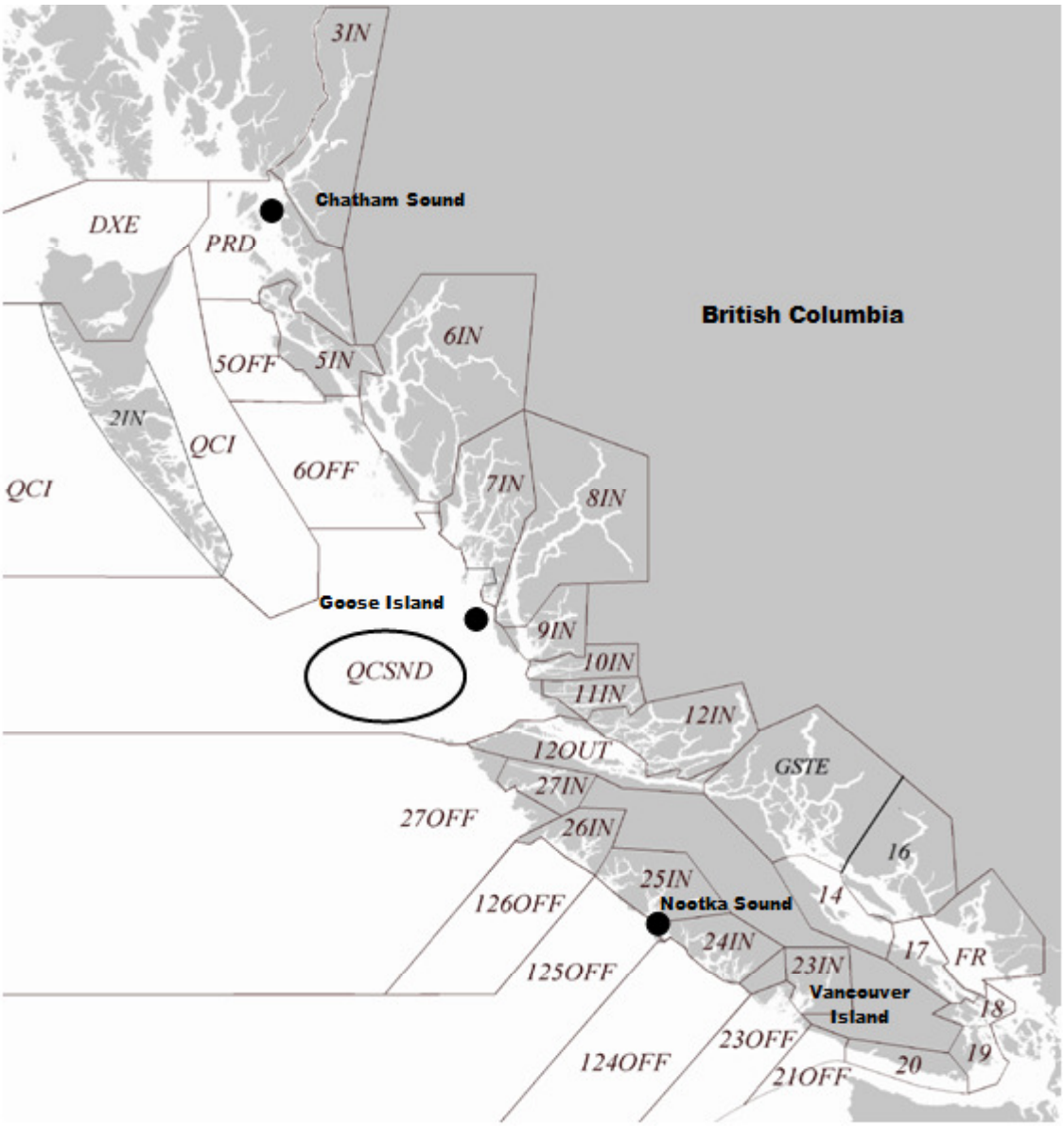

Figure 69. British Columbia shrimp trawl management areas established by DFO. Map also includes the locations where eulachon samples were obtained for mixed-stock DNA analysis testing (Beacham *et al.,* 2005). Source: DFO, 2007c.

Shrimp bycatch

During the 1990s bycatch emerged as a major issue in the management of fisheries worldwide as the public became informed by conservation and environmental groups (Alverson and Hughes, 1995). In 1995, a bycatch subcommittee of the STSC was formed to address bycatch issues in the BC shrimp trawl fishery. One of the main objectives of the committee was the development of a sampling program to document the spatial and temporal nature of bycatch associated with the fishery (Olsen *et al.*, 2000). In 1997, concern over halibut bycatch was expressed by the BC halibut fishery and resulted in an analysis of BC shrimp trawl bycatch by DFO during the 1997 and 1998 seasons. The analysis provided estimates of total bycatch, by species group, gear-type, shrimp management area and year (Olsen *et al.*, 2000). The analysis found that eulachon bycatch was "fairly high" in some areas and it was estimated that over 160 t of eulachon was taken in 1997 with 90 t taken from the QCSnd area (Hay *et al.*, 1999). The shrimp industry contended that a portion of these bycatch landings were the direct result of a few vessels "fear fishing" (Clayton, 2001). Fear fishing is a term used to describe fishing that occurs when participants actively try to record higher volumes of vessels because they "fear" the fishery may be managed under an individual vessel quota (IVQ) system in the future (Clayton, 2001) and quotas may be based on the size of historical catches. Nonetheless, a large amount of eulachon were captured as bycatch by the BC shrimp trawl fishery and in 1994 a sudden sharp decline occurred in three major eulachon spawning rivers; the Fraser River, the Columbia River and the Klinaklini River of Knight Inlet (Hay and McCarter, 2000).

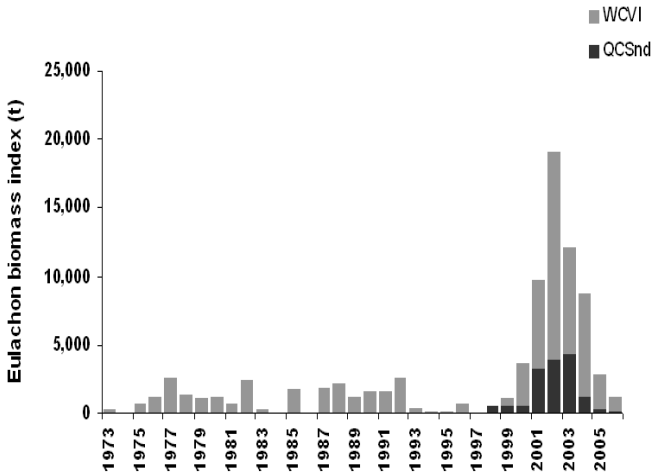

Figure 70. Offshore eulachon biomass indices for the West Coast Vancouver Island (WCVI) and for Queen Charlotte Sound (QCSnd) Source: Hay *et al.,* 1997; DFO, 2008.

Offshore eulachon abundance

The marine abundance and location of eulachon in the marine environment has been estimated from fish caught as bycatch in trawl fisheries and in multi-species research trawls (Hay and McCarter, 2000). An annual eulachon biomass index is calculated from data collected during annual shrimp trawl surveys in two areas on the BC Coast: 1) West Coast of Vancouver Island (WCVI) since 1973, and 2) QCSnd since 1998 (Figure 71). It is cautioned that these estimates are relative and not necessarily the absolute estimate of density and biomass (Hay *et al.*, 1997).

The Alaskan Department of Fish and Game (ADFG) also conduct small-mesh bottom trawl surveys for shrimp and forage fish in the waters of the Westward Region, around the Southern Peninsula and Kodiak Island. These surveys have been conducted intermittently since 1976 (Figure 72). Eulachon are also consistently found by groundfish fisheries and surveys between Unimak Island and the Pribilof Islands in

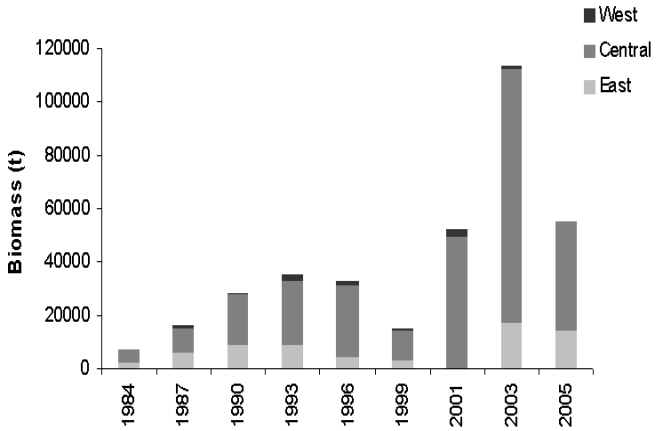

Figure 71. Offshore eulachon biomass indices for the Gulf of Alaska. Source: Conners and Guttormsen, 2005.

the Bering Sea and in the Shelikof Strait, GOA (Conners and Guttormsen, 2005). As with the BC surveys, the Alaskan surveys' primary purpose is to determine shrimp and groundfish biomass levels. However, they are also used to generate density estimates for forage fish (Jackson, 2006). The importance of forage fish populations to the marine ecosystem have been recognized by Alaskan fisheries management. Thus, prohibitions have been adopted on directed take of forage fish in the North Pacific and the Bearing Sea (Jackson, 2006). The two dominant smelt species found in the GOA are capelin (*Mallotus villosus)* and eulachon and they represent the majority of biomass and incidental catch of forage fish[16] (Conners and Guttormsen, 2005). Eulachon were the most abundant forage fish caught in bottom trawls in the GOA with biomass estimates ranging between 20,000 and 80,000 tonnes and it is even likely that these surveys underestimate their abundance (Conners and Guttormsen, 2005). The highest measured biomass in the GOA occurred in 2003 (~115,000 t) and was approximately 9 times the combined total biomass measured in WCVI and QCsnd (~12,000 t). The biomass estimates, prior to 2001, for both BC and Alaska are much lower than in recent years (Figures 70 and 72) and have shown substantial increases between 2001 and 2005. However, good returns have only been observed in the central Alaskan Rivers, such as the Copper River and Cook Inlet, while the populations in southeastern Alaska, southern and central BC, Washington/Oregon and California have not observed any significant increases (*Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system*).

Figure 72. The general locations of the offshore Alaskan areas where the majority of eulachon have been captured by shrimp and groundfish surveys. Source: Conners and Guttormsen, 2005; Jackson, 2005.

<u>*Do eulachon belong to distinct populations?*</u>

After it was discovered that there were significant amounts of eulachon caught as bycatch in the shrimp trawl fishery (Hay *et al*., 1999), the question was raised "if eulachon home to their natal rivers to spawn, then is it possible that a number of distinct populations exist?" (McLean *et al*., 1999). This question is very significant because if eulachon are a single stock then the declining returns may be attributed to changes in distribution, not a decrease in abundance. Thus bycatch of eulachon may not be as significant. However, if each eulachon-bearing river is a distinct population, even a small bycatch of eulachon may

[16] herring are not considered forage fish

significantly impact the returns because "the size of the bycatch may be very large relative to the size of some small runs" (Hay *et al.*,1999).

Previously, it has been suggested that since eulachon spend such a short time in freshwater they may not be as dependent on specific freshwater habitats as other anadromous species (McLean and Taylor, 2001). There have been three different methods used to determine the population structure of the eulachon: vertebral number counts (Hart and McHugh, 1944), mitochondrial DNA (McLean *et al.*, 1999) and microsatellite variation (McLean and Taylor, 2001; Beacham *et al.*, 2005). Although Hart and McHugh's (1944) study indicated there were significant differences among watersheds, the results of McLean *et al.*'s (1999) mitochondrial DNA study revealed that eulachon were a weakly sub-divided population, essentially a single stock and not structured on a river-by-river basis. Thus eulachon were managed in Canadian waters under this assumption until a more recent investigation, using microsatellite variation, showed that eulachon do display genetic differentiation among spawning aggregations of major rivers (Beacham *et al.*, 2005). This differentiation between rivers was also sufficient to allow reliable stock composition when applied to mixed-stock samples.

An analysis was conducted on samples of mixed-stock eulachon collected from three BC shrimp management areas: WCVI (Nootka Sound), QCSnd (Goose Island) and Chatham Sound (Figure 69). These mixed-stock samples were compared to 9 eulachon river populations[17] (Beacham *et al.*, 2005). The analysis of these samples indicated that the marine area of WCVI was composed of mainly Fraser and Columbia River eulachon. The Central Coast sample included eulachon from all 9 river populations, whereas the northern BC, Chatham Sound sample, was dominated by Northern and Central Coast eulachon populations. Thus, the eulachon bycatch captured off the WCVI would impact the Fraser and Columbia eulachon populations and the bycatch caught in QCSnd and Chatham Sound would impact the central and northern eulachon populations.

The drastic decline of the Bella Coola eulachon population in 1999 suspiciously occurred two years after the large 1997 eulachon bycatch taken in the BC commercial shrimp trawl fishery in area QCSnd. It is unfortunate that the largest bycatch occurred in the offshore areas inhabited by Central Coast eulachon, as they are some of the smaller eulachon populations. However, QCSnd has been closed to shrimp trawl fishing since 2000 and the overall effort has remained low, only 70 out of 245 licensed vessels were active in the 2006/07 season (DFO, 2007). Yet eulachon fail to return in fishable numbers to the Bella Coola and to other Central Coast rivers, such as Wannock River, Rivers Inlet. These populations have either been reduced to extremely low levels past the point of recovery, or there is another factor preventing their recovery. Since there is a large discrepancy between the amount of eulachon returning to these rivers (see *Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system*) and the amount measured in offshore marine surveys (Figure 70), some other factor preventing their recovery, may be plausible. The Bella Coola eulachon relative abundance has been estimated at less than 50 kg for the past six seasons (Lewis and O'Connor, 2002; Winbourne and Dow, 2002; Moody, 2005, 2006; Nuxalk Fisheries, 2005-06) and the lowest reported offshore abundance in QCSnd at 193.2 t in 2006 (DFO, 2008). There are nine months between the time the DFO offshore shrimp surveys calculate eulachon biomass and the time that the eulachon are to return to the rivers. Thus, eulachon marine survival has been greatly reduced during these months and several climate change hypotheses have been suggested.

Bycatch reduction devices (BRDs)

BRDs can be separated into those that separate species by differences in behavior and those that mechanically exclude unwanted organisms according to their size (Broadhurst, 2000). In an attempt to reduce bycatch in the BC shrimp fishery BRDs were made mandatory in the shrimp trawl fishery in 2000. Prior to 2000 there were no regulations in place to monitor or to reduce the amount of bycatch taken and BRDs were used purely voluntarily. By 1995, some of the otter trawlers had begun to use separator grates to reduce bycatch and a few years later, these and other devices expanded to the beam trawlers (Boutillier *et al.*, 1999). However, it was not until additional areas reported eulachon declines, such as the Bella Coola River and the Kemano River, and the amount of bycatch was made public that industry and DFO were motivated to create a new shrimp management plan that addressed the issue of eulachon bycatch.

[17] Columbia, Cowlitz, Fraser, Klinaklini, Bella Coola, Kemano, Skeena, Nass, Twenty-mile Rivers

Another major influence in the development of the BRD regulations was DFO's new Pacific Selective Fishing Policy released in 1999 which stated:

All Pacific fisheries, in which bycatch is an issue, will meet specified standards of selectivity. In fisheries where selective harvesting standards are not met, and bycatches remain a constraint to achievement of conservation objectives fishing opportunities will be curtailed (DFO, 1999b).

The use of BRDs in the eastern Canadian shrimp fishery became mandatory in 1993, seven years before British Columbia (Brothers, 1996). Experimentation to reduce bycatch by East Coast fishers also started as early as 1970. However, fishers were reluctant to use sorting devices because of their complicated designs and the assumption that the grid increased the cost of shrimp trawling (Brothers, 1996). However, in 1991 DFO extensively monitored the shrimp fishery in the Gulf of St. Lawrence and found that from 435 sets observed, the total catch of shrimp was 275.4 t with a bycatch of 53.4 t of cod, 27 t of redfish, and 17.2 t of turbot; most of these species were juvenile fish with no commercial value (Brothers, 1996). Thus, the need to decrease bycatch became very apparent on the Canadian East Coast.

The states of Washington, Oregon and California made BRD use mandatory during 2001 and 2003. However, the Oregon Department of Fish and Wildlife (ODFW) had completed a study on fish excluder technology in 1996 (Hannah *et al.*,1996). Prior to BRD use, the unmarketable catch would occasionally be so large that entire tows were dumped (Hannah *et al.*, 1996). There were also reports of high levels of eulachon bycatch by shrimp fisheries in areas located from northern Oregon to the southern end of British Columbia (Bargmann, 1998). In 2001, shrimpers in Oregon were encouraged to use BRDs voluntary, but most "didn't attempt to use excluders until they were required" (Hannah *et al.*, 1996). After the 2001 season, the ODFG made it known that shrimpers should be prepared to implement BRDs sometime during the 2002 season. In California BRDs were already required and in Washington they were made mandatory mid season in 2001 and 2002, and then permanently in 2003 (WDFW, 2008). After the 2002 season, BRDs became mandatory in Oregon. The use of BRDs in these shrimp fisheries was initiated after each state committed to reducing the incidental catch of canary rockfish (*Sebastes pinniger*). The canary rockfish were declared overfished by the Pacific Fishery Management Council in 2000. Hence without the use of BRDs the maximum catch of canary rockfish could occur well before the shrimp quota is landed (Hannah and Jones, 2007). Prior to the use of BRDs, the Oregon shrimp fishery had bycatch percentages of 32% to 61% of total catch with the majority of the catch consistently composed of Pacific hake and various smelt species (Hannah and Jones, 2007). The highest percent catch of smelt was calculated in June 2000 (28.32%) (Hannah and Jones, 2007). However, it was not specified how much of this catch was eulachon. Overall the use of BRDs in Oregon has resulted in a large reduction of total fish bycatch (66% - 88%) with smelt bycatch between 0.25% - 1.69% (Hannah and Jones, 2007).

The BC shrimp trawl industry believes that there are no longer issues related to bycatch since BRDs became mandatory and feel that that they should be commended for their proactive work in reducing bycatch (Clark and Boehner, 2003). The BC shrimp trawl has made efforts in addressing eulachon bycatch issues. They have completed preliminary bycatch reduction studies (2000 and 2001), held an international conference on bycatch reduction, reduced eulachon bycatch (although exact figures are debatable), and recommended 100% use of bycatch reduction devices starting in 2000 (Clark and Boehner, 2003).

Bycatch reduction studies

In 2000, the BC shrimp trawl industry conducted a preliminary bycatch reduction study to collect information and identify gear configurations that could benefit the eulachon (Clayton, 2001). The initial study was used to justify additional, more intensive, detailed, testing using commercial size nets. Three gear configurations were found to effectively reduce eulachon bycatch without significantly impacting the catch of shrimp; (1) adding a 2"rigid mesh, (2) the addition of 2 fish eyes[18] to the cod end, and (3) adding both the rigid mesh and the 2 fish eyes. These gear configurations provided a means of escape for eulachon once they enter the trawl net. The 2" mesh gear configuration consisted of a rigid square hung mesh net inserted into the hood of an otter net. The fisheyes consisted of two escape holes placed in the

[18] Escape holes in the top part of the net

top part of the cod-end of the trawl net. The combination of the 2" (5 cm) rigid mesh with the fisheyes had better reduction results than either gear did by itself, with minimal reduction in shrimp catch. The earlier in the tow the fish were allowed to escape the greater the reduction in eulachon catch because there was less chance that the fish would 'gill' on the net and die. However, the most effective method tested prevented eulachon from being captured at all. This method added a 100 lb (45 kg) chain clump to the net which in turn scared the eulachon away from the net and prevented capture. Unfortunately this method did not effectively catch shrimp and the chain clump dug into the ocean bottom, increasing ocean debris in the catch. The final outcome from the 2000 preliminary study was the recommendation to DFO that "all otter trawl nets install a 42 sq ft (3.9 sq m) [panel] of 2"(5 cm) rigid square mesh" starting in 2001. The recommendation was accepted and included in the 2001 management plan for shrimp trawling (DFO, 2001) and in return, industry was allowed to conduct the 2001 selectivity trials.

The first three gear configurations indentified in the preliminary study were used in the 2001 selectivity trials (Clayton, 2002). One of the objectives of the 2001 study was to test the potential of these gear configurations to reduce eulachon bycatch rates in otter trawls. The final gear configuration that was found to be optimal at reducing eulachon and other species and retaining shrimp, was the use of a separator grid and a combination of soft square mesh placed lengthwise and crosswise in the upper belly of the otter net. Total eulachon reduction was estimated at 53.5%. In Oregon, the BRD with the smallest percent of smelt bycatch by weight (0.25 %) was a rigid grate with bar spacing of 25-31 mm (Hannah and Jones, 2007).

Collateral damage

Although the BC shrimp trawl industry has claimed to have reduced eulachon bycatch by some 80% over the period from 2000-2001 (Clayton, 2002), the issue of collateral damage has not been addressed. Collateral damage is the damage and mortality of escaping and discarded organisms caused by towed gears (Broadhurst *et al.*, 2006). If the majority of discarded or escaped eulachon do not survive evasion of the net, capture by trawl gear, or the sorting using BRDs, it is of little importance that the amount of bycatch has been reduced.

Broadhurst *et al.* (2006) identified several biological, environmental and technical factors that occur during the sorting process which have been demonstrated to, or can lead to, escape mortalities, for example damage to an organism's skin or scales during the capture leading to infection; capture-induced exhaustion; the size of the individual being caught; the size of the catch and its composition (large catches cause fish to strike the mesh and each other more often); the size and shape of the mesh; and the amount of times an individual comes into contact with gear components. The estimated escape mortality has rarely been attributed to only one of these factors thus mortality usually occurs as a result of a combination, for example from both skin injuries and exhaustion (Suuronen *et al.*, 1996b).

The reduction of eulachon bycatch has been studied to a limited extent by the BC shrimp trawl industry (Clayton, 2001). However, the mortality of eulachon escaping from trawl nets and BRDs has not. Eulachon have several attributes that make them more vulnerable to discard or escape mortality, for example, small fish are less able to avoid capture and thus have less endurance to escape when they are captured (Suuronen *et al.*, 1996a). A study conducted on herring by Suuronen *et al.* (1996a), indicated that the mortality of herring escapees from trawl codend meshes was found to be size dependent. Although the smaller fish showed less skin injury and infections than the larger fish, the smaller fish were dead after 1 week of caging whereas the larger fish were not. It was suggested that the smaller fish were more vulnerable to stress, exhaustion and damage during the trawl capture process. The survival of smaller (<12 cm) herring escapees was not improved by the sorting grid. Thus eulachon would have a harder time escaping from faster towed nets, for example, the otter trawls.

Otter trawls in the BC shrimp trawl fishery have a significantly higher eulachon CPUE than beam trawls (Olsen *et al.*, 2000). This is unfortunate as juvenile eulachon sizes offshore range between (6 and 20 cm) with an average size of 12.4 cm (personal observation[19], 2006). Underwater observations of herring in an off-bottom trawl also indicated that the fish did not readily pass through the web of the cod-end even though they readily could do so (High and Lusz, 1965). The herring instead maintained a position in a

[19] Personal observation on DFO shrimp survey conducted in QCSnd May 12-18, 2006

specific area of the web and on a few occasions herring from the outside swam through the mesh into the bag to join those fish within the net. Thus it may be essential to develop a BRD that prevents eulachon from entering a trawl net, such as the 100lb (45 kg) weight used in the BC shrimp industry preliminary bycatch reduction trials, with the condition that the BRD also be effective in catching shrimp. Thus a scare tactic BRD may be the most successful way to reduce eulachon bycatch. Notwithstanding, Broadhurt *et al.* (2006) state that the mortality from discards is much greater than that of escapees thus the primary focus should always be to facilitate the rapid selection of fish using BRDs, designed and demonstrated to have minimal negative effects on escapees. Thus the 2" (5 cm) rigid mesh used by the BC shrimp fishery should hopefully help to prevent eulachon from entering the cod-end and prevent eulachon mortality from discards. Nevertheless, the survival success of eulachon passing through this mesh should to be determined through further investigations.

Climate change

At the 2007 Workshop, the impact hypothesis "changing climate conditions have resulted in a decline in eulachon" included six sub-hypotheses (H11-H16) that emphasized impacts to eulachon spawning habitat and juvenile rearing grounds (Pickard and Marmorek, 2007). These included changes to freshwater hydrology due to reduced glacier/snowmelt; changes in the estuarine environment affecting larvae growth and survival; changes in the marine environment affecting juvenile survival (increased predation, competition for food, food composition and food availability).

The earth's climate naturally varies over time and these climate variations can occur gradually or abruptly. Recently worldwide concern has grown over human generated greenhouse gases and their connection to intensified climate changes. Large-scale climate shifts were first introduced to fisheries scientists as "regime" shifts by Isaacs (1975). Generally, a climate regime shift can be defined as a characteristic behavior of a natural phenomenon, for example sea level pressure, that has undergone an abrupt change in a short period of time (Hare and Mantua, 2000). There have been two major regime shifts in the last century, the widely accepted shift of 1976-1977 and the shift that occurred during 1988-89 (Beamish *et al.*, 1999). These regime shifts can cause "major reorganizations of ecological relationships over vast oceanic regions" (Francis and Hare, 1994) and also alter the mix and abundance of coexisting species, from primary producers to top predators (Benson and Trites, 2002).

A climate regime also has inter-annual climatic events referred to as El Niños and La Niñas. An El Niño event is the wind driven reversal of the Pacific equatorial currents resulting in the accumulation of warm tropical surface water along the coast of the Americas (Duxbury and Duxbury, 1997). A La Niña event occurs when there is colder than normal surface water in the eastern tropical Pacific (Duxbury and Duxbury, 1997). A severe El Niño event causes the displacement of atmospheric pressure cells which affect climate patterns over large areas of the earth (Duxbury and Duxbury, 1997). Certain processes have been identified by the appearance of one of these events. For example, the Southern Oscillation Index (SOI) identifies El Niño and La Niña conditions in the tropical Pacific Ocean (DFO, 2006) and the Pacific Decadal Oscillation (PDO) is used to describe interdecadal climate variability based on northwestern hemisphere extratropical sea surface temperatures and sea level pressures (Mantua *et al.*, 1997).

An extreme low pressure event occurred between 1976 and 1978 over most of the Pacific North Coast and resulted in a general warming over Alaska and a cooling in the central and western North Pacific (Beamish, 1993). This included warmer than average Sea Surface Temperatures (SST) along the West Coast of North America (Miller *et al.*, 1994). During this regime the SOI changed from a regular oscillation of El Niño and La Niña anomalies to fairly persistent El Niño conditions (Beamish *et al.*, 1999). This shift was associated with increases in primary and secondary production on a large scale and brought with it major changes in fish abundance (Beamish, 1993). In 1989 a new regime began and was dominated by extreme and persistent El Niño conditions (Beamish *et al.*, 1999). It has been found that during an El Niño event the thermocline is depressed and upwelling only brings nutrient-depleted water to the surface (Dorn, 1995). This new regime caused a major decline in fish productivity during the 1990s along on the West Coast of Canada (McFarlane, 2000). Globally, the decade from 1996-2005 has experienced nine of the ten warmest years ever recorded (surface temperature; DFO, 2006). Between 1997 and 1998 one of the strongest El Niño events occurred followed by a La Niña event in 1999 (Zamon and Welch, 2005). And between 1999 and 2002, cool marine conditions have occurred, however, since 2003 warm ocean surface

temperatures have persisted (DFO, 2006). Warm years increase the vertical stratification of the water column and lead to reduced productivity, thus a return to cooler more "normal" conditions would allow for more normal mixing and nutrients to be resupplied to the surface layers (DFO, 2006). Pelagic fish along the North Pacific Coast have been suggested as good indicators for climate change, as the environment pelagic fish inhabit and their life history, seem to be directly related to atmospheric and oceanographic variability (Klyashtorin, 1997; Benson *et al.*, 2002; Agostini *et al.*, 2006). And as eulachon are a northern, cold-water pelagic species, and appear to be quite sensitive to small environmental changes, they have also been suggested as an indicator species (Hay, 1995).

The theoretical concept of an ecological regime shift has been criticized (Lees *et al.*, 2006). It is felt that the factors which influence marine communities and the dynamics and impacts of these interactions are not fully understood and overfishing, not merely, climate regime shifts, tend to be related to ecological regime shifts. In any case, the possible impacts of climate regime shifts to in-river eulachon abundance will be summarized in this section and then tested against the concept of climate regime shifts in the next sections.

Marine environment

Food availability

Hypothesis 14 from the 2007 Workshop suggested that "climate-driven changes in near-shore ocean and continental shelf conditions have reduced the availability of food, reducing the survival of eulachon." Zooplankton (e.g., euphausiids and copepods) form a critical link between primary producers (phytoplankton) and pelagic fish. For example, the summer distribution of hake has shown a strong overlap with euphausiid distribution (Ware and McFarlane, 1995) and the eulachon's primary prey appears to be a specific euphausiid species (*Thysanoessa spinifera*; Cooper, 2000). Euphausiids can generally be found in most areas of the ocean but are more common in upwelling regions which are commonly located along the edges of the continental shelf or at the shelf break (Simard, 1986) where nutrients are most available for planktonic growth.

From 1951 to 1993 the surface layer of the ocean steadily warmed and the zooplankton volume within the California Current decreased by an estimated 80% (Roemmich and McGowan, 1995). The California Current, which is also referred to as the Coastal Upwelling Domain (CUD; Ware and McFarlane, 1989), is located on the Pacific North Coast between 25°N to 51°N latitude. From 1985-1999 eupahusiid species increased in abundance the northern tip of the California Current (waters off the southern tip of Vancouver Island), during the late 1980s and declined in abundance throughout the mid and late 1990s (Mackas *et al.*, 2001). From 1990-1998 this zooplankton community shifted from a dominant "boreal" species, to those commonly found from 40°N to the Bering Sea, to one which was dominated by southerly copepod and chaetognath species, or those common to the southern parts of the California Current (Mackas *et al.*, 2001). Thus the species that made up this zooplankton community for any given year, were more variable than the total biomass of zooplankton (Mackas *et al.*, 2001). This change in zooplankton composition likely affected the growth and survival of certain pelagic fishes. For example, Pacific herring stocks in Barkley Sound, Canada, have experienced poorer growth in the 1990s which is suspected to be linked to a decline in the availability of their key euphausiid prey (Tanasichuk, 1997). As eulachon primarily prey on euphausiids, their growth is likely similarly affected. On the other hand, sardines may benefit from the shift in species composition as their reproductive success has been linked with increases in diatom abundance (Ware and Thomson, 1991).

Food composition

Pacific Sardines (*Sardinops sagax*) are a warm water species restricted to the latitudes of 60 °N and 50 °S. Sardines were once the largest fishery in British Columbia with annual catches averaging 40,000 t annually between 1925 and 1946. In 1947, they suddenly disappeared entirely from Canadian waters (McFarlane and Beamish, 2001). The collapse of this stock was described as a classic example of over-fishing (Hilborn and Walters, 1992) and it was generally believed that there was little hope of the stock ever recovering (McFarlane and Beamish, 2001). However, in 1992, sardines were reported in catches of Pacific hake and their abundance has increased so that they are now a dominant species in British

Columbia surface waters (McFarlane and Beamish, 1999). An experimental fishery began in 1995 and catches reached 1500 t in 1999 (McFarlane and Beamish, 1999). The range of sardines has continued to expand as they were captured in Queen Charlotte Sound and in Dixon Entrance in 1997 and 1998 and in the waters off of southeastern Alaska in 1998 (McFarlane and Beamish, 1999). The demise of the South Coast BC stock coincided with the 1947 regime shift which was believed to have been initiated by large-scale changes in coastal runoff and a decline in upwelling winds affecting summer salinity (Ware and Thomson, 1991). It has been suggested that the reduced salinity led to a reduction in nutrient levels which reduced the production of diatoms and copepods (Ware and Thomson, 1991). Sardines prey on copepods, euphausiids and phytoplankton (Emmet *et al.*, 2005). It has been hypothesized that the fluctuations in sardine abundance are related to changes in species composition and abundances of phytoplankton, particularly diatoms (McFarlane and Beamish, 2001). Sardines do not compete with eulachon for food (Pickard and Marmorek, 2007), but the reappearance of sardines in BC waters may indicate that the composition of zooplankton has changed to one that benefits sardine but not eulachon.

Increase in eulachon competitors and predators

Hypothesis 15 and 16 suggested that the northward migration of warm water species has increased predation on eulachon and increased the competition for food resources, resulting in reduced survival of juvenile (1+) eulachon (Pickard and Marmorek, 2007). "You know, they eat lots…in the early summer there's mackerel that have been coming as far as the lower Burke…they eat lots, water's getting warmer and there's [also] more predators coming up from the south" (048 Nuxalk Interviews, 2006). The dominant pelagic fish species in the CUD are northern anchovy (*Engraulis mordax*), Pacific sardine, chub mackerel and Pacific hake (Benson *et al.*, 2002). There have been large shifts in the composition of these species within the CUD and these shifts have been linked to fluctuations in the ocean climate. For example, there have been increases in the biomass of migratory chum mackerel (McCall *et al.*, 1985), more abundant, smaller migratory Pacific hake (Ware and McFarlane, 1995) and as mentioned previously, the reappearance of Pacific sardine on the British Columbia Coast (McFarlane and Beamish, 2001). There are approximately nine months between the time the DFO offshore shrimp surveys calculate eulachon biomass and when eulachon return to the rivers. Is it possible that the increases in eulachon competitors or predators are affecting the number of eulachon returning to the rivers?

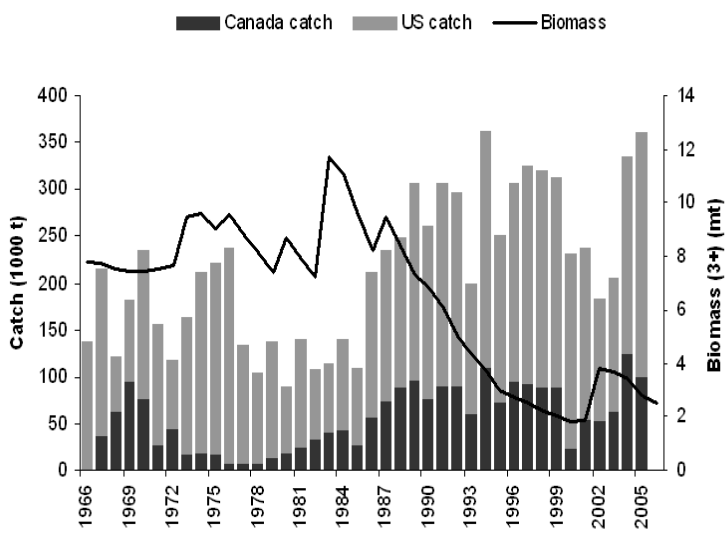

Figure 73. Commercial catch of hake for Canada and the United States and the biomass of age (3+) hake. Source: Helser *et al.* 2006 using biomass predictions from the BM model.

Pacific hake

Pacific hake are a pelagic fish found off the West Coast of Canada and the United States within the CUD. There are four distinct stocks of hake in this area, three smaller isolated inshore stocks and a large coastal migrating stock (Methot and Dorn, 1995). The larger coastal stock spawns in the offshore waters of southern California during the winter and then during the spring and summer migrates north to feed, typically in the offshore areas around central Vancouver Island (Bailey *et al.*, 1982).

During the spring and summer months there is a large commercial hake fishery conducted in US and Canadian waters. This fishery first began in the mid 1960s with the majority of the Canadian catch taken below 49°N off the South Coast of Vancouver Island. Canadian catches have increased steadily since 1977 with 124,237 t taken in 2004 (Figure 73). In 1991 and 1992, the level of fishable quota became controversial between the US and Canada, as more hake were found north of their previous northern limit (Methot and Dorn, 1995). The total biomass of hake has declined steadily since the mid 1980s. Coast wide hake biomass surveys indicate that their northern limit has extended during the 1990s. In 1995 their limit was estimated around 51 °N, however, in 1998 it was estimated near Cape Spencer, Alaska (58°N; Benson *et al.*, 2002). The percentage of mature hake that migrate into Canadian waters has previously been estimated between 25 and 30% but since the early 1990s it has increased to approximately 40% (Benson *et al.*, 2002; Figure 74). Hake biomass off the Southwest Coast of Vancouver Island was found to be strongly correlated with average temperature indicating that considerably more hake move into this area during warmer summers (Ware and McFarlane, 1995). Thus these range extensions were found to occur more often during El Niño events (Dorn, 1995).

Hake have been found to prey on euphausiids, swimming crabs, pandalid shrimp, squid, schooling fish (herring and eulachon) and juvenile fishes in the Pacific Northwest (Buckley and Livingston, 1997). Euphausiids are the hake's primary food source, but as euphausiid productivity and biomass decrease, fish become of greater importance to hake (Rexstad and Pikitch, 1986; Ware and McFarlane, 1995). Also as hake grow the importance of fish to their diet becomes more important (Rexstad and Pikitch, 1986). Eulachon have been found in the stomach contents of hake caught off the West Coast of Vancouver Island and off the coast of Oregon State (Livingston, 1983; Rexstad and Pikitch, 1986; Buckley and Livingston, 1997). During the spring of 1980 eulachon comprised 22% of the hake's diet (hake sized 450-549 mm) and 79.6% of (550+ mm) sized hake off the coast of Oregon (Livingston 1983). In the summer of 1989 the hake's diet was dominated by fishes, of which herring were the most important, within the Columbia and Vancouver areas (43°00 N to 49°35'N; Livingston, 1983). "Other fish", which included eulachon and whitebait smelt (*Allosmerus elongates*), contributed 21% of the hake's diet in the Columbia area and 10% in the Vancouver area (Livingston, 1983). However, the proportion of fish in a hake's diet can vary widely among years (Tanasichuk *et al.*, 1991). Even though some species may comprise only a small percentage of the hake's diet their voracious feeding habits and large biomass, can have a significant impact on species below them in the food chain (Rexstad and Pikitch, 1986).

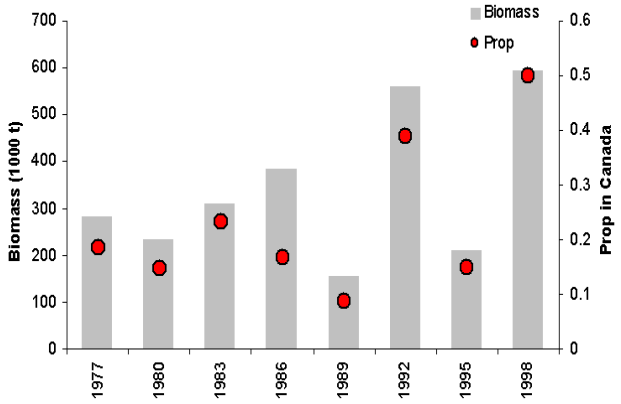

Figure 74. Biomass of hake and the proportion of the stock in the Canadian zone. Source: redrawn from Benson *et al.*, 2002.

During the 1983 El Niño event, 3 year old hake were common in Canadian waters where usually only older hake have been observed (Methot and Dorn, 1995). Since 1994 there have been significant changes in juvenile and adult hake distribution, as the presence of juveniles along the Oregon and BC coasts suggests that spawning and juvenile settlement has spread northwards (Dorn *et al.*, 1999). The summer distribution pattern of hake has also been shown to strongly overlap with the distribution of euphausiids (Ware and McFarlane, 1995). Thus juvenile hake may be competing with eulachon for food resources which are common to both species (i.e., euphausiids). It has also been suggested that the shift of hake distribution northward may be related to the poleward subsurface flow of the California Current (Agostini *et al.*, 2006). Hence in warm years when a stronger undercurrent is produced the migration of hake is assisted whereas a weaker flow may obstruct their migration. A stronger current would then benefit the smaller fish because they would be able to travel farther distances along the shelf break where food supply is high and expend less energy traveling within the current (Agostini *et al.*, 2006). Thus, the higher numbers of juvenile hake in Canadian waters may be reducing the survival of juvenile eulachon populations by competing with them for food sources. On the other hand, during La Niña conditions,

there is apparently a southward shift in the percent of the hake's stock distribution and a smaller portion of the population found in Canadian waters, for example during 2001 (Helser *et al.*, 2006).

There is also the possibility that the hake are not migrating back south and instead may be spawning in the north (Helser *et al.*, 2006). The herring mortality from hake predation was studied in the La Perouse region, the Southwest Coast of Vancouver Island, using data from 1983 to 1991 (Ware and McFarlane, 1995). During this time it was estimated that 208 t of herring were eaten daily or about 12,700 t during the months of August and September. This mortality was also found to increase during warmer summers. Thus, the increased northern migration of adult hake and their possible residency in Canadian waters may have increased hake's predation impact on juvenile eulachon since the mid-1990s. If hake predation on eulachon impacted offshore eulachon populations it would by and large affect the age 1+ and 2+ eulachon; that is the eulachon that return to spawn in the rivers 2 to 3 years later.

Freshwater environment

Hypothesis 11 from the 2007 Workshop suggests that "climate-driven changes in freshwater hydrology are causing the decline in eulachon" (Pickard and Marmorek, 2007). Changes to freshwater hydrology due to climate change have come about as snow packs and glaciers decrease in size thus changing runoff quantity and the overall timing of the glacier melt. However, the conclusion at the end of the workshop was that these changes were unlikely the primary factor driving the decline but may be a secondary factor preventing recovery (Pickard and Marmorek, 2007). Also, there is some evidence that these changes may be affecting the timing of some eulachon runs.

As early as 1954, it was questioned as to whether the arrival timing of the Fraser River eulachon run could be related to the temperature of the river or to the adjacent ocean (Ricker *et al.*, 1954). Some of the eulachon system's migration has reportedly begun earlier in recent years. For example, the Columbia River eulachon usually enter the river in January but more recently they have begun to enter in December (Bargmann, 2002); in the Kemano River the migration has been getting earlier since 1988 (Lewis and Ganshorn, 2004) and in recent years the Copper River Delta eulachon in Alaska have shown a wide range in timing migration, "eulachon have been found as early as January and as late as June" (Joyce *et al.*, 2004).

Table 24. Date of first and peak eulachon capture for the 2001-2006 Bella Coola eulachon assessment studies

Year	Date of first capture	Date of peak capture
2001	25-Mar	25-Mar-01
2002	29-Mar	03-Apr-02
2003	05-Mar	27-Mar-03
2004	06-Mar	23-Mar-04
2005	05-Mar	05-Mar-05
2006	20-Feb	25-Mar-06

Source: Lewis and O'Connor 2002; Winbourne and Dow 2002; Moody 2005, 2006; Nuxalk Fisheries 2005-06

During the 2006 Nuxalk interviews, participants suggested that climate change was having an effect on the Bella Coola eulachon run timing. Previously, the weather during the eulachon season was referred to as "fierce" (019 Nuxalk Interviews, 2006). "There'd be wind blowing, rain, hail and snow, all together, 'eulachon time', that's what they were waiting for" (019 Nuxalk Interviews, 2006). But over the last ten years the weather in the Bella Coola valley has become increasingly milder. "When I was a kid, it was nothing to see three or four feet of snow on the ground, you don't even get it now and not cold" (043 Nuxalk Interviews, 2006). "My theory is that it's global warming. We've got no more snow capped mountains or glaciers to keep the rivers cold" (Horace Walkus Nuxalk Interviews 2006). Studies of 100 or more glaciers indicate that glacier melting around the world has been pervasive during the last century (Meier *et al.*, 2003). The erosion of mountain glaciers can provide the "most readily visible evidence of the effects of climate change" (Barry, 2006). In addition, the erosion of glaciers is an important factor because water resources are affected in terms of runoff amount and the timing of the runoff (Barry, 2006). The Columbia River eulachon migration has been reported to slow or to stop at temperatures colder than 4°C (WDFW & ODFW, 2001), thus if warmer temperatures are reached sooner this may cause the migration to start early. The Nass River migration has been suggested to be dependent upon the severity of the winter, if there was an abnormally severe winter the run was delayed for a week (Langer *et al.*, 1977). Kerstan Stahl, a speaker at the 2007 Eulachon workshop from the UBC Department of Geography, presented evidence that freshets throughout BC were coming earlier than in the past (Stahl, 2007). Thus, the milder weather in recent years that has caused earlier spring freshets, may have triggered adult eulachon to enter the rivers sooner than in the past.

The majority of participants in the 2006 Nuxalk interviews reported that the earliest known observation of eulachon in the Bella Coola River was the second week of March. Of the twenty-nine participants, fifteen commented on the timing of the run and of these, 60% stated that the first wave of eulachon came in late March, followed by a second wave in mid-April. Anthropologist Thomas McIlwraith described in detail "The taking and preparation of olachen" in his ethnographic study of the Nuxalk Indians from 1922 to 1924 (McIlwraith Vol. II., 1948). In his account he reported that the Bella Coola eulachon usually arrived in late April. However, he also reported an even later run in a letter to a colleague in May 1922, "around the 1st of May came a huge run of oulachons," (Barker and Cole, 2003). It was also noted more recently by Nuxalk fishers that the Bella Coola run had started to come earlier (010, 047 and Anfinn Siwallace Nuxalk Interviews 2006) and by Nuxalk elders in the 2002 Central Coast Eulachon Project (CCEP):

For the last 20 years, eulachon have been coming up the Bella Coola at the end of March. Before that, they used to come in April, from April 10th on (007 and 010 in 2002 CCEP).

"It used to be April when we caught eulachons, and then it moved earlier and earlier as the weather got warmer and warmer. It's really early if the weather's warm" (012 and 013 in 2002 CCEP).

The 2001-2006 Bella Coola eulachon assessment studies, which estimate the relative abundance of the Bella Coola eulachon spawning population, also catch adult eulachon in stationary gillnets to estimate the peak timing of the run (Table 24). During the 2006 study, the first adult was captured on February 20th with the peak capture on March 25th.

Historical descriptions of the peak of the Bella Coola eulachon run have also been found in two other sources 1) nineteen annual comments made in DFO fisheries officer's weekly reports from (1944-1989) and 2) a single comment in the "1998 Nuxalk Fisheries eulachon fishery report." These sources were used to plot the peak of the Bella Coola eulachon run against the year. The plot illustrated a decreasing trend of peak spawners over time with an r^2 value of 0.54 (Figure 75). This suggests that the peak of Bella Coola eulachon run has begun to arrive earlier in the last few decades.

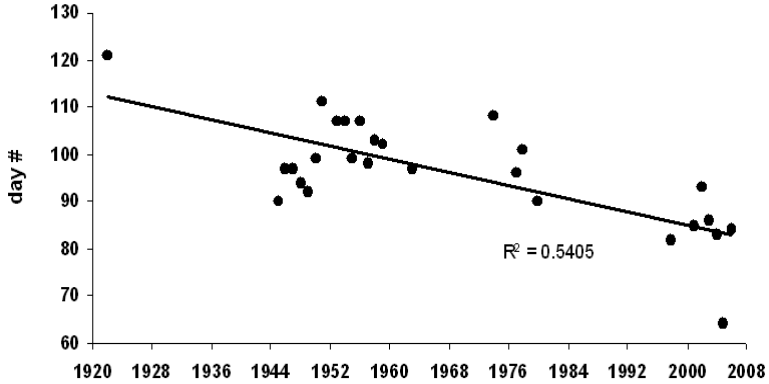

Figure 75. Peak of the Bella Coola eulachon run versus day number in the calendar year (r^2 value: 0.54). Source: Lewis and O'Connor 2002; Winbourne and Dow, 2002; Moody, 2005, 2006; Nuxalk Fisheries, 2005-06.

Although the run timing of eulachon returns in recent years appear to have been coming earlier in some rivers, the relationship of glacial runoff and its timing to eulachon abundance remains unknown.

Estuarine environment

Hypothesis 12 from the 2007 Workshop suggested that "climate-driven changes in the estuary have caused a reduction in larvae growth and survival" (Pickard and Marmorek, 2007). Larval surveys were conducted in Johnstone Strait and the Central BC Coast areas during 1994, 1996 and 1997 (McCarter and Hay, 1999). The surveys indicated that larvae dispersed and mixed in these areas during an 18-20 week period approximately 4 weeks after adult spawning had occurred. The majority of larvae were captured in the surface waters between 0 and 15 m depth. During this period, it was also estimated that the larvae grew from approximately 3-4 mm to 30-35 mm. The timing and duration of eulachon larvae occurance was observed in the Bella Coola estuary from 2002 to 2006 during the 2002-2006 Bella Coola eulachon surveys (Winbourne and Dow, 2002; Moody, 2005, 2006; Nuxalk Fisheries, 2005-06). The earliest that the larvae were captured in the Bella Coola estuary was mid-March and the latest was mid-May. The

largest numbers were captured during mid-April. Thus eulachon larvae may spend up to 2 months in this estuary. The long resident time of eulachon larvae in estuaries has been suggested as an important criterion for population configuration (McCarter and Hay, 1999). Accordingly, if climate change affects the conditions of the estuary, eulachon larval growth and survival may be reduced. For example, it was suggested that the smaller spawning eulachon runs in "BC's deep, cold and remote inlets" may be more sensitive to ocean climate changes, "particularly those that impact freshwater discharge" because the majority of larvae are located in the upper layers of low saline water, eliminating most marine fishes and invertebrate predators (McCarter and Hay, 1999). However, there is very limited information regarding the extent that eulachon use the estuary but it may be a very important part of their life cycle and key to their initial survival. Thus more information regarding the connection between eulachon larval survival and the estuary is needed.

Freshwater predators

Hypothesis 25 from the 2007 Workshop suggested that "mammal/bird/fish predation of spawners has been a significant factor contributing to the recent decline in eulachon" (Pickard and Marmorek, 2007). The harbour seal population decreased significantly in British Columbia during the mid 1960s as they were hunted for pelts and bounties between 1913 and 1964 (Olesiuk *et al.*, 1990). However, after they were protected in 1970 in Canada and in 1972 in the United States, the populations began to increase (Olesiuk *et al.*, 1990; Olesiuk, 1999). An aerial census was conducted on the lower Skeena River from 1977-1987 and in the Georgia Strait since the mid-1960s (Olesiuk *et al.*, 1990). The estimated population in the lower Skeena River area increased from 520 in 1977 to 1,590 in 1987 and in the Strait of Georgia from 2,170 in 1973 to 15,810 in 1988. The total population in 1988 was estimated between 75,000 and 88,000 whereas in 1970 in was estimated between 9000 and 10500 individuals. The total BC population estimate was revised for 1996-1998 to 108,000 individuals (Olesiuk, 1999). In Washington State the population increased 3-fold since 1978 and, 7 to 10-fold since 1970 (Jefferies *et al.*, 2003). The total of all estimates from California to Alaska put the total range-wide harbour seal population for the mid-1990s in the order of 267,000 with approximately 40% occurring in BC and a large proportion of the BC population in the Strait of Georgia (Olesiuk, 1999). Nuxalk fishers have also noticed that in recent years there have been "hundreds" of dolphins in the Central Coast inlets and fjords where they were never seen before (006, 048 and Robert Andy Jr., Nuxalk Interviews, 2006). Large numbers of predators are known to aggregate in the lower reaches of rivers during the beginning of eulachon runs (Marston *et al.*, 2002; Sigler, 2004). With large increases in predator numbers and decreased numbers of eulachon spawners, it is possible that these predators are having a large impact on depressed eulachon populations.

Comparisons (eulachon abundance vs. impact hypotheses)

To test a few of the impact hypotheses suggested in this chapter, Spearman's rank correlation was used to calculate the r^2 value between seven of the fifteen eulachon abundance status time-series estimated in the section on *Assessing the impacts on eulachon populations* and: (1) shrimp catch data; (2) hake catch data; (3) hake 3+ biomass data; (4) Northern BC harbour seal and sea lion abundance; and (5) four climate indices (Table 25). Each data comparison was also tested using a 2 year lag and a 3 year lag for each of the eulachon abundance time-series. For example, shrimp catch data were compared with Columbia River eulachon abundance for the same year, then with Columbia River eulachon abundance two years later and finally with Columbia River eulachon abundance three years later. The results can be seen in Table 25.

Table 25. Correlation of determination (COD r² value) of in-river eulachon abundance with factors that have been suggested to affect in-river eulachon abundance. Negative (-) correlations are indicated with shades of grey, positive (+) correlations are indicated with shades of blue (darker shades of grey and blue denote a stronger linear association). Non-shaded squares with r² values indicate that no significant relationship was found to exist and the blank squares indicate that the relationship was not tested.

	RIVER (Correlation of Determination (COD) r^2 value)						
FACTORS	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Shrimp catch	0.05	0.01	0.14	0.17	0.05	0.00	0.28
Shrimp catch (2 yr lag)	0.11	0.04	0.30	0.01	0.38	0.02	0.45
Shrimp catch (3 yr lag)	0.31	0.26	0.34	0.00	0.36	0.09	0.42
Total hake catch	0.08	0.08	0.13	0.17	0.13	0.00	0.17
Total hake catch (2 yr lag)	0.04	0.08	0.12	0.03	0.20	0.03	0.20
Total hake catch (3 yr lag)	0.01	0.19	0.29	0.03	0.24	0.08	0.20
CAN hake catch	0.09	0.00	0.04	0.23	0.06	0.01	0.27
CAN hake catch (2 yr lag)	0.01	0.01	0.00	0.11	0.18	0.00	0.18
CAN hake catch (3 yr lag)	0.02	0.05	0.04	0.01	0.22	0.00	0.12
US hake catch	0.05	0.10	0.14	0.08	0.13	0.00	0.10
US hake catch (2 yr lag)	0.03	0.10	0.17	0.00	0.11	0.05	0.16
US hake catch (3 yr lag)	0.01	0.20	0.37	0.02	0.19	0.12	0.16
Seal/sea lion abun.	0.04	0.00	0.10	0.46	0.05	0.01	0.36
Seal/sea lion abun. (2 yr lag)	0.00	0.02	0.10	0.33	0.21	0.03	0.35
Seal/sea lion abun.(3 yr lag)	0.01	0.11	0.08	0.13	0.30	0.01	0.33
SST total	0.01	0.00	0.12	0.03	0.00	0.15	0.03
SST total (2 yr lag)	0.02	0.02	0.10	0.11	0.00	0.02	0.04
SST total (3 yr lag)	0.11	0.00	0.07	0.08	0.01	0.01	0.01
SST Apr-June	0.02	0.01	0.12	0.15	0.02	0.24	0.04
SST Apr-June (2 yr lag)	0.00	0.19	0.09	0.23	0.00	0.03	0.01
SST Apr-June (3 yr lag)	0.06	0.04	0.06	0.29	0.00	0.02	0.00
Hake biomass	0.07	0.48	0.29	0.10	0.24	0.08	0.39
Hake biomass (2 yr lag)	0.10	0.51	0.22	0.00	0.21	0.08	0.46
Hake biomass (3 yr lag)	0.11	0.53	0.18	0.03	0.30	0.01	0.37
UI north	0.00	0.03	0.08				
UI north (2 yr lag)	0.02	0.02	0.06				
UI north (3 yr lag)	0.09	0.02	0.02				
UI central		0.00	0.06	0.01	0.00		
UI central (2 yr lag)		0.09	0.06	0.01	0.00		
UI central (3 yr lag)		0.08	0.02	0.06	0.02		
UI south			0.03	0.00	0.04	0.01	0.03
UI south (2 yr lag)			0.03	0.00	0.01	0.05	0.04
UI south (3 yr lag)			0.01	0.00	0.01	0.02	0.04
NOI	0.03	0.05	0.05	0.00	0.00	0.21	0.02
NOI (2 yr lag)	0.02	0.02	0.06	0.29	0.00	0.02	0.06
NOI (3 yr lag)	0.12	0.07	0.03	0.18	0.01	0.01	0.00
SOI	0.00	0.02	0.04	0.00	0.00	0.12	0.03
SOI (2 yr lag)	0.00	0.01	0.01	0.30	0.00	0.00	0.10
SOI (3 yr lag)	0.04	0.03	0.01	0.16	0.02	0.00	0.02

Shrimp catch

There was a negative correlation between five of the seven eulachon river's abundance tested and the shrimp catch data, with the exception of the Nass River which had a positive correlation (r^2= 0.30). The positive correlation was found with a three year time lag in eulachon abundance. The strongest negative correlation was found between shrimp catch and the Columbia River eulachon abundance with a 2 year lag (r^2 = 0.46). The other rivers with negative correlations were the Kemano (3 year lag), the Bella Coola (all three tests) and the Klinaklini River (2 and 3 year lags).

Hake catch

The hake data were divided into three data sets (Canadian hake catch, United States [US] hake catch and total hake catch [Canadian + US]) and tested separately. There was a negative correlation found between four of the seven rivers with at least one of the hake catch data sets. The Nass was the only river where a correlation was not found between eulachon abundance and hake catch. The Kemano River eulachon abundance did not have a correlation with the Canadian catch but had significant negative correlation with total (r^2= 0.19) and US (r^2= 0.2) hake catches after a three year lag in eulachon abundance. The Bella Coola River and the Fraser River abundances did not correlate with the Canadian hake catch. But the Bella Coola eulachon abundance did have a significant correlation with total hake catch and US hake catch. The highest r^2 values values were found with a three year lag in eulachon abundance (total: r^2= 0.29 and US: r^2= 0.37). The Kingcome River eulachon abundance only had one significant correlation and that was with the Canadian hake catch (r^2= 0.23). The Klinaklini River eulachon abundance had significant correlation with all three hake catch data sets. The most significant correlation was found with a 3-year lag in eulachon abundance and Canadian catch (r^2= 0.22); US catch (r^2= 0.19); total catch (r^2= 0.24). The Fraser River eulachon abundance only had a significant correlation with the US hake catch (r^2= 0.12). And finally the Columbia River had a significant correlation with all hake catch data sets. The correlations between the Columbia eulachon abundance, 2-year and 3 year lags, and hake total catch both had the exact same r^2-values (0.20). The correlations found between the Columbia eulachon abundance, 2-year and a 3 year lags, and hake US catch, also had the exact same r^2 values (0.16). And the highest r^2 value was found between the Canadian catch and the Columbia River eulachon abundance for the same year (r^2= 0.27). These positive relationships suggest that as hake catch increases eulachon abundance decreases and most significantly with a three year time lag in eulachon abundance.

Hake biomass

A positive correlation was found between hake biomass and four of the seven river's eulachon abundance time-series. No correlations were found between the Nass, Kingcome and Fraser River's eulachon abundance status and hake biomass. The strongest correlation was found between hake biomass and Kemano River eulachon abundance with a three year lag (r^2 = 0.53). This also occurred between the Klinaklini River eulachon abundance with a three year lag (r^2 = 0.30). The Columbia River's eulachon abundance with a two year lag had its strongest correlation with hake biomass (r^2 = 0.46) and the Bella Coola River eulachon abundance had its strongest correlation with hake biomass for the same year (r^2 = 0.29).

Seal and sea lion abundance

There was a negative correlation between three of the seven rivers' eulachon abundance time-series (i.e., Kingcome, Klinaklini and Columbia Rivers) and seal and sea lion abundance. The strongest correlation was found between the Kingcome River eulachon abundance for the same year (r^2 = 0.46). This was also found using the Columbia River eulachon abundance for the same year (r^2 = 0.36). The strongest correlation for the Klinaklini River eulachon abundance was found with a three year lag in eulachon abundance (r^2 = 0.30).

Climate indices

Sea Surface Temperature (SST): The average annual mean temperature and the mean temperature from April to June were used in this analysis. This data came from Amphitrite Point, located off the West Coast of Vancouver Island and closer to the more southern eulachon rivers (i.e., Fraser and Columbia Rivers). The average temperatures from April-June were used in this comparison because these months were used by Hay *et al.* (1997) when they compared temporal changes with Fraser River and Columbia River eulachon catches. Several weak significant negative relationships were found between SST and nearly all eulachon abundances, with the exception of the Klinaklini and Columbia rivers. The Nass River eulachon abundance significantly correlated with mean annual SST when eulachon abundance had a three year lag ($r^2 = 0.11$). The Kemano River eulachon abundance also had only one significant correlation with SST (April-June) and this occurred when eulachon abundance had a two year lag ($r^2 = 0.19$). There were very similar correlations found between the Bella Coola River eulachon abundance and the two sets of SST data. Eulachon abundance for the same year with annual SST ($r^2 = 0.12$) and from April to June SST ($r^2 = 0.12$). Eulachon abundance with a two year lag and annual SST ($r^2 = 0.10$) and from April to June SST ($r^2 = 0.09$). The Kingcome River eulachon abundance only had a significant correlation with the SST data from April to June. The highest correlation was found when eulachon abundance had a 3 year lag ($r^2 = 0.29$). The Fraser River eulachon abundance, for the same year, had a significant correlation with both sets of SST data (annual SST $r^2 = 0.15$; April-June SST $r^2 = 0.24$).

Upwelling Index (UI): Only one significant correlation was found in the 36 comparison tests between eulachon abundance and the UI. There are several different UI's calculated along the Pacific Coast, thus for the northern rivers (i.e., Nass, Kemano and Bella Coola) the UI from 54°N 134°W was used; for the Central Coast rivers (i.e., Kemano, Bella Coola, Klinaklini and Kingcome) the UI from 51°N 131°W; and for the Southern rivers (i.e., Bella Coola, Klinaklini, Kingcome, Fraser and Columbia) the UI from 48°N 125°W was used. The Bella Coola River was included in all area comparisons, and the Klinaklini and Kingcome Rivers were used in both the central and southern area comparisons. This was done because it was unknown which areas best fit these rivers. Only the Bella Coola eulachon abundance was found to have a significant, yet weak, positive correlation ($r^2 = 0.08$) with the UI North data.

Northern Oscillation Index (NOI): The NOI had a significant positive correlation with three of the seven rivers (i.e., Nass, Kingcome and Fraser). The Nass River eulachon abundance with a three year lag had a significant positive correlation with the NOI ($r^2 = 0.12$); the Kingcome River eulachon abundance, with a two year and three year lag, also had a significant positive correlation with the NOI ($r^2 = 0.29$ and 0.18); and the Fraser River eulachon abundance with no lag had a significant positive correlation with the NOI ($r^2 = 0.21$).

Southern Oscillation Index (SOI): The SOI had a significant positive correlation with three of the seven rivers abundance time-series (i.e., Kingcome, Fraser and Columbia). The Kingcome River eulachon abundance with two and three year lags had a significant positive correlation with the SOI ($r^2 = 0.30$ and $r^2 = 0.16$); the Fraser River abundance with no lag had a significant positive correlation with the SOI ($r^2 = 0.12$); and the Columbia River eulachon abundance with a two year lag, also had a significant positive correlation with the SOI ($r^2 = 0.10$). The Fraser River and Kingcome River's correlations with the SOI were very similar to those found with the NOI.

CONCLUSION

There is a high level of complexity in a natural ecosystem and it is not always possible assess what the critical factors in the life of a population of fish are. Several impact hypotheses have been suggested in this chapter to explain the recent decline of Pacific Coast eulachon populations. A few of these hypotheses have been compared with seven eulachon system's abundance estimates from *Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system*. A negative correlation was found between eulachon abundance status for at least one of the seven rivers tested and shrimp catch, hake catch, seal/sea lion abundance and SST. This suggests that these factors negatively affect eulachon spawning abundance. A positive correlation was found between hake biomass and the climate indices UI, NOI and SOI and suggests that some eulachon system's abundance follows a similar pattern.

The Nass River eulachon abundance had few significant relationships between the factors tested. This may be because the Nass River is located the farthest north of all the eulachon systems tested and thus may not be affected in the same way as the more southern systems. Also, the majority of these indicators are calculated from data south of the Nass River. For example, the majority of shrimp and hake catch are taken from the West Coast of Vancouver Island (WCVI) and the SST measurements are also collected from this area.

The correlation between shrimp catch was the strongest between Columbia River eulachon abundance with a two and three year lag. This is likely the result of the majority of the shrimp catch coming from the WCVI and the bycatch including 1+ and 2+ eulachon juveniles. Thus affecting the eulachon returns to the Columbia River two to three years later. The Klinaklini and Bella Coola eulachon abundance status was also negatively affected two and three years later with the highest significant correlation occurring three years later. This is likely because the more northern eulachon populations are found to return to spawn between three and four years of age whereas the majority of Columbia River eulachon have been found to spawn after two years of age (Clarke *et al.*, 2007). The negative relationship between hake catch and eulachon populations may occur because it is possible that eulachon are caught as bycatch in groundfish trawl fisheries.

The positive correlation between eulachon abundance and hake biomass does not support the hypothesis that hake have negatively impacted eulachon abundance by migrating further north. The positive relationship instead suggests that ocean conditions that positively benefit hake biomass may also positively affect eulachon abundance one to three years later. This seems probable as the eulachon in the ocean are between one and three years of age with the majority 1+ and 2+ juveniles which would result in improved eulachon abundance two and three years later. However, the increased northern hake migrations have only been observed since the mid-1990s. Thus the time-series may be too short to reveal a negative correlation.

The seal and sea lion abundance was found to negatively affect the more southern rivers tested (i.e., Kingcome, Klinaklini and Columbia). This is surprising because the seal and sea lion data, estimates the northern BC seal and sea lion populations, thus the more northern rivers would be the ones expected to be negatively affected. But it is possible that there are similar seal/sea lion abundance trends throughout the Pacific Northwest Coast and it is these three rivers which are most highly affected by increases in marine mammals.

"What are the contributing factors to the decline?" This was the most common question asked during my interviews with the Nuxalk Nation community in 2006. "If we don't know that, all we'll continue to do is point fingers because if they do return we want to know what we can do better nowadays" (Anfinn Siwallace Nuxalk Interviews, 2006). This chapter has provided a summary of the possible negative impacts to the eulachon and drawn attention to the factors which may have the largest impact on eulachon populations. Future investigations preparing to study eulachon declines should focus on the factors highlighted in this chapter, particularly those which have displayed significant negative relationships with eulachon abundance.

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Personal Communication

Glendale, Fred. 2007. Member of the Da'naxda'xw/Awaetlala Nation, Knight Inlet, BC. Conversation: July 8, 2007

DISCUSSION, CONCLUSIONS AND ACKNOWLEDGMENTS

Eulachon populations have been declining over the past few decades especially since the mid-1990s (Hay and McCarter, 2000). However, there are a few exceptions: there are still healthy populations in the central Alaska (e.g., Copper River and Cook Inlet Rivers) and in the Nass River, northern British Columbia, which supports an annual fishery by the Nisga'a First Nation. Historically, there has been poor documentation on eulachon populations and eulachon fisheries. Thus, the objectives of this study were to provide a summary of past and present eulachon fisheries and provide a series of coast-wide annual eulachon population abundance estimates which could be used to analyze the possible impacts to eulachon populations.

Strengths, weaknesses and future work

There were three main analyses contained in this study, an estimation of eulachon catch from past eulachon grease production (*A review of historical eulachon fisheries*), an estimation of past eulachon abundance using a fuzzy logic expert system (*Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system*) and a comparison of these estimates of abundance status with several impact hypotheses (*Assessing the impacts on eulachon populations*).

The interviews with the Nuxalk Nation community (see *Estimating historical catches of the Nuxalk Nation eulachon fishery*) demonstrated that traditional ecological knowledge (TEK) and local ecological knowledge (LEK) information are very useful to acquire knowledge and an understanding of a fishery, in addition to making estimations of past eulachon catches and abundance trends possible. Thus, this methodology could be applied in other coastal communities with First Nation eulachon fisheries.

The fuzzy expert system used in *Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system* was found to be a useful tool for estimating the abundance status of certain eulachon populations. Although eulachon data were limited, it was possible to combine the available quantitative and qualitative information to gain an understanding of the eulachon abundance trends for several populations. Many of the abundance index estimations could be improved if more information was available from each region. Interviews using the methodology from *Estimating historical catches of the Nuxalk Nation eulachon fishery*, could be conducted with First Nations and local experts to obtain information on past run sizes and to estimate past catches. The fuzzy expert system was built with the assumption that more information would, or could, be added to its existing data base, so that future estimations could be made and past estimations could be improved upon. A more extensive correlation analysis (*Assessing the impacts on eulachon populations*) could be conducted with improved eulachon abundance status estimates and with additional climate indices that were not tested. A multiple step regression could also be conducted to determine which factors contribute and by how much, to specific eulachon population declines. However, the correlation analysis that was conducted in *Assessing the impacts on eulachon populations* should draw attention to the factors which may have the most significant impact to eulachon populations. These findings should be addressed when future investigations prepare to study eulachon declines.

This project provides historical background of the main eulachon areas and highlights vulnerable eulachon populations. This project also provides methodology (see *Estimating historical catches of the Nuxalk Nation eulachon fishery*) for areas with the least historical information to improve the current abundance status estimates from *Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system*. Eulachon assessment and monitoring programs could then be established in areas where the historical background of an eulachon population is known so that present biomass estimates would have baseline data to relate findings to.

The status of the eulachon is an important topic for fisheries management. The eulachon is a key component to the culture and traditions of many First Nations communities thus the severe decline of some eulachon populations has devastated their communities. The health of some predator populations, which depend on the eulachon as a source of food, for example, avian predators, marine mammals (Sigler *et al.*, 2004) and sturgeon (*Acipenser transmontanus*; Eulachon Research Council, 1998) may be

negatively affected by poor eulachon returns. Also fisheries managers who manage commercial fisheries, such as the BC shrimp trawl fishery, need to know the status of certain eulachon populations, as fishing opportunities are contingent on the strength of eulachon returns (DFO, 2006). And finally the decline in eulachon populations may be an indicator of changes in the ocean climate.

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I would first like to thank the members of the Nuxalk Nation who took part in the research I conducted within their community. I am extremely appreciative for their willingness to participate and for volunteering their time so that I may understand and document the importance and the demise of the Nuxalk eulachon fishery. I would also like to thank the local experts, government workers and the members of several First Nation communities (specifically members of the Tsimshian, Haisla, Wuikinuxv, Da'naxda'xw/Awaetlala and Tsawataineuk Nations) who took time during this project to discuss eulachon issues and to also allow me access to their valuable information

I am very grateful for the opportunity I had to learn from and work with the members of my committee—Doug Hay and Steve Martell—whose knowledge and insight was very much appreciated, and my supervisor, Tony Pitcher, who was instrumental in motivating me and helping to structure the study.

I would also not have been able to complete this project without the generous help and advice provided to me by the students of my graduate group (Fisheries Ecosystems Restoration Research) to whom I am extremely grateful. I would like to extend a special thank you to Dr. William Cheung who spent a great deal of his time discussing and explaining to me the complexities of fuzzy logic. His patience and willingness to help always amazed me. Also, I thank Divya Varkey who was always willing to help with coding and statistics problems.

Thank you, to my family, friends and community who have continued to support and encourage me throughout my graduate school experience. With a special thank-you to my parents and siblings who have listened, shared their own experiences, and extended never-ending support.

And last but not least, I'd like to thank Nigel Haggan, who first convinced me to attend grad school and then provided the final edits to the draft.

I would finally like to thank the Nuxalk Education Authority for sponsoring me throughout the duration of my project and the Faculty of Graduate Studies at the University of British Columbia for financial support in the form of a fellowship.

CO-AUTHORSHIP STATEMENT

The research for this study were identified and designed by myself, with the help of Tony J. Pitcher. I performed all research, data analysis and manuscript preparation of the study. Tony J. Pitcher also reviewed the prepared manuscripts and also helped with the analysis. William Cheung, then a postdoctoral fellow, reviewed the prepared manuscript for *Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system* and helped to develop the fuzzy logic system used in the data analysis for this chapter.

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resource: a prespawning aggregation of eulachon (*Thaleichthys pacificus*). *Canadian Journal of Fisheries Aquatic Science* 61: 1475-1484.

APPENDIX 1: SOURCES OF EULACHON CATCH, CPUE, FISHING EFFORT AND ANNUAL RUN STRENGTH FOR THE NASS RIVER

Appendix table 1. All sources of eulachon catch, CPUE, comments on fishing effort and annual run strength for the Nass River

Year	Source
1878-1916 1919-1920 1924 1926-1927 1929-1932 1935	• Commercial catch data (1881-1940) adapted from Figure 12 page 14 Clemens, W. & Wilby, G. 1946. Fishes of the Pacific Coast of Canada (1st edition). Fisheries Research Board of Canada Bulletin no.68. 368 p.
1929	• First Nation's catch data (1929) Department of Marine and Fisheries and Dominion Bureau of Statistics. 1929. Fisheries Statistics, sub district no. 8 – Naas River Area, Prince Rupert, British Columbia, Canada.
1931	• First Nation's catch data (1931) Department of Fisheries and Oceans. 1931 Indian food fishery annual statistics: Nass River area.
1933-1941	• First Nation's catch data (1933-1941) Eulachon catch statistics: Indian take in the Nass (1933-1941) adapted from Figure 12 page14. *In* Clemens, W. & Wilby, G. 1946. Fishes of the Pacific Coast of Canada (1st edition). Fisheries Research Board of Canada Bulletin no.68. 368 p.
1941-1950	• First Nation's commercial catch as reported in: Department of Fisheries and Oceans Canada. 1941-1973. Fisheries Inspectors weekly reports and annual narrative reports (1941-46, 1948, 1950, 1953-60, and 1965-73). Nass and Skeena sub-districts. Prince Rupert, British Columbia.
1953-1957	• First Nation's catch and comments on run strength Department of Fisheries and Oceans Canada. 1941-1973. Fisheries Inspectors weekly reports and annual narrative reports (1941-46, 1948, 1950, 1953-60, and 1965-73). Nass and Skeena sub-districts. Prince Rupert, British Columbia.
1958-1967	• First Nation's catch data (1881-1940) Connor, J. W. 1967. Letter Re: oulachan catch- Nass River. September 7. To A.L. Murray, Conservation and Protection from J.W. Connor, District Protection Officer. Department of Fisheries and Oceans Canada, Prince Rupert, British Columbia
1968	• First Nation's catch data (1968) Kent, J. A. 1968. Letter Re: Nass River Native Indian Oulachon Fishery- 1968. April 23. To J.W. Connor, District Protection Officer, from J.A. Kent, Assistant District Protection Officer. Department of Fisheries and Oceans Canada, Prince Rupert, British Columbia

1969-1973	• First Nation catch and comments on run strength
	Department of Fisheries and Oceans Canada. 1941-1973. Fisheries Inspectors weekly reports and annual narrative reports (1941-46, 1948, 1950, 1953-60, and 1965-73). Nass and Skeena sub-districts. Prince Rupert, British Columbia.
1978	• First Nation's catch data (1978)
	McIntyre, D. 1978. Letter Re: eulachon runs for 1978 [Nass River]. April 11. For eulachon file, by District Supervisor. Department of Fisheries and Oceans Canada, Prince Rupert, British Columbia
1983	• First Nation's catch data (1983)
	Orr, U. 1984. Eulachon sampling on the lower Nass River in relation to log handling. Unpublished data report. Department of Fisheries and Oceans Canada. Prince Rupert, British Columbia or Vancouver, British Columbia. 25 p.
1990	• First Nation's catch data and effort information (1990)
	Nisga'a Tribal Council. 1990. Nisga'a eulachon fishery 1990. Unpublished report prepared by Nisga'a fisheries crew and Nortec Consulting. 24 p.
1989 and 1995	First Nation's catch data- Nass River. *In*: Hay, D. E. & McCarter, P. 2000. Status of the eulachon *Thaleichthys pacificus* in Canada. Department of Fisheries and Oceans Canada, Canadian Stock Assessment Secretariat, Research Document 2000/145. 92 p.
1997-2006	Nass Catch and CPUE estimates- Nisga'a Fisheries and LGL Consulting. *In*:
	Pickard, D. & Marmorek, D. R. 2007. A workshop to determine research priorities for eulachon, workshop report. Prepared by ESSA Technologies Ltd., Vancouver British Columbia for Fisheries and Oceans Canada, Nanaimo, British Columbia. 58 p.

APPENDIX 2: COPY OF THE UBC RESEARCH ETHICS BOARD CERTIFICATE OF APPROVAL

The University of British Columbia
Office of Research Services and Administration
Behavioural Research Ethics Board

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	NUMBER
Pitcher, T.J.	Fisheries	**B05-1093**

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT

CO-INVESTIGATORS:
Moody, Megan, Fisheries

SPONSORING AGENCIES
Westcoast Energy Inc.

TITLE:
Historical Analysis of 'Grease Production' by the Nuxalk First Nation

APPROVAL DATE	TERM (YEARS)	DOCUMENTS INCLUDED IN THIS APPROVAL:
DEC 15 2005	1	Dec. 7, 2005, Consent form / Nov. 15, 2005, Contact letter / Questionnaires

CERTIFICATION:

The protocol describing the above-named project has been reviewed by the Committee and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approved on behalf of the Behavioural Research Ethics Board
by one of the following:

This Certificate of Approval is valid for the above term provided there is no change in the experimental procedures

APPENDIX 3: LETTER SENT TO NUXALK COMMUNITY MEMBERS REQUESTING PARTICIPATION IN 2006 INTERVIEWS

Dec. 2005

To:

RE: Request for participation in the study titled, 'Historical Analysis of 'Grease Production' by the Nuxalk First Nation'

We would like to ask for your participation in a research study on the eulachon. Megan Moody, a member of the Nuxalk Nation will solely conduct the interviews. Megan is the daughter of Quatsinas (Edward Moody) and Sandy Burgess (formerly Sandy Moody), granddaughter of Cecilia Siwallace, and Edward Moody Sr.

Megan grew up in Bella Coola and returned every summer during her years at the University of Victoria. She also worked for the Nuxalk Band Administration as the Fisheries Program Manager for three years (Nov 2001- Aug 2004). At this time she managed the Bella Coola eulachon study with the local eulachon crew. It was during this time that she decided to go back to school and pursue her Master's degree in Fisheries science and focus her research on the eulachon.

This study will reconstruct historical eulachon catch by analyzing past 'grease' production. This will be determined through interviews, that question the amount of 'grease' produced each year, the number of families involved and the amount of 'grease' consumed each year, etc. The purpose of this study is to gather information on the historical abundance of the Bella Coola eulachon run. It will also be used to further understand the decline of the Bella Coola eulachon run and hopefully provide valuable information for future management decisions. A final report using the information gathered during the interview will be submitted to the University of British Columbia as a requirement for the completion of a Master's of Science degree with the department of Resource Management and Environmental Studies.

The interviews will be conducted early in 2006. We anticipate that the interview will take two to three hours. A series of set questions will be asked, but you will also be given an opportunity to provide any additional information, should you so desire. The interview will also be audio recorded.

We have attached two copies of a consent form. We ask that you read through the form, and if you agree to participate in our study, please sign both copies. Please keep one copy for yourself and return the second copy to us.

We will be pleased to provide you with results of this study. The results will also be available to the Nuxalk community and a summary posted in the local flyer. If you have any questions or concerns, please do not hesitate to contact us. Thank you for your time and assistance. We consider your opinions valuable and appreciate any input that you can give.

Sincerely,

Dr. Tony Pitcher

Professor
UBC Fisheries Centre

Megan Moody

MSc. Student
UBC Fisheries Centre

APPENDIX 4: CONSENT FORMS SIGNED BY NUXALK COMMUNITY PARTICIPANTS FOR THE 2006 NUXALK INTERVIEWS

Title: Historical Analysis of 'Grease Production' by the Nuxalk First Nation

Principal Investigator:

Professor Tony J. Pitcher, University of British Columbia Fisheries Centre.

Co-Investigator:

Megan Moody, M.Sc. student, University of British Columbia Fisheries Center.

Study Purpose:
The purpose of the research is to reconstruct historical eulachon catch by applying local environmental knowledge (LEK) of past 'Grease' production to improve the understanding of past Bella Coola eulachon runs sizes. This will be determined through interview questions, such as: the amount of grease produced each year, the number of families involved, the amount of 'grease' consumed each year, etc. This project is funded by a scholarship awarded to Megan Moody by the UBC faculty of Graduate Studies.

Study Procedures:
This research study, "Historical Analysis of 'Grease Production by the Nuxalk First Nation", is one part of a Master's of Science thesis document entitled "A Historical Analysis of the current and past runs of the Pacific Coast Eulachon and the impacts that traditional fisheries, commercial fisheries and bycatch in the shrimp trawl fishery, have had on these runs." Megan Moody, whom is a member of the Nuxalk Nation will conduct the interviews.

Your participation will involve one interview, 2-3 hours in length and will be recorded on audiotape. The interview is being recorded to ensure that your responses are accurately recorded however you may, at any time, refuse to answer any or all questions, and may request that the audiotape be turned off.

Your contribution to this project will be combined with contributions from other Nuxalk members with past knowledge of the eulachon fishery and the eulachon 'grease' making process. The information gathered will be used to improve the understanding of past Bella Coola River eulachon abundances. The thesis will be made public and a copy of the final interview results will be provided to you upon request. A summary of the results will also be posted in the Nuxalk community flyer.

Contact for information about the study:
If you have any questions or desire further information with respect to this study, you may contact Megan Moody at xxx-xxxx

Compensation:
No compensation will be received for participation in this research project.

Contact for concerns about the rights of research subjects:
If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at (604) 822-8598.

Storage of audio recording:
The audio recording of your interview will be stored by the research team for 5 years and then destroyed after this time period. If you do not want your interview recording destroyed the original and all copies can be returned to you.

I want the recording of my interview destroyed _____
I want the recording of my interview returned to me _____

Confidentiality:

I understand that the interview responses and audiotape will be made available only to myself and to members of the research team. I understand that notes will also be taken during the interview and that on audiotapes and interview notes I will be identified only by a numeric code; my name will not appear on these materials. I have the right to decide whether I want my contribution to be anonymous or to be credited to me.

I do I do not want my contribution to this project to be credited to me.

Consent:
I understand that my participation in this study is entirely voluntary and that I may refuse to participate or withdraw from the study at any time without penalty or prejudice. I agree to the above conditions, and I have received a copy of this consent form for my own records.

Participant's Name Signature Date

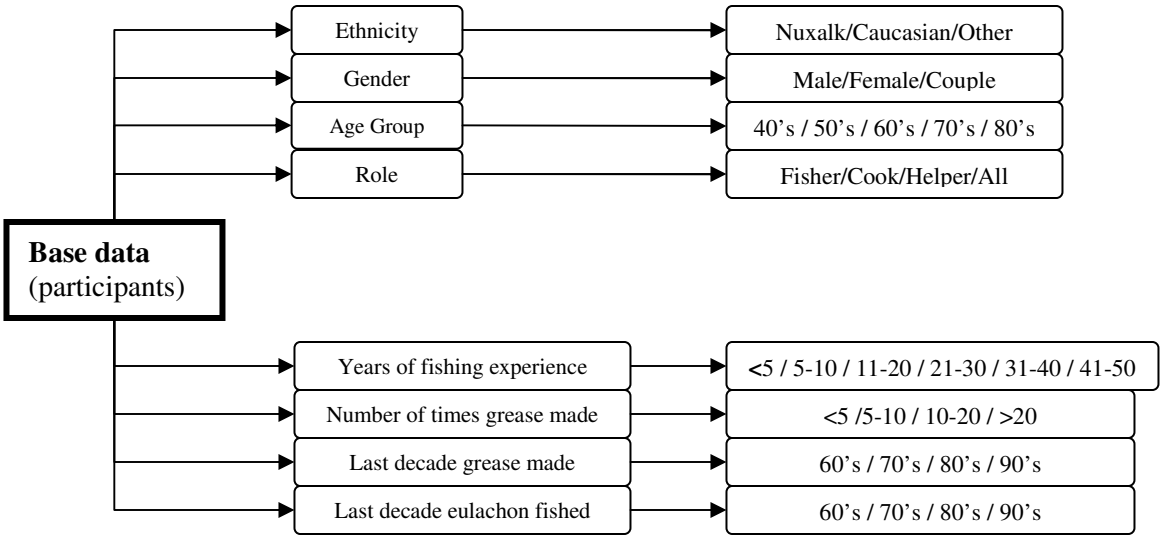
Thank you for your time, interest, and participation. Your opinions are valuable and any input that you can give this study is appreciated

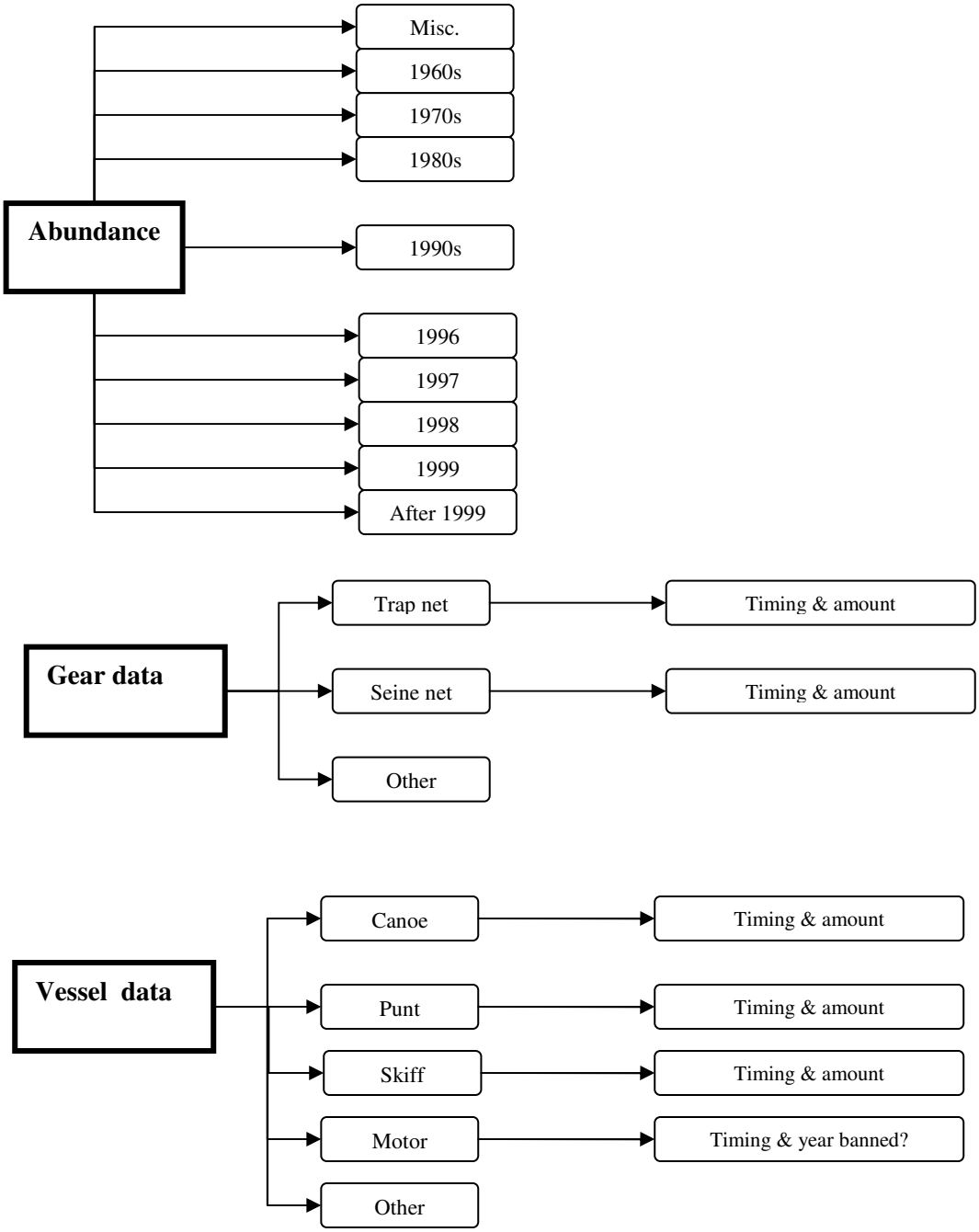
APPENDIX 5: N6 CATEGORIES USED TO ORGANIZE 2006 NUXALK INTERVIEW DATA

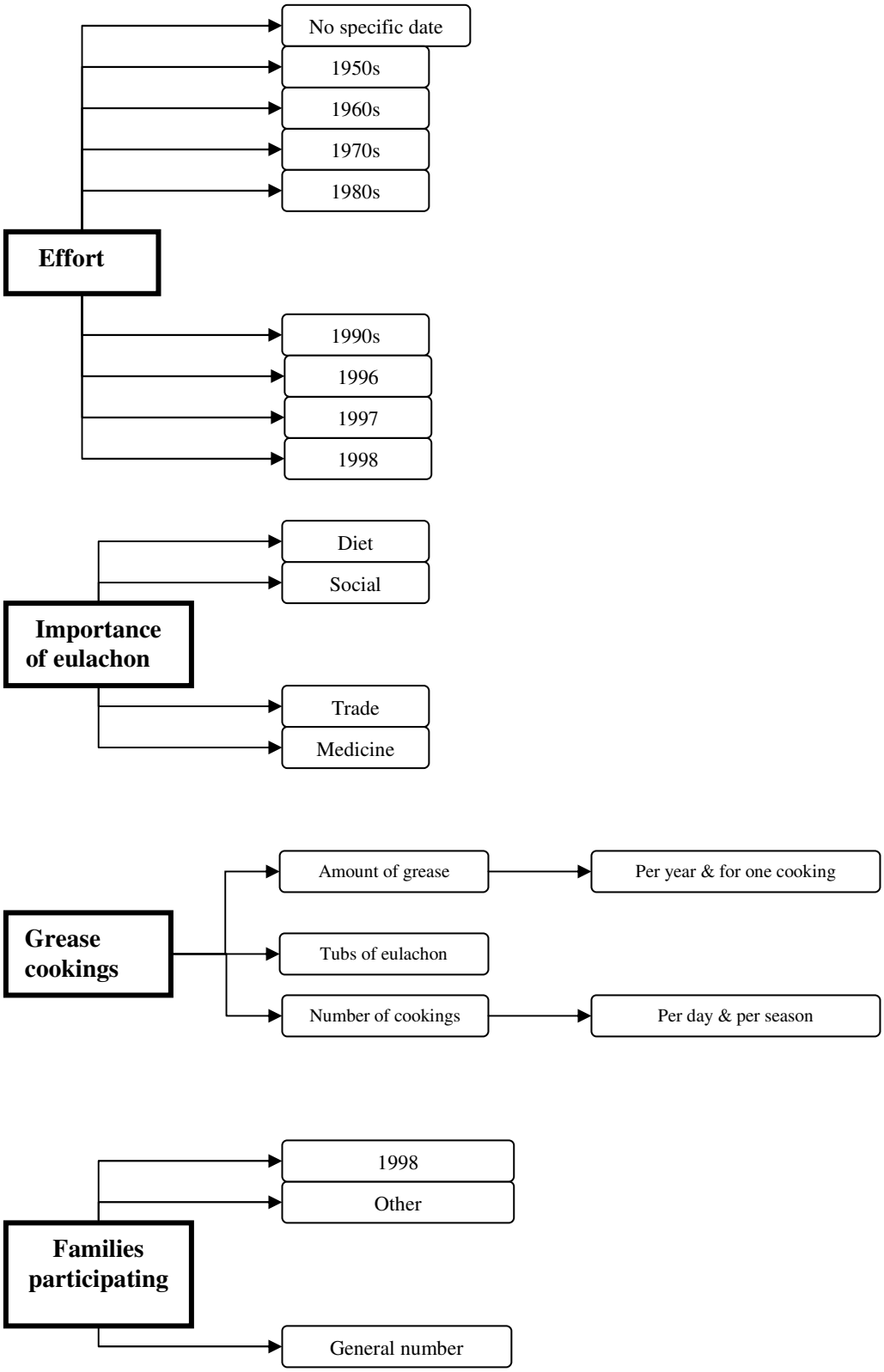
1) Free node categories

Eulachon life cycle	Fish description	Run timing	River conditions	Weather changes	Predators of eulachon
Grease process	Stink box	Fermenting process	Cooking process	Cooking box	Size of crew
Learning & teaching	Trade	Herring fishing	Odd occurrences		
Personal consumption of grease/eulachon	Sharing of labour/catch/ grease	South Bentinck eulachon fishing	Eulachon in other rivers		
Who's to blame for declines?	Traditional rules for fishery	Changes in attitudes towards	Collapse of Bella Coola eulachon run		

2) Tree Node categories




Abundance
Misc.
1960s
1970s
1980s
1990s
1996
1997
1998
1999
After 1999
Gear data
Trap net
Timing & amount
Seine net
Timing & amount
Other
Vessel data
Canoe
Timing & amount
Punt
Timing & amount
Skiff
Timing & amount
Motor
Timing & year banned?
Other


Effort
No specific date
1950s
1960s
1970s
1980s
1990s
1996
1997
1998
Importance of eulachon
Diet
Social
Trade
Medicine
Grease cookings
Amount of grease
Per year & for one cooking
Tubs of eulachon
Number of cookings
Per day & per season
Families participating
1998
Other
General number

APPENDIX 6: RESULTS FROM THE EULACHON GREASE MODEL INCLUDING ORIGINAL DATA

Appendix table 6. Results from the eulachon grease model including original data

Year	Total grease prod. (gallons) best estimate	DFO catch (t)	Total grease prod. SD	DFO catch SD	Grease model estimated catch C= (GP/gt) + x	Fresh catch (t)
1998	190		29		13.6	2.2
1997	125		19		12.6	2.6
1996	195		30		13.4	1.1
1995	81		13		7.9	1.7
1994	255		40		17.9	1.8
1993	256		40		20.7	2.6
1992	190		29		16.4	2.6
1991	340		53		26.5	1.5
1990	430		67		32.1	2.4
1989	230	8.5	36	0.9	19.6	1.7
1988	460	60	71	6.4	38.6	2.8
1987	255	15	40	1.8	20.5	1.5
1986	365	15	57	1.8	25.6	1.3
1985	175	5	27	0.6	15.0	2.1
1984	355	30	55	3.5	26.4	1.9
1983	282	30	44	3.2	23.2	2.7
1982	315	50	49	2.3	24.4	2.3
1981	410	35	64	4.1	33.0	2.0
1980	380	30	59	3.5	30.3	2.4

Estimated (gt) value	14.07
Standard deviation of (gt)	0.780
95%tile (gt)	
Upper	15.58
Lower	12.37

APPENDIX 7: SOURCES OF DATA COLLECTED FROM EACH EULACHON SYSTEM.

Appendix table 7. Sources of data collected from each eulachon system. Catches and CPUE have been displayed in "A review of historical eulachon fisheries"and all data sources here have been used in "Reconstructing abundance of eulachon throughout its geographic range using a fuzzy expert system" to estimate in-river eulachon abundance status.

River	Sources of data
Klamath	• Run size comments made in: Larson, Z. & Belchik, M. 1998. A preliminary status review of eulachon and Pacific lamprey in the Klamath River Basin. Yurok Tribal Fisheries Program, Klamath, California. • Run size comments made in: Moyle, P. B., Yoshiyama, R. M., Williams, J. E., and Wikramanayake, E. D. 1995. Fish species of special concern in California (second edition). California Department of Fish and Game. Sacramento, California. 72 p.
Columbia	• Catch data (1938-2006) • CPUE data (1988-2005) • Catch (larvae per m^3) (1996-2005) • Low effort (1960-1977 limited to 3 ½ days/week, 1965-1966 4 ½ days /week). In 1978 the fishery was expanded to 7 days/week, until 1995) • Report comments- "extremely poor returns of 1994-1999" *In*: Washington Department of Fish and Wildlife & Oregon Department of Fish Wildlife. 2001. Washington and Oregon eulachon management plan. Washington Department of Fish and Wildlife: Olympia. 32 p. Washington Department of Fish and Wildlife & Oregon Department of Fish Wildlife. 2004. Joint staff report concerning commercial seasons for sturgeon and smelt in 2005. Washington Department of Fish and Wildlife & Oregon Department of Fish Wildlife. 2005. Joint staff report concerning commercial seasons for sturgeon and smelt in 2006.
Fraser	• Catch and CPUE data (1941-1953) Ricker, W. E., Manzer, D. F., and Neave, E. A. 1954. The Fraser River eulachon fishery, 1941-1953. Fisheries Research Board of Canada, Manuscript report no. 583. 35 p. • Catch data (1881-1940) adapted from Figure 12 p14 Clemens, W. & Wilby, G. 1946. Fishes of the Pacific Coast of Canada (1st edition). Fisheries Research Board of Canada Bulletin no.68. 368 p. • Catch data (1954-2000) Hay, D. E. & McCarter, P. 2000. Status of the eulachon *Thaleichthys pacificus* in Canada. Department of Fisheries and Oceans Canada, Canadian Stock Assessment Secretariat, Research Document 2000/145. 92 p. • Catch data (2001-2006) and test fishery (1995-2005) and biomass estimates (1995-2006) Department of Fisheries and Oceans Canada. 2007. Pacific region integrated fisheries

	management plan: eulachon- April 1, 2007 to March 31, 2008. 22 p. • First Nation catch (1974-1991) Fast, E. 1992. Memorandum re: IFF eulachon harvest- Steveston sub-district 1974-1991. January 13. To Al. MacDonald, Biologist, from Elmer Fast, Fisheries Officer in charge. Department of Fisheries and Oceans Canada. • Recreational catch, run size comments and low effort comments Forbes, C. & Harris, R. 1974-1989. Eulachons- summary of weekly reports of the fisheries patrol vessel Star Rock and Stuart Post for the Steveston sub-district. Department of Fisheries and Oceans Canada. Department of Fisheries and Oceans Canada. 1940-1979. Fisheries Inspectors weekly reports and annual narrative reports. Districts of: Chilliwack-Hope, Mission-Harrison, Steveston, Chilliwack-Yale. Vancouver, British Columbia. • CPUE data (1982-1996 DFO) Department of Fisheries and Oceans. 2008. Overview of the eulachon fishery. Pelagics & minor finfish- Pacific Region, Canada. Retrieved January 30, 2008, from: http://www.pac.dfo-mpo.gc.ca/ops/fm/herring/eulachon/default_e.htm#.com
Kingcome	• Catch data and run size comments from: Berry, M. D. & Jacob, W. 1998. 1997 Eulachon research on the Kingcome and Wannock Rivers. Final report to the Science Council of British Columbia (SCBC #96/97-715). 62 p. Common Resources Consulting Ltd. 1998. An historic overview of the Kwawkewlth, Knight, and Kingcome inlet oolachon fishery. A report prepared for the Department of Fisheries and Oceans Canada, Vancouver, British Columbia. • Run size comments from (1978, 1993-2007): Nicolsen, M. 2006/07. Member of the Tsawataineuk Nation, Kingcome Inlet, BC. Telephone conversation: February 1, 2006 Email: September 9, 2007
Klinaklini	• Catch data and run size comments from: Berry, M. D. & Jacob, W. 1998. 1997 Eulachon research on the Kingcome and Wannock Rivers. Final report to the Science Council of British Columbia (SCBC #96/97-715). 62 p. Common Resources Consulting Ltd. 1998. An historic overview of the Kwawkewlth, Knight, and Kingcome inlet oolachon fishery. A report prepared for the Department of Fisheries and Oceans Canada, Vancouver, British Columbia.

Wannock	• Run size comments from: Berry, M. D. & Jacob, W. 1998. 1997 Eulachon research on the Kingcome and Wannock Rivers. Final report to the Science Council of British Columbia (SCBC #96/97-715). 62 p. Department of Fisheries and Oceans Canada. 1967-68 & 1971. Fisheries Inspectors weekly reports and annual narrative reports. Rivers Inlet District. Rivers Inlet, British Columbia. Burrows, B. 2006. Unpublished. Rivers Inlet oolichan project 2006. Wuikinuxv Fisheries Department. Rivers Inlet, British Columbia.
Bella Coola	• Catch data, run size and low effort comments from: 2006 Nuxalk interviews (Thesis section, "Estimating historical catches of the Nuxalk Nation eulachon fishery") Department of Fisheries and Oceans. 1944-1989. Fisheries Inspectors weekly reports and annual narrative reports. Bella Coola District, Bella Coola, British Columbia, Canada. Tallio, N. and Webber, W. 1998. Nuxalk Nation eulachon enumeration of the Bella Coola River, 1998. Nuxalk Fisheries Department, Bella Coola, British Columbia.
Kemano	• Run size and low effort comments from: Department of Fisheries and Oceans Canada. 1969-1973. Fisheries Inspectors annual narrative reports. Butedale sub-district. Department of Fisheries and Oceans, Canada. Kitimat, British Columbia. Eulachon Conservation Society. 2002. Eulachon Conservation Society workshop minutes, December 5-6, 2002. Prince Rupert, British Columbia. 24 p. Eulachon Research Council. 2000. Eulachon Research Council, May 2000. Minutes summarizing meetings in New Westminister, Terrace and Bella Coola, BC. Informal joint report prepared jointly by BC Forests and Fisheries and Oceans Canada. 24 p. • Catch data 1969-1973 Department of Fisheries and Oceans Canada. 1969-1973. Fisheries Inspectors annual narrative reports. Butedale sub-district. Department of Fisheries and Oceans, Canada. Kitimat, British Columbia. • Catch data 1988-2004 and CPUE data 1998-2004 Lewis, A.F.J. & Ganshorn, K. 2004. Alcan's Kemano River eulachon (*Thaleichthys pacificus*) monitoring program: Haisla fishery monitoring 2004. Consultant's report prepared for Alcan Primary Metal Ltd., Kitimat, British Columbia. Lewis, A. F.J., McGurk, M.D., & Galesloot, M.G. 2002. Alcan's Kemano River eulachon (*Thaleichthys pacificus*) monitoring program 1988-1998. Consultant's report prepared by Ecofish Research Ltd. For Alcan Primary Metal Ltd., Kitimat, British Columbia. 136 p. EcoMetrix Incorporated. 2006. Summary of 2006 eulachon study results and 2007 study design. Report prepared for EUROCAN PULP and PAPER CO., Kitimat, British Columbia.
Kitimat	• Run size, low effort comments and catch data 1969-1972 from: Department of Fisheries and Oceans Canada. 1969-1973. Fisheries Inspectors annual

	narrative reports. Butedale sub-district. Department of Fisheries and Oceans, Canada. Kitimat, British Columbia.
	Eulachon Research Council. 2000. Eulachon Research Council, May 2000. Minutes summarizing meetings in New Westminister, Terrace and Bella Coola, BC. Informal joint report prepared jointly by BC Forests and Fisheries and Oceans Canada. 24 p.
	• Run size, low effort, CPUE and SSB data from:
	EcoMetrix Incorporated. 2006. Summary of 2006 eulachon study results and 2007 study design. Report prepared for EUROCAN PULP and PAPER CO., Kitimat, British Columbia.
Nass	• Catch data and run size/low effort comments from several sources, see Appendix 1.
	• Catch and CPUE data 1997-2006 Nisga'a Fisheries in:
	Pickard, D. & Marmorek, D. R. 2007. A workshop to determine research priorities for eulachon, workshop report. Prepared by ESSA Technologies Ltd., Vancouver British Columbia for Fisheries and Oceans Canada, Nanaimo, British Columbia. 58 p.
Skeena	• Run size comments from:
	Lewis, A. 1997. Skeena eulachon study 1997. Report prepared by Triton Environmental Consultants Ltd., Terrace, BC and the Tsimshian Tribal Council, Prince Rupert, British Columbia for Forest Renewal BC.
	Eulachon Conservation Society. 2002. Eulachon Conservation Society workshop minutes, December 5-6, 2002. Prince Rupert, British Columbia. 24 p.
	Eulachon Research Council. 2000. Eulachon Research Council, May 2000. Minutes summarizing meetings in New Westminister, Terrace and Bella Coola, BC. Informal joint report prepared jointly by BC Forests and Fisheries and Oceans Canada. 24 p.
	Roberts, D. 2006/07. Member of the Kitsumkalum Nation, Terrace BC. Telephone conversation: March 6, 2006 and February 7, 2007
Unuk	• Run size comments and catch data from:
	Eulachon Research Council. 2000. Eulachon Research Council, May 2000. Minutes summarizing meetings in New Westminister, Terrace and Bella Coola, BC. Informal joint report prepared jointly by BC Forests and Fisheries and Oceans Canada. 24 p.
	Tisler, T. & Spangler, R. 2003. Unpublished. 2003 eulachon harvest and distribution report. United States Forest Service. Ketchikan, Alaska.
	United States Forest Service. 2006. Unpublished. 2001-2005 Unuk River eulachon survey summary. Ketchikan, Alaska.
	United States Forest Service. 2007. Unpublished. 2006 Unuk River eulachon monitoring summary. Ketchikan, Alaska.

Chilkat	• Run size and low effort comments from: Mills, D. D. 1982. Historical and contemporary fishing for salmon and eulachon at Klukwan: an interim report. Alaska Department of Fish and Game, Division of Subsistence, technical paper no. 69. Juneau. 28 p. Morphet, T. 2005. Fish scientist hopes study will help crack eulachon mystery. *The Chilkat Valley News*, Haines, Alaska, 9 June. Retrieved February 6, 2007, from http://www.chilkatvalleynews.com/archive/2005-22-4.html Morphet, T. 2006. 2006: the year in review. *Chilkat Valley News*, Haines, Alaska, 21 December. Retrieved February 6, 2007, from http://www.chilkatvalleynews.com/archive/2006-50-4.html • Catch data 1983 and 1987 Betts, M. F. 1994. The subsistence hooligan fishery of the Chilkat and Chilkoot Rivers. Alaska Department of Fish and Game: Division of Subsistence, technical paper no. 213, Juneau, Alaska. 69 p.
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APPENDIX 8: VISUAL BASICS FOR APPLICATIONS (VBA) CODE FOR THE FUZZY EXPERT SYSTEM USED TO ESTIMATE 15 EULACHON SYSTEM'S ANNUAL ABUNDANCE STATUS

```
'Class modules used
'Note: the class defines what properties, methods and events an object possesses.
```

'cFMF

```
Option Explicit
Public strMemShape As String
Public intFMFa As Double
Public intFMFb As Double
Public intFMFc As Double
Public intFMFd As Double
Public strCatName As String
Public intMaxC As Integer
```

'cFMF2

```
Option Explicit
Public strMemShape2 As String
Public intFMF2a As Double
Public intFMF2b As Double
Public intFMF2c As Double
Public intFMF2d As Double
Public strCatName2 As String
```

'InputData

```
Option Explicit
Public strDataName As String

'Fuzzy logic method
Public colFMF As Collection
Public colFMF2 As Collection
```

'cRiver

```
Option Explicit
Public strName As String
Public strIndex As String
Public strDataName As String
Public colYearData As Collection
Public colRiverData As Collection
```

'cRiverdata

```
Option Explicit
Public bolCA As Boolean
Public bolCPUE As Boolean
Public bolSSB As Boolean
Public bolLS As Boolean
Public bolTF As Boolean
Public bolRC As Boolean
Public bolILC As Boolean
```

```
Public bolLE As Boolean
```

'cYeardata

```
Option Explicit
Public strRiver As String
Public dYear As Double

Public strCatch As String
Public strCPUE As String
Public strLE As String
Public strRC As String
Public strILC As String
Public strSSB As String
Public strLS As String
Public strTF As String

Public dL As Double
Public dML As Double
Public dM As Double
Public dMH As Double
Public dH As Double
Public dC1 As Double
Public dC2 As Double
Public dC3 As Double
Public dC4 As Double
Public dC5 As Double
Public dC6 As Double
Public dCPUE1 As Double
Public dCPUE2 As Double
Public dCPUE3 As Double
Public dCPUE4 As Double
Public dCPUE5 As Double
Public dLS1 As Double
Public dLS2 As Double
Public dLS3 As Double
Public dLS4 As Double
Public dLS5 As Double
Public dSSB1 As Double
Public dSSB2 As Double
Public dSSB3 As Double
Public dSSB4 As Double
Public dSSB5 As Double
Public dTF1 As Double
Public dTF2 As Double
Public dTF3 As Double
Public dTF4 As Double
Public dTF5 As Double
Public dRC1 As Double
Public dRC2 As Double
Public dRC3 As Double
Public dRC4 As Double
Public dRC5 As Double
Public dILC1 As Double
Public dILC2 As Double
Public dILC3 As Double
Public dILC4 As Double
Public dILC5 As Double
```

```
Public dReachMaxCatch As Integer
```

```
Public Sub Main()     'model for estimating eulachon abundance indices for 15 eulachon systems

Dim ColRivers As Collection
Dim ColFuzzyData As Collection
Dim ColFuzzyData2 As Collection
Set ColRivers = Load
Set ColFuzzyData = LoadFMF
Set ColFuzzyData2 = LoadFMF2
Call Module1.ReadMaxCatch(ColRivers)
Call Module1.GetMembershipCA(ColRivers, ColFuzzyData)
Call Module1.GetMembershipCPUE(ColRivers, ColFuzzyData2)
Call Module1.GetMembershipTF(ColRivers, ColFuzzyData2)
Call Module1.GetMembershipLS(ColRivers, ColFuzzyData2)
Call Module1.GetMembershipSSB(ColRivers, ColFuzzyData2)
Call Module1.GetMembershipRC(ColRivers, ColFuzzyData2)
Call Module1.GetMembershipILC(ColRivers, ColFuzzyData2)
Call Module3.ReadCF
Call Module3.Reasoning(ColRivers)
Worksheets("Results").Activate
Call colcol
MsgBox "yaaaaaa!!!!"
End Sub
```

```
Public Function LoadFMF() As Collection
Dim cInputData As cInputData
Dim ColFuzzyData As New Collection
Dim cFMF As cFMF
Dim rngCAFMF As Range
Dim i, j, k As Integer

   Set rngCAFMF = Range("Cafmf")
   Set cInputData = New cInputData
   cInputData.strDataName = CStr(rngCAFMF(1, 1))
   Set cInputData.colFMF = New Collection

 For i = 1 To rngCAFMF.Columns.Count - 1
      Set cFMF = New cFMF
      cFMF.strCatName = rngCAFMF(1, i + 1)
      cFMF.strMemShape = rngCAFMF(2, i + 1)
      cFMF.intMaxC = rngCAFMF(3, i + 1)
      cFMF.intFMFa = rngCAFMF(4, i + 1)
      cFMF.intFMFb = rngCAFMF(5, i + 1)
      cFMF.intFMFc = rngCAFMF(6, i + 1)
      If rngCAFMF(7, i + 1) = "" Then
         cFMF.intFMFd = 0
      Else
         cFMF.intFMFd = rngCAFMF(7, i + 1)
      End If
     Call cInputData.colFMF.Add(cFMF)
   Next i
   Call ColFuzzyData.Add(cInputData, cInputData.strDataName)

  Set LoadFMF = ColFuzzyData
   End Function
```

```
Public Function LoadFMF2() As Collection
Dim cInputData As cInputData
Dim ColFuzzyData2 As New Collection
Dim cFMF2 As cFMF2
Dim rngOtherFMF As Range
Dim i, j, k As Integer

   Set rngOtherFMF = Range("Otherfmf")
   Set cInputData = New cInputData
   cInputData.strDataName = CStr(rngOtherFMF(1, 1))
   Set cInputData.colFMF2 = New Collection

For i = 1 To rngOtherFMF.Columns.Count - 1
      Set cFMF2 = New cFMF2
      cFMF2.strCatName2 = rngOtherFMF(1, i + 1)
      cFMF2.strMemShape2 = rngOtherFMF(2, i + 1)
      cFMF2.intFMF2a = rngOtherFMF(3, i + 1)
      cFMF2.intFMF2b = rngOtherFMF(4, i + 1)
      cFMF2.intFMF2c = rngOtherFMF(5, i + 1)
      If rngOtherFMF(6, i + 1) = "" Then
         cFMF2.intFMF2d = 0
      Else
         cFMF2.intFMF2d = rngOtherFMF(6, i + 1)
      End If
      Call cInputData.colFMF2.Add(cFMF2)
   Next i
   Call ColFuzzyData2.Add(cInputData, cInputData.strDataName)

  Set LoadFMF2 = ColFuzzyData2

End Function

Public Function CheckForData(strData As String) As String
   If strData = vbNullString Then
      CheckForData = ""
   Else
      CheckForData = strData
   End If
End Function
```

```
Public Function Load() As Collection                    'this function loads the data for each river

Dim rngRiverMaster As Range
Dim rngData As Range
Dim cRiver As cRiver                              'name the business objects for later use
Dim cYearData As cYearData
Dim cRiverdata As cRiverdata
Dim ColRivers As New Collection                         'name the big collection of rivers
Dim x, y, z As Integer

'read in table of data sets available
Set rngRiverMaster = Range("rngRiverMaster")            'define range of rivers
Set rngData = Range("rngData")                          'define range of data

For x = 1 To rngRiverMaster.Rows.Count            'make a new river object
   Set cRiver = New cRiver
   Set cRiver.colRiverData = New Collection
```

```
   cRiver.strName = rngRiverMaster(x, 1)          'set the name and index of the current river
   cRiver.strIndex = rngRiverMaster(x, 2)

   Set cRiverdata = New cRiverdata

'Go to River Master table and look if data exists (CA CPUE SSB LS TF RC ILC LE)

     If rngRiverMaster(x, 3) = 1 Then
        cRiverdata.bolCA = True
      Else
        cRiverdata.bolCA = False
      End If

      If rngRiverMaster(x, 4) = 1 Then
        cRiverdata.bolCPUE = True
      Else
        cRiverdata.bolCPUE = False
      End If

      If rngRiverMaster(x, 5) = 1 Then
        cRiverdata.bolSSB = True
      Else
        cRiverdata.bolSSB = False
      End If

      If rngRiverMaster(x, 6) = 1 Then
        cRiverdata.bolLS = True
      Else
        cRiverdata.bolLS = False
      End If

      If rngRiverMaster(x, 7) = 1 Then
        cRiverdata.bolTF = True
      Else
        cRiverdata.bolTF = False
      End If

      If rngRiverMaster(x, 8) = 1 Then
        cRiverdata.bolRC = True
      Else
        cRiverdata.bolRC = False
      End If

      If rngRiverMaster(x, 9) = 1 Then
        cRiverdata.bolILC = True
      Else
        cRiverdata.bolILC = False
      End If

      If rngRiverMaster(x, 10) = 1 Then
        cRiverdata.bolLE = True
      Else
        cRiverdata.bolLE = False

      End If

      Call cRiver.colRiverData.Add(cRiverdata)
```

```
  Set cRiver.colYearData = New Collection                    'make a new collection of year data for the current river

 'if data exists (1) then read in data if no data, go to next data set

  For y = 1 To rngData.Rows.Count                            'loop through data range

  If rngData(y, 2) = cRiver.strName Then                     'the river matches

     Set cYearData = New cYearData                           'make a new year data for the current river
     'set the info for the current year data for the current river

     cYearData.dYear = rngData(y, 1)
     cYearData.strRiver = cRiver.strName

     cYearData.strCatch = CheckForData(rngData(y, 5))
     cYearData.strLE = CheckForData(rngData(y, 6))
     cYearData.strCPUE = CheckForData(rngData(y, 8))
     cYearData.strRC = CheckForData(rngData(y, 10))
     cYearData.strILC = CheckForData(rngData(y, 12))
     cYearData.strSSB = CheckForData(rngData(y, 14))
     cYearData.strLS = CheckForData(rngData(y, 16))
     cYearData.strTF = CheckForData(rngData(y, 18))

  Call cRiver.colYearData.Add(cYearData, CStr(cYearData.dYear))

 End If

 Next y

    'this river is done, add it to the big collection of all rivers
    Call ColRivers.Add(cRiver, cRiver.strName)

Next x

  Set Load = ColRivers

End Function
```

```
Function Triangle(ByVal x As Double, ByVal a As Double, ByVal b As Double, ByVal c As Double) As
Double

'Function for a triangle density function

     Dim temp As Double

     If x <= a Then temp = 0

     If x > a And x < b Then temp = (x - a) / (b - a)

     If x >= b And x < c Then temp = (c - x) / (c - b)

     If x >= c Then temp = 0

     Triangle = temp

  End Function
```

```
Function MYCIN(Evidence1 As Double, Evidence2 As Double, Optional Evidence3 As Double, Optional Evidence4 As Double, Optional Evidence5 As Double, Optional Evidence6 As Double, Optional Evidence7 As Double, Optional Evidence8 As Double, Optional Evidence9 As Double, Optional Evidence10 As Double, Optional Evidence11 As Double, Optional Evidence12 As Double, Optional Evidence13 As Double, Optional Evidence14 As Double) As Double

'calculate combined memberships (Function MYCIN)

Dim temp As Double

   temp = 0
   temp = Evidence1
   temp = temp + Evidence2 * (1 - temp)
   temp = temp + Evidence3 * (1 - temp)
   temp = temp + Evidence4 * (1 - temp)
   temp = temp + Evidence5 * (1 - temp)
   temp = temp + Evidence6 * (1 - temp)
   temp = temp + Evidence7 * (1 - temp)
   temp = temp + Evidence8 * (1 - temp)
   temp = temp + Evidence9 * (1 - temp)
   temp = temp + Evidence10 * (1 - temp)
   temp = temp + Evidence11 * (1 - temp)
   temp = temp + Evidence12 * (1 - temp)
   temp = temp + Evidence13 * (1 - temp)
   temp = temp + Evidence14 * (1 - temp)

   MYCIN = temp

End Function
```

```
Function trapezoid(ByVal x As Double, ByVal a As Double, ByVal b As Double, ByVal c As Double, ByVal d As Double) As Double

'Function for a trapezoid density function

Dim temp As Double

      If x <= a Then temp = 0

      If x > a And x < b Then temp = (x - a) / (b - a)

      If x >= b And x < c Then temp = 1

      If x >= c And x < d Then temp = (d - x) / (d - c)

      If x >= d Then temp = 0

      trapezoid = temp

End Function
```

```
'This sub function finds the maximum catch of a data set and sets the year

Sub ReadMaxCatch(ColRivers As Collection)
Dim MaxCatch As Double
```

```
Dim MaxCatchYr As Integer
Dim cRiver As cRiver
Dim cYearData As cYearData
Dim i, j As Integer

Set cRiver = New cRiver
Set cYearData = New cYearData

For i = 1 To ColRivers.Count
   Set cRiver = ColRivers(i)
   MaxCatch = 0: MaxCatchYr = 0

   For j = 1 To cRiver.colYearData.Count
   Set cYearData = cRiver.colYearData(j)
      If cYearData.strCatch <> "" Then
         If MaxCatch < CDbl(cYearData.strCatch) Then
           MaxCatch = CDbl(cYearData.strCatch)
           MaxCatchYr = cYearData.dYear
         End If
      End If
   Next j

For j = 1 To cRiver.colYearData.Count
   Set cYearData = cRiver.colYearData(j)
      If cYearData.dYear < MaxCatchYr Then
        ColRivers.Item(i).colYearData(j).dReachMaxCatch = 0
      Else
         ColRivers.Item(i).colYearData(j).dReachMaxCatch = 1
      End If
   Next
Next i

End Sub

Sub GetMembershipCA(ColRivers As Collection, ColFuzzyData As Collection)

'This sub function calculates the membership for the Catch

Dim rngCAFMF As Range
Dim cRiver As cRiver
Dim cRiverdata As cRiverdata
Dim cYearData As cYearData
Dim cInputData As cInputData
Dim cFMF As cFMF
Dim valCAFMF() As Variant
Dim strCACat() As String
Dim CAMembership() As Double
Dim CAMemDeplTemp As Double
Dim rngCAMem As Range
Dim i, j, yr, rvcnt As Integer
Dim IntDeplCount As Integer                    'Count the number of consecutive depleted years

ReDim CAMembership(6)

Set rngCAFMF = Range("CAfmf")
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
```

```
Set cInputData = New cInputData
Set cInputData = ColFuzzyData(1)
Set rngCAMem = Range("CAOutput")
rvcnt = 0

For i = 1 To ColRivers.Count
   Set cRiver = ColRivers(i)
   Set cRiverdata = cRiver.colRiverData(1)
   If cRiverdata.bolCA = True Then        'if CA data exists
   IntDeplCount = 0    'Clear variable for each data series
   For yr = 1 To cRiver.colYearData.Count

'*********************************************
'loop through each year' catch

Set cYearData = cRiver.colYearData(yr)

  For j = 1 To cInputData.colFMF.Count
     Set cFMF = cInputData.colFMF(j)

     Select Case cFMF.strCatName

Case "C1"
If cYearData.strCatch <> "" And cYearData.dReachMaxCatch = cFMF.intMaxC Then
Select Case cFMF.strMemShape
Case "Tri"
CAMembership(1) = Triangle(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc)
Case "Trap"
CAMembership(1) = trapezoid(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb,
cFMF.intFMFc, cFMF.intFMFd)
End Select
          'Else
          'CAMembership(1) = 0
End If

Case "C2"
If cYearData.strCatch <> "" And cYearData.dReachMaxCatch = cFMF.intMaxC Then
Select Case cFMF.strMemShape
Case "Tri"
CAMembership(2) = Triangle(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc)
Case "Trap"
 CAMembership(2) = trapezoid(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb,
cFMF.intFMFc, cFMF.intFMFd)
 End Select
          'Else
          'CAMembership(2) = 0
End If

Case "C3"
If cYearData.strCatch <> "" And cYearData.dReachMaxCatch = cFMF.intMaxC Then
Select Case cFMF.strMemShape
Case "Tri"
CAMembership(3) = Triangle(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc)
Case "Trap"
  CAMembership(3) = trapezoid(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb,
cFMF.intFMFc, cFMF.intFMFd)
  End Select
```

```
            'Else
            'CAMembership(3) = 0
           End If
```

Case "C4"

```
If cYearData.strCatch <> "" And cYearData.dReachMaxCatch = cFMF.intMaxC Then
Select Case cFMF.strMemShape
Case "Tri"
CAMembership(4) = Triangle(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc)
Case "Trap"
CAMembership(4) = trapezoid(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb,
cFMF.intFMFc, cFMF.intFMFd)
End Select
            'Else
            'CAMembership(4) = 0
End If
```

Case "C5"

```
If cYearData.strCatch <> "" And cYearData.dReachMaxCatch = cFMF.intMaxC Then
Select Case cFMF.strMemShape
Case "Tri"
CAMembership(5) = Triangle(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc)
Case "Trap"
CAMembership(5) = trapezoid(CDbl(cYearData.strCatch), cFMF.intFMFa, cFMF.intFMFb,
cFMF.intFMFc, cFMF.intFMFd)
End Select
End If
CAMemDeplTemp = CAMembership(5)

'IF LE exists and >3yrs depleted                    'Dim LETemp As Integer

           If cYearData.strLE = "1" Then             'get whether LE is true or not
              LETemp = 1
           ElseIf cYearData.strLE = "" Then
              LETemp = 0
           End If

           If LETemp = 1 Then
                 If CAMembership(5) > 0 Then
             IntDeplCount = IntDeplCount + 1
                 Else
                 IntDeplCount = 0
                 End If

                 'If IntDeplCount > 10 Then
                 'IndDeplCount = 0
                 'End If

              Set cFMF = cInputData.colFMF(8)
Select Case cFMF.strMemShape
Case "Tri"
CAMembership(5) = WorksheetFunction.Min(CAMemDeplTemp, Triangle(CDbl(IntDeplCount),
cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc))
Case "Trap"
CAMembership(5) = WorksheetFunction.Min(CAMemDeplTemp, trapezoid(CDbl(IntDeplCount),
cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc, cFMF.intFMFd))
End Select
```

```
            Set cFMF = cInputData.colFMF(7)

Select Case cFMF.strMemShape
Case "Tri"
CAMembership(6) = WorksheetFunction.Min(CAMemDeplTemp, Triangle(CDbl(IntDeplCount),
cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc))
Case "Trap"
CAMembership(6) = WorksheetFunction.Min(CAMemDeplTemp, trapezoid(CDbl(IntDeplCount),
cFMF.intFMFa, cFMF.intFMFb, cFMF.intFMFc, cFMF.intFMFd))
End Select
                Set cFMF = cInputData.colFMF(j)
End If
End Select
Next j

      For j = 1 To UBound(CAMembership)
            Set cFMF = cInputData.colFMF(j)
            If cYearData.strCatch <> "" Then
               rngCAMem(2 + 7 * (rvcnt) + j, yr + 1) = CAMembership(j)
               rngCAMem(2 + 7 * (rvcnt) + 1, 1) = "C1"
               rngCAMem(2 + 7 * (rvcnt) + 2, 1) = "C2"
               rngCAMem(2 + 7 * (rvcnt) + 3, 1) = "C3"
               rngCAMem(2 + 7 * (rvcnt) + 4, 1) = "C4"
               rngCAMem(2 + 7 * (rvcnt) + 5, 1) = "C5"
               rngCAMem(2 + 7 * (rvcnt) + 6, 1) = "C6"
            Else
               rngCAMem(2 + 7 * (rvcnt) + j, yr + 1) = ""
            End If

'make a new year data for the current river
      'set the info for the current year data for the current river

      Next j

      'Store membership in class
      If cYearData.strCatch <> "" Then
         cYearData.dC1 = CAMembership(1)
         cYearData.dC2 = CAMembership(2)
         cYearData.dC3 = CAMembership(3)
         cYearData.dC4 = CAMembership(4)
         cYearData.dC5 = CAMembership(5)
         cYearData.dC6 = CAMembership(6)
      End If
      ReDim CAMembership(6)
   Next yr

    rngCAMem(2 + 7 * (rvcnt), 1) = cRiver.strName
    rvcnt = rvcnt + 1

   End If

Next i
End Sub
```

```
Sub GetMembershipCPUE(ColRivers As Collection, ColFuzzyData2 As Collection)

'This sub function calculates the membership for the CPUE data
```

```
Dim rngOtherFMF As Range
Dim cRiver As cRiver
Dim cRiverdata As cRiverdata
Dim cYearData As cYearData
Dim cInputData As cInputData
Dim cFMF2 As cFMF2
Dim rngCPUEMem As Range
Dim i, j, yr, rvcnt As Integer                    'rvcnt = river count
Dim CPUEMembership() As Double

ReDim CPUEMembership(5)
Set rngOtherFMF = Range("Otherfmf")
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
Set cInputData = New cInputData
Set cInputData = ColFuzzyData2(1)
Set rngCPUEMem = Range("CPUEOutput")
rvcnt = 0

For i = 1 To ColRivers.Count
   Set cRiver = ColRivers(i)
   Set cRiverdata = cRiver.colRiverData(1)
   If cRiverdata.bolCPUE = True Then

For yr = 1 To cRiver.colYearData.Count

'loop through each year' catch
   Set cYearData = cRiver.colYearData(yr)

For j = 1 To cInputData.colFMF2.Count
   Set cFMF2 = cInputData.colFMF2(j)
   Select Case cFMF2.strCatName2

Case "C1"
If cYearData.strCPUE <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
CPUEMembership(1) = Triangle(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
CPUEMembership(1) = trapezoid(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'CPUEMembership(1) = 0
End If

Case "C2"
If cYearData.strCPUE <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
CPUEMembership(2) = Triangle(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
CPUEMembership(2) = trapezoid(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
```

```
End Select
        'Else
        'CPUEMembership(2) = 0
End If

Case "C3"
If cYearData.strCPUE <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
CPUEMembership(3) = Triangle(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
CPUEMembership(3) = trapezoid(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'CPUEMembership(3) = 0
End If

Case "C4"
If cYearData.strCPUE <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
CPUEMembership(4) = Triangle(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
CPUEMembership(4) = trapezoid(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'CPUEMembership(4) = 0
End If

Case "C5"
If cYearData.strCPUE <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
CPUEMembership(5) = Triangle(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
CPUEMembership(5) = trapezoid(CDbl(cYearData.strCPUE), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'CPUEMembership(5) = 0

End If
End Select

Next j

   For j = 1 To UBound(CPUEMembership)
            Set cFMF2 = cInputData.colFMF2(j)
            If cYearData.strCPUE <> "" Then
            rngCPUEMem(2 + 6 * (rvcnt) + j, yr + 1) = CPUEMembership(j)
            rngCPUEMem(2 + 6 * (rvcnt) + 1, 1) = "C1"
            rngCPUEMem(2 + 6 * (rvcnt) + 2, 1) = "C2"
```

```
            rngCPUEMem(2 + 6 * (rvcnt) + 3, 1) = "C3"
            rngCPUEMem(2 + 6 * (rvcnt) + 4, 1) = "C4"
            rngCPUEMem(2 + 6 * (rvcnt) + 5, 1) = "C5"
         Else
            rngCPUEMem(2 + 6 * (rvcnt) + j, yr + 1) = ""
         End If
         'CPUEFinalMem(rvcnt, j, yr) = CPUEMembership(j)
   Next j
      'Store membership in class
      If cYearData.strCPUE <> "" Then
         cYearData.dCPUE1 = CPUEMembership(1)
         cYearData.dCPUE2 = CPUEMembership(2)
         cYearData.dCPUE3 = CPUEMembership(3)
         cYearData.dCPUE4 = CPUEMembership(4)
         cYearData.dCPUE5 = CPUEMembership(5)
      End If
      ReDim CPUEMembership(5)
Next yr
            rngCPUEMem(2 + 6 * (rvcnt), 1) = cRiver.strName
            rvcnt = rvcnt + 1
End If

Next i

End Sub

Sub GetMembershipTF(ColRivers As Collection, ColFuzzyData2 As Collection)

'This sub function calculates the membership for the TF data

Dim rngOtherFMF As Range
Dim cRiver As cRiver
Dim cRiverdata As cRiverdata
Dim cYearData As cYearData
Dim cInputData As cInputData
Dim cFMF2 As cFMF2
Dim rngTFMem As Range
Dim i, j, yr, rvcnt As Integer
Dim CPUEMembership() As Double

ReDim TFMembership(5)
Set rngOtherFMF = Range("Otherfmf")
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
Set cInputData = New cInputData
Set cInputData = ColFuzzyData2(1)
Set rngTFMem = Range("TFOutput")
rvcnt = 0      'river count

For i = 1 To ColRivers.Count
   Set cRiver = ColRivers(i)
   Set cRiverdata = cRiver.colRiverData(1)
   If cRiverdata.bolTF = True Then

For yr = 1 To cRiver.colYearData.Count

'loop through each year' T.fish
```

```
    Set cYearData = cRiver.colYearData(yr)

For j = 1 To cInputData.colFMF2.Count
  Set cFMF2 = cInputData.colFMF2(j)
  Select Case cFMF2.strCatName2

Case "C1"
If cYearData.strTF <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
TFMembership(1) = Triangle(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
TFMembership(1) = trapezoid(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'TFMembership(1) = 0
End If

Case "C2"
If cYearData.strTF <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
TFMembership(2) = Triangle(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
TFMembership(2) = trapezoid(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'TFMembership(2) = 0
End If

Case "C3"
If cYearData.strTF <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
TFMembership(3) = Triangle(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
TFMembership(3) = trapezoid(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
       'TFMembership(3) = 0
End If

Case "C4"
If cYearData.strTF <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
TFMembership(4) = Triangle(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
TFMembership(4) = trapezoid(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
```

```
End Select
        'Else
        'TFMembership(4) = 0
End If

Case "C5"
If cYearData.strTF <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
TFMembership(5) = Triangle(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
TFMembership(5) = trapezoid(CDbl(cYearData.strTF), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
       'Else
       'TFMembership(5) = 0
End If
End Select

Next j

   For j = 1 To UBound(TFMembership)
            Set cFMF2 = cInputData.colFMF2(j)
            If cYearData.strTF <> "" Then
            rngTFMem(2 + 6 * (rvcnt) + j, yr + 1) = TFMembership(j)
            rngTFMem(2 + 6 * (rvcnt) + 1, 1) = "C1"
            rngTFMem(2 + 6 * (rvcnt) + 2, 1) = "C2"
            rngTFMem(2 + 6 * (rvcnt) + 3, 1) = "C3"
            rngTFMem(2 + 6 * (rvcnt) + 4, 1) = "C4"
            rngTFMem(2 + 6 * (rvcnt) + 5, 1) = "C5"
         Else
            rngTFMem(2 + 6 * (rvcnt) + j, yr + 1) = ""
         End If
   Next j
     'Store membership in class
      If cYearData.strTF <> "" Then
         cYearData.dTF1 = TFMembership(1)
         cYearData.dTF2 = TFMembership(2)
         cYearData.dTF3 = TFMembership(3)
         cYearData.dTF4 = TFMembership(4)
         cYearData.dTF5 = TFMembership(5)
      End If
ReDim TFMembership(5)

Next yr
            rngTFMem(2 + 6 * (rvcnt), 1) = cRiver.strName
            rvcnt = rvcnt + 1
End If
    Next i

End Sub

Sub GetMembershipLS(ColRivers As Collection, ColFuzzyData2 As Collection)

'This sub function calculates the membership for the LS data

Dim rngOtherFMF As Range
```

```
Dim cRiver As cRiver
Dim cRiverdata As cRiverdata
Dim cYearData As cYearData
Dim cInputData As cInputData
Dim cFMF2 As cFMF2
Dim rngLSMem As Range
Dim i, j, yr, rvcnt As Integer
Dim LSMembership() As Double

ReDim LSMembership(5)
Set rngOtherFMF = Range("Otherfmf")
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
Set cInputData = New cInputData
Set cInputData = ColFuzzyData2(1)
Set rngLSMem = Range("LSOutput")
rvcnt = 0      'river count

For i = 1 To ColRivers.Count
   Set cRiver = ColRivers(i)
   Set cRiverdata = cRiver.colRiverData(1)
   If cRiverdata.bolLS = True Then

For yr = 1 To cRiver.colYearData.Count

'loop through each year' Larval surveys
      Set cYearData = cRiver.colYearData(yr)

For j = 1 To cInputData.colFMF2.Count
   Set cFMF2 = cInputData.colFMF2(j)
   Select Case cFMF2.strCatName2

Case "C1"
 If cYearData.strLS <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
LSMembership(1) = Triangle(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
LSMembership(1) = trapezoid(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'LSMembership(1) = 0
End If

Case "C2"
If cYearData.strLS <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
LSMembership(2) = Triangle(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
LSMembership(2) = trapezoid(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
```

```
        'Else
        'LSMembership(2) = 0
End If

Case "C3"
If cYearData.strLS <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
LSMembership(3) = Triangle(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
LSMembership(3) = trapezoid(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'LSMembership(3) = 0
End If

Case "C4"
If cYearData.strLS <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
LSMembership(4) = Triangle(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
LSMembership(4) = trapezoid(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'LSMembership(4) = 0
End If

Case "C5"
If cYearData.strLS <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
LSMembership(5) = Triangle(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
LSMembership(5) = trapezoid(CDbl(cYearData.strLS), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'LSMembership(5) = 0

End If
End Select

Next j

   For j = 1 To UBound(LSMembership)
        Set cFMF2 = cInputData.colFMF2(j)
        If cYearData.strLS <> "" Then
           rngLSMem(2 + 6 * (rvcnt) + j, yr + 1) = LSMembership(j)
           rngLSMem(2 + 6 * (rvcnt) + 1, 1) = "C1"
           rngLSMem(2 + 6 * (rvcnt) + 2, 1) = "C2"
           rngLSMem(2 + 6 * (rvcnt) + 3, 1) = "C3"
           rngLSMem(2 + 6 * (rvcnt) + 4, 1) = "C4"
```

```
            rngLSMem(2 + 6 * (rvcnt) + 5, 1) = "C5"
         Else
            rngLSMem(2 + 6 * (rvcnt) + j, yr + 1) = ""
         End If
   Next j

   'Store membership in class
   If cYearData.strLS <> "" Then
      cYearData.dLS1 = LSMembership(1)
      cYearData.dLS2 = LSMembership(2)
      cYearData.dLS3 = LSMembership(3)
      cYearData.dLS4 = LSMembership(4)
      cYearData.dLS5 = LSMembership(5)
   End If

   ReDim LSMembership(5)

Next yr
    rngLSMem(2 + 6 * (rvcnt), 1) = cRiver.strName
    rvcnt = rvcnt + 1
End If

Next i

End Sub

Sub GetMembershipSSB(ColRivers As Collection, ColFuzzyData2 As Collection)

'This sub function calculates the membership for the SSB data

Dim rngOtherFMF As Range
Dim cRiver As cRiver
Dim cRiverdata As cRiverdata
Dim cYearData As cYearData
Dim cInputData As cInputData
Dim cFMF2 As cFMF2
Dim rngSSBMem As Range
Dim i, j, yr, rvcnt As Integer
Dim SSBMembership()

ReDim SSBMembership(Range("Otherfmf").Columns.Count - 1)
Set rngOtherFMF = Range("Otherfmf")
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
Set cInputData = New cInputData
Set cInputData = ColFuzzyData2(1)
Set rngSSBMem = Range("SSBOutput")
rvcnt = 0      'river count

For i = 1 To ColRivers.Count
   Set cRiver = ColRivers(i)
   Set cRiverdata = cRiver.colRiverData(1)
   If cRiverdata.bolSSB = True Then

For yr = 1 To cRiver.colYearData.Count
```

```
'loop through each year' SSB estimates
      Set cYearData = cRiver.colYearData(yr)

For j = 1 To cInputData.colFMF2.Count
   Set cFMF2 = cInputData.colFMF2(j)
   Select Case cFMF2.strCatName2

Case "C1"
If cYearData.strSSB <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
SSBMembership(1) = Triangle(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
SSBMembership(1) = trapezoid(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
          'Else
          'SSBMembership(1) = 0
End If

Case "C2"
If cYearData.strSSB <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
SSBMembership(2) = Triangle(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
SSBMembership(2) = trapezoid(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
         'Else
         'SSBMembership(2) = 0
End If

Case "C3"
If cYearData.strSSB <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
SSBMembership(3) = Triangle(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
SSBMembership(3) = trapezoid(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'SSBMembership(3) = 0
End If

Case "C4"
If cYearData.strSSB <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
SSBMembership(4) = Triangle(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
SSBMembership(4) = trapezoid(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
```

```
End Select
        'Else
        'SSBMembership(4) = 0
End If

Case "C5"
If cYearData.strSSB <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
SSBMembership(5) = Triangle(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
SSBMembership(5) = trapezoid(CDbl(cYearData.strSSB), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        ' Else
        'SSBMembership(5) = 0
End If
End Select

Next j

   For j = 1 To UBound(SSBMembership)
        Set cFMF2 = cInputData.colFMF2(j)
        If cYearData.strSSB <> "" Then
           rngSSBMem(2 + 6 * (rvcnt) + j, yr + 1) = SSBMembership(j)
           rngSSBMem(2 + 6 * (rvcnt) + 1, 1) = "C1"
           rngSSBMem(2 + 6 * (rvcnt) + 2, 1) = "C2"
           rngSSBMem(2 + 6 * (rvcnt) + 3, 1) = "C3"
           rngSSBMem(2 + 6 * (rvcnt) + 4, 1) = "C4"
           rngSSBMem(2 + 6 * (rvcnt) + 5, 1) = "C5"
        Else
        rngSSBMem(2 + 6 * (rvcnt) + j, yr + 1) = ""
        End If
   Next j
    'Store membership in class
   If cYearData.strSSB <> "" Then
      cYearData.dSSB1 = SSBMembership(1)
      cYearData.dSSB2 = SSBMembership(2)
      cYearData.dSSB3 = SSBMembership(3)
      cYearData.dSSB4 = SSBMembership(4)
      cYearData.dSSB5 = SSBMembership(5)
   End If

ReDim SSBMembership(Range("Otherfmf").Columns.Count - 1)

Next yr
    rngSSBMem(2 + 6 * (rvcnt), 1) = cRiver.strName
    rvcnt = rvcnt + 1
End If

Next i

End Sub

Sub GetMembershipRC(ColRivers As Collection, ColFuzzyData2 As Collection)
```

```
'This sub function calculates the membership for the Report Comments data

Dim rngOtherFMF As Range
Dim cRiver As cRiver
Dim cRiverdata As cRiverdata
Dim cYearData As cYearData
Dim cInputData As cInputData
Dim cFMF2 As cFMF2
Dim rngRCMem As Range
Dim i, j, yr, rvcnt As Integer
Dim RCMembership() As Double

ReDim RCMembership(Range("Otherfmf").Columns.Count - 1)
Set rngOtherFMF = Range("Otherfmf")
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
Set cInputData = New cInputData
Set cInputData = ColFuzzyData2(1)
Set rngRCMem = Range("RCOutput")
rvcnt = 0      'river count

For i = 1 To ColRivers.Count
   Set cRiver = ColRivers(i)
   Set cRiverdata = cRiver.colRiverData(1)
   If cRiverdata.bolRC = True Then

For yr = 1 To cRiver.colYearData.Count

'loop through each year' RC comment data
      Set cYearData = cRiver.colYearData(yr)

For j = 1 To cInputData.colFMF2.Count
   Set cFMF2 = cInputData.colFMF2(j)
   Select Case cFMF2.strCatName2

Case "C1"
If cYearData.strRC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
RCMembership(1) = Triangle(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
RCMembership(1) = trapezoid(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
         'Else
         'RCMembership(1) = 0
End If

      Case "C2"
If cYearData.strRC <> "" Then
Select Case cFMF2.strMemShape2
      Case "Tri"
RCMembership(2) = Triangle(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
```

```
RCMembership(2) = trapezoid(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'RCMembership(2) = 0
End If

Case "C3"
If cYearData.strRC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
RCMembership(3) = Triangle(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
RCMembership(3) = trapezoid(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'RCMembership(3) = 0
End If

Case "C4"
If cYearData.strRC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
RCMembership(4) = Triangle(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
RCMembership(4) = trapezoid(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'RCMembership(4) = 0
End If

Case "C5"
If cYearData.strRC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
RCMembership(5) = Triangle(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
RCMembership(5) = trapezoid(CDbl(cYearData.strRC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'RCMembership(5) = 0
End If
End Select

Next j

   For j = 1 To UBound(RCMembership)
        Set cFMF2 = cInputData.colFMF2(j)
        If cYearData.strRC <> "" Then
           rngRCMem(2 + 6 * (rvcnt) + j, yr + 1) = RCMembership(j)
           rngRCMem(2 + 6 * (rvcnt) + 1, 1) = "C1"
```

```
            rngRCMem(2 + 6 * (rvcnt) + 2, 1) = "C2"
            rngRCMem(2 + 6 * (rvcnt) + 3, 1) = "C3"
            rngRCMem(2 + 6 * (rvcnt) + 4, 1) = "C4"
            rngRCMem(2 + 6 * (rvcnt) + 5, 1) = "C5"
        Else
        rngRCMem(2 + 6 * (rvcnt) + j, yr + 1) = ""
        End If
    Next j

    'Store membership in class

     If cYearData.strRC <> "" Then
       cYearData.dRC1 = RCMembership(1)
       cYearData.dRC2 = RCMembership(2)
       cYearData.dRC3 = RCMembership(3)
       cYearData.dRC4 = RCMembership(4)
       cYearData.dRC5 = RCMembership(5)
    End If

ReDim RCMembership(Range("Otherfmf").Columns.Count - 1)

Next yr
    rngRCMem(2 + 6 * (rvcnt), 1) = cRiver.strName
    rvcnt = rvcnt + 1
End If

Next i

End Sub

Sub GetMembershipILC(ColRivers As Collection, ColFuzzyData2 As Collection)

'This sub function calculates the membership for the Interview or Local Comments

Dim rngOtherFMF As Range
Dim cRiver As cRiver
Dim cRiverdata As cRiverdata
Dim cYearData As cYearData
Dim cInputData As cInputData
Dim cFMF2 As cFMF2
Dim rngILCMem As Range
Dim i, j, yr, rvcnt As Integer
Dim ILCMembership() As Double

ReDim ILCMembership(Range("Otherfmf").Columns.Count - 1)
Set rngOtherFMF = Range("Otherfmf")
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
Set cInputData = New cInputData
Set cInputData = ColFuzzyData2(1)
Set rngILCMem = Range("ILCOutput")
rvcnt = 0      'river count

For i = 1 To ColRivers.Count
    Set cRiver = ColRivers(i)
    Set cRiverdata = cRiver.colRiverData(1)
    If cRiverdata.bolILC = True Then
```

```
For yr = 1 To cRiver.colYearData.Count

'loop through each year' RC comment data
      Set cYearData = cRiver.colYearData(yr)

For j = 1 To cInputData.colFMF2.Count
   Set cFMF2 = cInputData.colFMF2(j)
   Select Case cFMF2.strCatName2

Case "C1"
If cYearData.strILC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
ILCMembership(1) = Triangle(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
ILCMembership(1) = trapezoid(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
          'Else
          'ILCMembership(1) = 0
      End If

Case "C2"
If cYearData.strILC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
ILCMembership(2) = Triangle(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
ILCMembership(2) = trapezoid(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
         'Else
         'ILCMembership(2) = 0
End If

Case "C3"
If cYearData.strILC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
ILCMembership(3) = Triangle(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
ILCMembership(3) = trapezoid(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        I'LCMembership(3) = 0
End If

Case "C4"
If cYearData.strILC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
```

```
ILCMembership(4) = Triangle(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
ILCMembership(4) = trapezoid(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
        'Else
        'ILCMembership(4) = 0
End If
```

Case "C5"

```
If cYearData.strILC <> "" Then
Select Case cFMF2.strMemShape2
Case "Tri"
ILCMembership(5) = Triangle(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c)
Case "Trap"
ILCMembership(5) = trapezoid(CDbl(cYearData.strILC), cFMF2.intFMF2a, cFMF2.intFMF2b,
cFMF2.intFMF2c, cFMF2.intFMF2d)
End Select
       'Else
       'ILCMembership(5) = 0
End If
End Select

Next j

   For j = 1 To UBound(ILCMembership)
         Set cFMF2 = cInputData.colFMF2(j)
         If cYearData.strILC <> "" Then
            rngILCMem(2 + 6 * (rvcnt) + j, yr + 1) = ILCMembership(j)
            rngILCMem(2 + 6 * (rvcnt) + 1, 1) = "C1"
            rngILCMem(2 + 6 * (rvcnt) + 2, 1) = "C2"
            rngILCMem(2 + 6 * (rvcnt) + 3, 1) = "C3"
            rngILCMem(2 + 6 * (rvcnt) + 4, 1) = "C4"
            rngILCMem(2 + 6 * (rvcnt) + 5, 1) = "C5"
         Else
         rngILCMem(2 + 6 * (rvcnt) + j, yr + 1) = ""
         End If
   Next j
          'Store membership in class
   If cYearData.strILC <> "" Then
      cYearData.dILC1 = ILCMembership(1)
      cYearData.dILC2 = ILCMembership(2)
      cYearData.dILC3 = ILCMembership(3)
      cYearData.dILC4 = ILCMembership(4)
      cYearData.dILC5 = ILCMembership(5)
   End If

ReDim ILCMembership(Range("Otherfmf").Columns.Count - 1)

Next yr
    rngILCMem(2 + 6 * (rvcnt), 1) = cRiver.strName
    rvcnt = rvcnt + 1
End If

Next i
```

```
End Sub

Public CF() As Double                          ‘Get confidence factor from table
Public dCAFinalMem() As Double
Public dCPUEFinalMem() As Double
Public dTFFinalMem() As Double
Public dSSBFinalMem() As Double
Public dLSFinalMem() As Double
Public dRCFinalMem() As Double
Public dILCFinalMem() As Double
Public FinalMembership() As Double
Public ABDN() As Double                        'ABDN(abundance level, data type)
Sub ReadCF()
Dim rngCF As Range
Dim i As Integer
Set rngCF = Range("rngCF")
ReDim CF(rngCF.Rows.Count)

For i = 1 To rngCF.Rows.Count
   CF(rngCF(i, 1)) = rngCF(i, 2)
Next

End Sub
```

```
Public Sub Reasoning(ColRivers As Collection)
Dim rngData As Range
Dim cRiver As cRiver                           'name the business objects for later use
Dim cYearData As cYearData
Dim cRiverdata As cRiverdata
Dim LETemp As Integer
Dim CAMemTemp() As Double
Dim CPUEMemTemp() As Double
Dim TFMemTemp() As Double
Dim LSMemTemp() As Double
Dim SSBMemTemp() As Double
Dim RCMemTemp() As Double
Dim ILCMemTemp() As Double
Dim RngResults As Range
Dim FinalAbd As Double
Dim SumMemTemp As Double

Set RngResults = Range("rngresults")
RngResults.ClearContents
Set cRiver = New cRiver
Set cRiverdata = New cRiverdata
Set cYearData = New cYearData
Dim i, j, k, yr, rvcnt As Integer

For i = 1 To RngResults.Columns.Count
   RngResults(1, i + 1) = 1877 + i
Next i
rvcnt = 0
For i = 1 To ColRivers.Count                   'loop by river
   Set cRiver = ColRivers(i)
   Set cRiverdata = cRiver.colRiverData(1)

   For yr = 1 To cRiver.colYearData.Count       'loop by year
```

```
  Set cYearData = cRiver.colYearData(yr)
  FinalAbd = 0: SumMemTemp = 0

  ReDim CAMemTemp(6)
  ReDim CPUEMemTemp(5)
  ReDim TFMemTemp(5)
  ReDim LSMemTemp(5)
  ReDim SSBMemTemp(5)
  ReDim RCMemTemp(5)
  ReDim ILCMemTemp(5)

  If cYearData.strLE = "1" Then                    'get whether LE is true or not
     LETemp = 1
  ElseIf cYearData.strLE = "" Then
     LETemp = 0
  End If

  'store membership in temp variables
  'For j = 1 To 5

CAMemTemp(1) = cYearData.dC1
  CAMemTemp(2) = cYearData.dC2
  CAMemTemp(3) = cYearData.dC3
  CAMemTemp(4) = cYearData.dC4
  CAMemTemp(5) = cYearData.dC5
  CAMemTemp(6) = cYearData.dC6

CPUEMemTemp(1) = cYearData.dCPUE1
  CPUEMemTemp(2) = cYearData.dCPUE2
  CPUEMemTemp(3) = cYearData.dCPUE3
  CPUEMemTemp(4) = cYearData.dCPUE4
  CPUEMemTemp(5) = cYearData.dCPUE5

LSMemTemp(1) = cYearData.dLS1
  LSMemTemp(2) = cYearData.dLS2
  LSMemTemp(3) = cYearData.dLS3
  LSMemTemp(4) = cYearData.dLS4
  LSMemTemp(5) = cYearData.dLS5

SSBMemTemp(1) = cYearData.dSSB1
  SSBMemTemp(2) = cYearData.dSSB2
  SSBMemTemp(3) = cYearData.dSSB3
  SSBMemTemp(4) = cYearData.dSSB4
  SSBMemTemp(5) = cYearData.dSSB5

TFMemTemp(1) = cYearData.dTF1
  TFMemTemp(2) = cYearData.dTF2
  TFMemTemp(3) = cYearData.dTF3
  TFMemTemp(4) = cYearData.dTF4
  TFMemTemp(5) = cYearData.dTF5

RCMemTemp(1) = cYearData.dRC1
  RCMemTemp(2) = cYearData.dRC2
  RCMemTemp(3) = cYearData.dRC3
  RCMemTemp(4) = cYearData.dRC4
  RCMemTemp(5) = cYearData.dRC5

ILCMemTemp(1) = cYearData.dILC1
```

```
      ILCMemTemp(2) = cYearData.dILC2
      ILCMemTemp(3) = cYearData.dILC3
      ILCMemTemp(4) = cYearData.dILC4
      ILCMemTemp(5) = cYearData.dILC5

      'repeat with other data types
      'Next

      Call Rules(CAMemTemp(), CPUEMemTemp(), SSBMemTemp(), TFMemTemp(), LSMemTemp(),
RCMemTemp(), ILCMemTemp(), LETemp)

      For j = 1 To 5
         RngResults(2 + 7 * (rvcnt) + j, yr + 1) = FinalMembership(j - 1)
         SumMemTemp = SumMemTemp + FinalMembership(j - 1)                    'is the sum of all
memberships
      Next j
      If SumMemTemp > 0 Then                                                 'if sum is greater than 0 then...
         FinalAbd = FinalMembership(0) * 100 + FinalMembership(1) * 75 + FinalMembership(2) * 50 +
FinalMembership(3) * 25 + FinalMembership(4) * 1
         FinalAbd = FinalAbd / SumMemTemp
      Else
         FinalAbd = 0
      End If

     RngResults(2 + 7 * (rvcnt) + 1, 1) = "ABDN1"
      RngResults(2 + 7 * (rvcnt) + 2, 1) = "ABDN2"
      RngResults(2 + 7 * (rvcnt) + 3, 1) = "ABDN3"
      RngResults(2 + 7 * (rvcnt) + 4, 1) = "ABDN4"
      RngResults(2 + 7 * (rvcnt) + 5, 1) = "ABDN5"
      RngResults(2 + 7 * (rvcnt) + 6, 1) = "Final"

      If FinalAbd > 0 Then                                                   'Store final abundance
membership to FinalAbd()
         RngResults(2 + 7 * (rvcnt) + 6, yr + 1) = FinalAbd                  'Print FinalAbd() on worksheet
      Else
         RngResults(2 + 7 * (rvcnt) + 6, yr + 1) = ""
      End If

   Next yr
   RngResults(2 + 7 * (rvcnt), 1) = cRiver.strName
   rvcnt = rvcnt + 1
Next i

End Sub

Public Sub Rules(CAMembership() As Double, CPUEMembership() As Double, SSBMembership() As
Double, TFMembership() As Double, LSMembership() As Double, RCMembership() As Double,
ILCMembership() As Double, LE As Integer)

'shift membership according to rule matrices      Or = Max function    And = Min function

Dim i As Integer
Dim ConfRCILC(5) As Double
ReDim FinalMembership(5)
ReDim ABDN(4, 14)

For i = 1 To 5
```

```
   If RCMembership(i) * CF(6) > ILCMembership(i) * CF(7) Then
        ConfRCILC(i) = RCMembership(i)
   Else
        ConfRCILC(i) = ILCMembership(i)
   End If

Next i

If WorksheetFunction.Max(RCMembership(1), RCMembership(2), RCMembership(3),
RCMembership(4), RCMembership(5)) * CF(6) > 0 Or WorksheetFunction.Max(ILCMembership(1),
ILCMembership(2), ILCMembership(3), ILCMembership(4), ILCMembership(5)) > 0 Then

      'If RC Is L Then ABDN = L
      ABDN(4, 6) = RCMembership(5) * CF(6)
      'If RC Is ML Then ABDN = ML
      ABDN(3, 6) = RCMembership(4) * CF(6)
      'If RC Is M Then ABDN = M
      ABDN(2, 6) = RCMembership(3) * CF(6)
      'If RC Is MH Then ABDN = MH
      ABDN(1, 6) = RCMembership(2) * CF(6)
      'If RC Is H Then ABDN = H
      ABDN(0, 6) = RCMembership(1) * CF(6)

        'If ILC Is L Then ABDN = L
      ABDN(4, 7) = ILCMembership(5) * CF(7)
      'If ILC Is ML Then ABDN = ML
      ABDN(3, 7) = ILCMembership(4) * CF(7)
      'If ILC Is M Then ABDN = M
      ABDN(2, 7) = ILCMembership(3) * CF(7)
      'If ILC Is MH Then ABDN = MH
      ABDN(1, 7) = ILCMembership(2) * CF(7)
      'If ILC Is H Then ABDN = H
      ABDN(0, 7) = ILCMembership(1) * CF(7)
```

```
 'rules when RC or ILC exist and LS exists AND = min   OR = max

ABDN(4, 9) = WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(5), LSMembership(4),
LSMembership(3)), ConfRCILC(5)) * CF(9)
ABDN(3, 9) = WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(2), LSMembership(1)),
ConfRCILC(5)) * CF(9)
ABDN(3, 9) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(5),
LSMembership(4), LSMembership(3)), ConfRCILC(4)) * CF(9), ABDN(3, 9))
ABDN(2, 9) = WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(2), LSMembership(1)),
ConfRCILC(4)) * CF(9)
ABDN(3, 9) = WorksheetFunction.Max(WorksheetFunction.Min(LSMembership(5), ConfRCILC(3)) *
CF(9), ABDN(3, 9))
ABDN(2, 9) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(4),
LSMembership(3), LSMembership(2), LSMembership(1)), ConfRCILC(3)) * CF(9), ABDN(2, 9))
ABDN(2, 9) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(5),
LSMembership(4)), ConfRCILC(2)) * CF(9), ABDN(2, 9))
ABDN(1, 9) = WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(3), LSMembership(2),
LSMembership(1)), ConfRCILC(2)) * CF(9)
```

```
ABDN(2, 9) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(5),
LSMembership(4)), ConfRCILC(1)) * CF(9), ABDN(2, 9))
ABDN(1, 9) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(LSMembership(3),
LSMembership(2)), ConfRCILC(1)) * CF(9), ABDN(1, 9))
ABDN(0, 9) = WorksheetFunction.Min(LSMembership(1), ConfRCILC(1)) * CF(9)
```

```
'Rules when SSB and RC or ILC exist

ABDN(4, 10) = WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(5),
SSBMembership(4), SSBMembership(3)), ConfRCILC(5)) * CF(10)
ABDN(3, 10) = WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(2),
SSBMembership(1)), ConfRCILC(5)) * CF(10)
ABDN(3, 10) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(5),
SSBMembership(4), SSBMembership(3)), ConfRCILC(4)) * CF(10), ABDN(3, 10))
ABDN(2, 10) = WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(2),
SSBMembership(1)), ConfRCILC(4)) * CF(10)
ABDN(3, 10) = WorksheetFunction.Max(WorksheetFunction.Min(SSBMembership(5), ConfRCILC(3)) *
CF(10), ABDN(3, 10))
ABDN(2, 10) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(4),
SSBMembership(3), SSBMembership(2), SSBMembership(1)), ConfRCILC(3)) * CF(10), ABDN(2, 10))
ABDN(2, 10) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(5),
SSBMembership(4)), ConfRCILC(2)) * CF(10), ABDN(2, 10))
ABDN(1, 10) = WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(3),
SSBMembership(2), SSBMembership(1)), ConfRCILC(2)) * CF(10)
ABDN(2, 10) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(5),
SSBMembership(4)), ConfRCILC(1)) * CF(10), ABDN(2, 10))
ABDN(1, 10) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(SSBMembership(3),
SSBMembership(2)), ConfRCILC(1)) * CF(10), ABDN(1, 10))
ABDN(0, 10) = WorksheetFunction.Min(LSMembership(1), ConfRCILC(1)) * CF(10)
```

```
'Rules when TF and RC or ILC exist

ABDN(4, 11) = WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(5), TFMembership(4),
TFMembership(3)), ConfRCILC(5)) * CF(11)
ABDN(3, 11) = WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(2), TFMembership(1)),
ConfRCILC(5)) * CF(11)
ABDN(3, 11) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(5),
TFMembership(4), TFMembership(3)), ConfRCILC(4)) * CF(11), ABDN(3, 11))
ABDN(2, 11) = WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(2), TFMembership(1)),
ConfRCILC(4)) * CF(11)
ABDN(3, 11) = WorksheetFunction.Max(WorksheetFunction.Min(TFMembership(5), ConfRCILC(3)) *
CF(11), ABDN(3, 11))
ABDN(2, 11) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(4),
TFMembership(3), TFMembership(2), TFMembership(1)), ConfRCILC(3)) * CF(11), ABDN(2, 11))
```

```
ABDN(2, 11) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(5),
TFMembership(4)), ConfRCILC(2)) * CF(11), ABDN(2, 11))
ABDN(1, 11) = WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(3), TFMembership(2),
TFMembership(1)), ConfRCILC(2)) * CF(11)
ABDN(2, 11) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(5),
TFMembership(4)), ConfRCILC(1)) * CF(11), ABDN(2, 11))
ABDN(1, 11) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(TFMembership(3),
TFMembership(2)), ConfRCILC(1)) * CF(11), ABDN(1, 11))
ABDN(0, 11) = WorksheetFunction.Min(TFMembership(1), ConfRCILC(1)) * CF(11)
```

```
'Rules when CPUE and  RC or ILC exist

ABDN(4, 12) = WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(5),
CPUEMembership(4), CPUEMembership(3)), ConfRCILC(5)) * CF(12)
ABDN(3, 12) = WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(2),
CPUEMembership(1)), ConfRCILC(5)) * CF(12)
ABDN(3, 12) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(5),
CPUEMembership(4), CPUEMembership(3)), ConfRCILC(4)) * CF(12), ABDN(3, 12))
ABDN(2, 12) = WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(2),
CPUEMembership(1)), ConfRCILC(4)) * CF(12)
ABDN(3, 12) = WorksheetFunction.Max(WorksheetFunction.Min(CPUEMembership(5), ConfRCILC(3)) *
CF(12), ABDN(3, 12))
ABDN(2, 12) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(4),
CPUEMembership(3), CPUEMembership(2), CPUEMembership(1)), ConfRCILC(3)) * CF(12), ABDN(2,
12))
ABDN(2, 12) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(5),
CPUEMembership(4)), ConfRCILC(2)) * CF(12), ABDN(2, 12))
ABDN(1, 12) = WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(3),
CPUEMembership(2), CPUEMembership(1)), ConfRCILC(2)) * CF(12)
ABDN(2, 12) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(5),
CPUEMembership(4)), ConfRCILC(1)) * CF(12), ABDN(2, 12))
ABDN(1, 12) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CPUEMembership(3),
CPUEMembership(2)), ConfRCILC(1)) * CF(12), ABDN(1, 12))
ABDN(0, 12) = WorksheetFunction.Min(CPUEMembership(1), ConfRCILC(1)) * CF(12)
```

```
'When LE, RC/ILC AND CA exist                    Or = Max function    And = Min function

        If LE = 1 Then

        ReDim CAMemTemp(6)

        CAMemTemp(4) = WorksheetFunction.Max(CAMembership(5), CAMembership(6)) * CF(0)
        ABDN(3, 1) = WorksheetFunction.Max(CAMembership(5), CAMembership(6)) * CF(0)

        CAMemTemp(3) = CAMembership(4) * CF(0)
        ABDN(2, 1) = CAMembership(4) * CF(0)

        CAMemTemp(2) = WorksheetFunction.Max(CAMembership(2), CAMembership(3)) * CF(0)
        ABDN(1, 1) = WorksheetFunction.Max(CAMembership(2), CAMembership(3)) * CF(0)
```

```
        CAMemTemp(1) = CAMembership(1) * CF(0)
        ABDN(0, 1) = CAMembership(1) * CF(0)

ABDN(3, 13) = WorksheetFunction.Min(CAMemTemp(6), ConfRCILC(5)) * CF(13)
ABDN(4, 13) = WorksheetFunction.Min(CAMemTemp(4), ConfRCILC(5)) * CF(13)
ABDN(3, 13) = WorksheetFunction.Max(WorksheetFunction.Min(CAMemTemp(3), ConfRCILC(5)) *
CF(13), ABDN(3, 13))
ABDN(2, 13) = WorksheetFunction.Min(WorksheetFunction.Max(CAMemTemp(2), CAMemTemp(1)),
ConfRCILC(5)) * CF(13)
ABDN(3, 13) = WorksheetFunction.Max(WorksheetFunction.Min(CAMemTemp(6), CAMemTemp(4),
CAMemTemp(3), ConfRCILC(4)) * CF(13), ABDN(3, 13))
ABDN(2, 13) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMemTemp(2),
CAMemTemp(1)), ConfRCILC(4)) * CF(13), ABDN(2, 13))
ABDN(2, 13) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMemTemp(6),
CAMemTemp(4), CAMemTemp(3), CAMemTemp(2)), ConfRCILC(3)) * CF(13), ABDN(2, 13))
ABDN(1, 13) = WorksheetFunction.Min(CAMemTemp(1), ConfRCILC(3)) * CF(13)
ABDN(2, 13) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMemTemp(6),
CAMemTemp(4)), ConfRCILC(2)) * CF(13), ABDN(2, 13))
ABDN(1, 13) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMemTemp(3),
CAMemTemp(2), CAMemTemp(1)), ConfRCILC(2)) * CF(13), ABDN(1, 13))
ABDN(2, 13) = WorksheetFunction.Max(WorksheetFunction.Min(CAMemTemp(6), ConfRCILC(1)) *
CF(13), ABDN(2, 13))
ABDN(1, 13) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMemTemp(3),
CAMemTemp(4)), ConfRCILC(1)) * CF(13), ABDN(1, 13))
ABDN(0, 13) = WorksheetFunction.Min(WorksheetFunction.Max(CAMemTemp(1), CAMemTemp(2)),
ConfRCILC(1)) * CF(13)
```

```
        Else

'Abundance changes if catch and RC/ILC occur but not LE                AND = min     OR = max

ABDN(4, 8) = WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(5), CAMembership(4)),
ConfRCILC(5)) * CF(8)
ABDN(3, 8) = WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(3), CAMembership(2)),
ConfRCILC(5)) * CF(8)
ABDN(2, 8) = WorksheetFunction.Min(CAMembership(1), ConfRCILC(5)) * CF(8)
ABDN(3, 8) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(5),
CAMembership(4), CAMembership(3)), ConfRCILC(4)) * CF(8), ABDN(3, 8))
ABDN(2, 8) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(2),
CAMembership(1)), ConfRCILC(4)) * CF(8), ABDN(2, 8))
ABDN(2, 8) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(5),
CAMembership(4), CAMembership(3), CAMembership(2)), ConfRCILC(3)) * CF(8), ABDN(2, 8))
ABDN(1, 8) = WorksheetFunction.Min(CAMembership(1), ConfRCILC(3)) * CF(8)
ABDN(2, 8) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(5),
CAMembership(4)), ConfRCILC(2)) * CF(8), ABDN(2, 8))
```

```
ABDN(1, 8) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(3),
CAMembership(2), CAMembership(1)), ConfRCILC(2)) * CF(8), ABDN(1, 8))
ABDN(2, 8) = WorksheetFunction.Max(WorksheetFunction.Min(CAMembership(5), ConfRCILC(2)) *
CF(8), ABDN(2, 8))
ABDN(1, 8) =
WorksheetFunction.Max(WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(4),
CAMembership(3)), ConfRCILC(1)) * CF(8), ABDN(1, 8))
ABDN(0, 8) = WorksheetFunction.Min(WorksheetFunction.Max(CAMembership(2), CAMembership(1)),
ConfRCILC(1)) * CF(8)

        End If

Else    'NO RC or ILC exist     'RULE SET 1 (YES LOW EFFORT)

        If LE = 1 Then

        ABDN(3, 1) = WorksheetFunction.Max(CAMembership(5), CAMembership(6)) * CF(0)
        ABDN(2, 1) = WorksheetFunction.Max(CAMembership(4), CAMembership(6)) * CF(0)
        ABDN(1, 1) = WorksheetFunction.Max(CAMembership(2), CAMembership(3)) * CF(0)
        ABDN(0, 1) = CAMembership(1) * CF(0)


        Else    'RULES SET FOR Catch with NO LOW EFFORT

ABDN(4, 1) = CAMembership(5) * CF(1) 'If CA Is L Then ABDN L
        ABDN(3, 1) = CAMembership(5) * CF(1) 'If CA Is ML Then ABDN L
        ABDN(3, 1) = WorksheetFunction.Max(ABDN(3, 1), CAMembership(4)) * CF(1)
        ABDN(2, 1) = CAMembership(4) * CF(1)
        ABDN(2, 1) = WorksheetFunction.Max(CAMembership(3), ABDN(2, 1)) * CF(1)
         ABDN(2, 1) = WorksheetFunction.Max(CAMembership(2), ABDN(2, 1)) * CF(1)
        ABDN(1, 1) = CAMembership(2) * CF(1)
        ABDN(0, 1) = CAMembership(1) * CF(1)

        End If

        ABDN(4, 4) = LSMembership(5) * CF(4)
        ABDN(3, 4) = LSMembership(4) * CF(4)
        ABDN(2, 4) = LSMembership(3) * CF(4)
        ABDN(1, 4) = LSMembership(2) * CF(4)
        ABDN(0, 4) = LSMembership(1) * CF(4)

        ABDN(4, 3) = SSBMembership(5) * CF(3)
        ABDN(3, 3) = SSBMembership(4) * CF(3)
        ABDN(2, 3) = SSBMembership(3) * CF(3)
        ABDN(1, 3) = SSBMembership(2) * CF(3)
        ABDN(0, 3) = SSBMembership(1) * CF(3)

        ABDN(4, 5) = TFMembership(5) * CF(5)
        ABDN(3, 5) = TFMembership(4) * CF(5)
        ABDN(2, 5) = TFMembership(3) * CF(5)
        ABDN(1, 5) = TFMembership(2) * CF(5)
        ABDN(0, 5) = TFMembership(1) * CF(5)

        ABDN(4, 2) = CPUEMembership(5) * CF(2)
        ABDN(3, 2) = CPUEMembership(4) * CF(2)
        ABDN(2, 2) = CPUEMembership(3) * CF(2)
        ABDN(1, 2) = CPUEMembership(2) * CF(2)
```

```
        ABDN(0, 2) = CPUEMembership(1) * CF(2)

End If

For i = 0 To 4

FinalMembership(i) = MYCIN(ABDN(i, 0), ABDN(i, 1), ABDN(i, 2), ABDN(i, 3), ABDN(i, 4), ABDN(i, 5),
ABDN(i, 8), ABDN(i, 9), ABDN(i, 10), ABDN(i, 11), ABDN(i, 12), ABDN(i, 13))                    '
Abundance level/data type

Next i

If WorksheetFunction.Max(FinalMembership(0), FinalMembership(1), FinalMembership(2),
FinalMembership(3), FinalMembership(4)) = 0 Then

        ABDN(4, 6) = RCMembership(5) * CF(6)
        ABDN(3, 6) = RCMembership(4) * CF(6)
        ABDN(2, 6) = RCMembership(3) * CF(6)
        ABDN(1, 6) = RCMembership(2) * CF(6)
        ABDN(0, 6) = RCMembership(1) * CF(6)

        ABDN(4, 7) = ILCMembership(5) * CF(7)
        ABDN(3, 7) = ILCMembership(4) * CF(7)
        ABDN(2, 7) = ILCMembership(3) * CF(7)
        ABDN(1, 7) = ILCMembership(2) * CF(7)
        ABDN(0, 7) = ILCMembership(1) * CF(7)

For i = 0 To 4
       FinalMembership(i) = MYCIN(ABDN(i, 6), ABDN(i, 7)) ' Abundance level/data type
Next i

End If

End Sub

Sub colcol()
Rem colors sell interior according cell value
Rem color scale here entered inside subroutine to use flexibly
Rem this version conceals the cell contents by colouring same as background

Dim colscale(11)
colscale(1) = 3: colscale(2) = 46: colscale(3) = 45: colscale(4) = 44: colscale(5) = 36
colscale(6) = 20: colscale(7) = 37: colscale(8) = 41: colscale(9) = 32: colscale(10) = 25
colscale(11) = 25

For i = 3 To 17
For j = 3 To 134

vali = Worksheets("FINAL").Cells(i, j).Value
If vali > 10 Then col = Null: GoTo skip
If vali < 0 Then col = Null: GoTo skip
If vali = "" Then col = 2: GoTo skip
If vali = 0 Then col = 2: GoTo skip
If vali < 0 > 1 Then col = 3: GoTo skip
vali = Int(vali + 0.01) + 1
col = colscale(vali)
skip: Worksheets("FINAL").Cells(i, j).Interior.ColorIndex = col
```

```
Worksheets("FINAL").Cells(i, j).Font.ColorIndex = col

Next j
Next i
End Sub
```

APPENDIX 9: RESULTS FROM CORRELATION ANALYSIS

Shrimp Results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.220588	0.096753	-0.333683	-0.318015	-0.17019	0.0257	-0.51793
Correlation (corrected)	0.220588	0.093812	-0.379291	-0.409614	-0.21522	0.022895	-0.5252
t-Test (n>10)	0.875911	0.410726	-2.354819	-1.73901	-1.16616	0.131556	-3.54534
Degrees of Freedom	15	19	33	15	28	33	33
Critical 2-sided T-value (5%)	2.131	2.093	2.042	2.131	2.048	2.042	2.042
Critical 1-sided T-value (5%)	1.753	1.729	1.697	1.753	1.701	1.697	1.697
D-square value (calculated)	636	1391	9522.5	1075.5	5260	6956.5	10838
D-square value (expected)	816	1540	7140	816	4495	7140	7140
Standard Deviation	204	344.3545	1224.499898	204	834.7005	1224.5	1224.5
z-Test	-0.88235	-0.43269	1.945692	1.272059	0.916496	-0.14986	3.020008
Probability	0.3734	0.66	0.0512	0.2006	0.3576	0.8808	0.0024
Observations	17	21	35	17	30	35	35
COD	0.048659	0.008801	0.143861663	0.1677836	0.04632	0.000524	0.275831

Shrimp Results	2 Year lag						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.332143	-0.18816	-0.486547	-0.011607	-0.54105	-0.15099	-0.66076
Correlation (corrected)	0.332143	-0.19287	-0.54763	-0.099304	-0.61509	-0.15494	-0.66886
t-Test (n>10)	1.269637	-0.81043	-3.644076	-0.359823	-3.97783	-0.87323	-5.00953
Degrees of Freedom	13	17	31	13	26	31	31
Critical 2-sided T-value (5%)	2.16	2.11	2.042	2.16	2.056	2.042	2.042
Critical 1-sided T-value (5%)	1.771	1.74	1.697	1.771	1.706	1.697	1.697
D-square value (calculated)	374	1354.5	8895.5	566.5	5631	6887.5	9938
D-square value (expected)	560	1140	5984	560	3654	5984	5984
Standard Deviation	149.6663	268.7006	1057.831745	149.6663	703.2126	1057.832	1057.832
z-Test	-1.24277	0.798286	2.752328	0.04343	2.811383	0.854106	3.737835
Probability	0.2112	0.4238	0.0058	0.9602	0.0048	0.3898	0.0002
Observations	15	19	33	15	28	33	33
COD	0.110319	0.037198	0.299898617	0.0098613	0.378334	0.024007	0.44737

Shrimp Results	3 Year lag						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.557143	-0.50044	-0.514571	0.102679	-0.52627	-0.30269	-0.6382
Correlation (corrected)	0.557143	-0.50639	-0.583175	0.025313	-0.59959	-0.30761	-0.64605
t-Test (n>10)	2.419035	-2.42129	-3.932038	0.091296	-3.82018	-1.7707	-4.63587
Degrees of Freedom	13	17	30	13	26	30	30
Critical 2-sided T-value (5%)	2.16	2.11	2.042	2.16	2.056	2.042	2.042
Critical 1-sided T-value (5%)	1.771	1.74	1.697	1.771	1.706	1.697	1.697
D-square value (calculated)	248	1710.5	8263.5	502.5	5577	7107.5	8938
D-square value (expected)	560	1140	5456	560	3654	5456	5456
Standard Deviation	149.6663	268.7006	979.926528	149.6663	703.2126	979.9265	979.9265
z-Test	-2.08464	2.123181	2.865011	-0.384188	2.734593	1.68533	3.553328
Probability	0.0366	0.0332	0.0042	0.6966	0.0062	0.091	0.0004
Observations	15	19	32	15	28	32	32
COD	0.310408	0.25643	0.340093081	0.0006407	0.359508	0.094623	0.417377

HakeB Results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.25692	0.697174	0.551829	0.347368	0.502252	0.289852	0.623563
Correlation (corrected)	-0.26128	0.69572	0.54107	0.315587	0.487069	0.287867	0.622132
t-Test (n>10)	-1.24042	4.542892	4.017918	1.371276	3.251879	1.87719	4.962516
Degrees of Freedom	21	22	39	17	34	39	39
Critical 2-sided T-value (5%)	2.08	2.074	2.042	2.11	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.721	1.717	1.697	1.74	1.697	1.697	1.697
D-square value (calculated)	2544	696.5	5145	744	3867.5	8152.5	4321.5
D-square value (expected)	2024	2300	11480	1140	7770	11480	11480
Standard Deviation	431.5183	479.5832	1815.147377	268.70058	1313.37	1815.147	1815.1474
z-Test	1.205048	-3.34353	-3.490075	-1.473759	-2.971364	-1.83318	-3.943757
Probability	0.2262	0.0008	0.0004	0.1388	0.0028	0.0658	0
Observations	23	24	41	19	36	41	41
COD	0.068267	0.484026	0.292756745	0.0995952	0.237236	0.082867	0.3870482

HakeB Results	2 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.31299	0.716087	0.478239	0.069143	0.480948	0.285374	0.676215
Correlation (corrected)	-0.31769	0.714411	0.464228	0.013149	0.461909	0.283089	0.674801
t-Test (n>10)	-1.46046	4.788852	3.188147	0.0526	2.804575	1.795407	5.561868
Degrees of Freedom	19	22	37	16	29	37	37
Critical 2-sided T-value (5%)	2.093	2.074	2.042	2.12	2.045	2.042	2.042
Critical 1-sided T-value (5%)	1.729	1.717	1.697	1.746	1.699	1.697	1.697
D-square value (calculated)	2022	653	5155	902	2574.5	7060.5	3199
D-square value (expected)	1540	2300	9880	969	4960	9880	9880
Standard Deviation	344.3545	479.5832	1602.747641	235.01702	905.568	1602.748	1602.7476
z-Test	1.39972	-3.43423	-2.948062	-0.285086	-2.634258	-1.75917	-4.168467
Probability	0.1616	0.0006	0.0032	0.7718	0.0082	0.0784	0
Observations	21	24	39	18	31	39	39
COD	0.100929	0.510383	0.215507636	0.0001729	0.21336	0.080139	0.4553564

HakeB Results	3 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.32669	0.731957	0.438779	0.210526	0.567155	0.096619	0.611062
Correlation (corrected)	-0.32919	0.730729	0.422915	0.163264	0.548234	0.093644	0.609226
t-Test (n>10)	-1.47908	5.020637	2.800236	0.661938	3.27764	0.564342	4.609547
Degrees of Freedom	18	22	36	16	25	36	36
Critical 2-sided T-value (5%)	2.101	2.074	2.042	2.12	2.06	2.042	2.042
Critical 1-sided T-value (5%)	1.734	1.717	1.697	1.746	1.708	1.697	1.697
D-square value (calculated)	1764.5	616.5	5129	765	1418	8256	3554.5
D-square value (expected)	1330	2300	9139	969	3276	9139	9139
Standard Deviation	305.1229	479.5832	1502.442345	235.01702	642.4765	1502.442	1502.4423
z-Test	1.424016	-3.51034	-2.668988	-0.868022	-2.891935	-0.58771	-3.716948
Probability	0.1528	0.0004	0.0076	0.3844	0.0038	0.5552	0.0002
Observations	20	24	38	18	27	38	38
COD	0.108367	0.533965	0.178857097	0.0266551	0.300561	0.008769	0.3711563

Hake total catch results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.289102	-0.28483	-0.329034	-0.356553	-0.328291	-0.03476	-0.407927
Correlation (corrected)	0.288701	-0.28897	-0.360858	-0.413035	-0.366326	-0.03685	-0.412367
t-Test (n>10)	1.34853	-1.38325	-2.385188	-1.814113	-2.261593	-0.2273	-2.79029
Degrees of Freedom	20	21	38	16	33	38	38
Critical 2-sided T-value (5%)	2.086	2.08	2.042	2.12	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.725	1.721	1.697	1.746	1.697	1.697	1.697
D-square value (calculated)	1259	2600.5	14167.5	1314.5	9484	11030.5	15008.5
D-square value (expected)	1771	2024	10660	969	7140	10660	10660
Standard Deviation	386.4639	431.5183	1706.96612	235.01702	1224.5	1706.966	1706.9661
z-Test	-1.32483	1.335981	2.054815	1.470106	1.914251	0.217052	2.547502
Probability	0.1836	0.1802	0.0394	0.1388	0.0548	0.8258	0.0108
Observations	22	23	40	18	35	40	40
COD	0.083348	0.083505	0.130218496	0.1705979	0.134195	0.001358	0.1700465

Hake total catch results	2 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.190602	-0.27989	-0.315625	-0.130515	-0.397226	-0.17436	-0.443976
Correlation (corrected)	0.190297	-0.28402	-0.350852	-0.186724	-0.444543	-0.17713	-0.449292
t-Test (n>10)	0.82239	-1.35743	-2.248019	-0.736127	-2.763149	-1.07987	-3.017458
Degrees of Freedom	18	21	36	15	31	36	36
Critical 2-sided T-value (5%)	2.101	2.08	2.042	2.131	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.734	1.721	1.697	1.753	1.697	1.697	1.697
D-square value (calculated)	1076.5	2590.5	12023.5	922.5	8361	10732.5	13196.5
D-square value (expected)	1330	2024	9139	816	5984	9139	9139
Standard Deviation	305.1229	431.5183	1502.442345	204	1057.832	1502.442	1502.4423
z-Test	-0.83081	1.312807	1.919874	0.522059	2.247049	1.060606	2.700603
Probability	0.4008	0.1868	0.0548	0.5962	0.0244	0.2846	0.0068
Observations	20	23	38	17	33	38	38
COD	0.036213	0.080665	0.123097126	0.0348659	0.197618	0.031376	0.2018633

Hake total catch results	3 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.110526	-0.43355	-0.498815	-0.103554	-0.441624	-0.28141	-0.440671
Correlation (corrected)	0.110526	-0.43817	-0.541036	-0.158394	-0.487528	-0.28446	-0.446418
t-Test (n>10)	0.458521	-2.23379	-3.805966	-0.621299	-3.05839	-1.7554	-2.951469
Degrees of Freedom	17	21	35	15	30	35	35
Critical 2-sided T-value (5%)	2.11	2.08	2.042	2.131	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.74	1.721	1.697	1.753	1.697	1.697	1.697
D-square value (calculated)	1014	2901.5	12644	900.5	7865.5	10810	12153.5
D-square value (expected)	1140	2024	8436	816	5456	8436	8436
Standard Deviation	268.7006	431.5183	1406	204	979.9265	1406	1406
z-Test	-0.46892	2.033518	2.992888	0.414216	2.458858	1.688478	2.644026
Probability	0.6384	0.0414	0.0026	0.6744	0.0138	0.091	0.008
Observations	19	23	37	17	32	37	37
COD	0.012216	0.191991	0.292719953	0.0250887	0.237684	0.080917	0.199289

Hake CAN CA results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.298701	0.062994	-0.163274	-0.416409	-0.210364	-0.11327	-0.512054
Correlation (corrected)	0.298305	0.059976	-0.191093	-0.475421	-0.244986	-0.11552	-0.516824
t-Test (n>10)	1.397697	0.275338	-1.200093	-2.161595	-1.451571	-0.71694	-3.721465
Degrees of Freedom	20	21	38	16	33	38	38
Critical 2-sided T-value (5%)	2.086	2.08	2.042	2.12	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.725	1.721	1.697	1.746	1.697	1.697	1.697
D-square value (calculated)	1242	1896.5	12400.5	1372.5	8642	11867.5	16118.5
D-square value (expected)	1771	2024	10660	969	7140	10660	10660
Standard Deviation	386.4639	431.5183	1706.96612	235.01702	1224.5	1706.966	1706.9661
z-Test	-1.36882	-0.29547	1.019645	1.716897	1.226623	0.707395	3.197779
Probability	0.1706	0.7642	0.3078	0.0854	0.2186	0.4776	0.0014
Observations	22	23	40	18	35	40	40
COD	0.088986	0.003597	0.036516535	0.2260251	0.060018	0.013346	0.267107

Hake CAN CA results	2 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.116917	0.088686	-0.017781	-0.272672	-0.37734	0.014608	-0.418262
Correlation (corrected)	0.116585	0.08575	-0.044952	-0.336104	-0.423975	0.012284	-0.423483
t-Test (n>10)	0.498025	0.394409	-0.269986	-1.382129	-2.606451	0.07371	-2.804822
Degrees of Freedom	18	21	36	15	31	36	36
Critical 2-sided T-value (5%)	2.101	2.08	2.042	2.131	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.734	1.721	1.697	1.753	1.697	1.697	1.697
D-square value (calculated)	1174.5	1844.5	9301.5	1038.5	8242	9005.5	12961.5
D-square value (expected)	1330	2024	9139	816	5984	9139	9139
Standard Deviation	305.1229	431.5183	1502.442345	204	1057.832	1502.442	1502.4423
z-Test	-0.50963	-0.41597	0.108157	1.090686	2.134555	-0.08886	2.544191
Probability	0.61	0.6744	0.9124	0.2714	0.0324	0.9282	0.0108
Observations	20	23	38	17	33	38	38
COD	0.013592	0.007353	0.002020682	0.1129659	0.179755	0.000151	0.1793379

Hake CAN CA results	3 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.12281	-0.21863	-0.174964	-0.052083	-0.421096	0.000474	-0.33766
Correlation (corrected)	-0.12281	-0.22255	-0.207978	-0.104308	-0.46634	-0.0019	-0.342996
t-Test (n>10)	-0.51021	-1.04611	-1.257923	-0.406199	-	-0.01125	-2.160238
Degrees of Freedom	17	21	35	15	30	35	35
Critical 2-sided T-value (5%)	2.11	2.08	2.042	2.131	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.74	1.721	1.697	1.753	1.697	1.697	1.697
D-square value (calculated)	1280	2466.5	9912	858.5	7753.5	8432	11284.5
D-square value (expected)	1140	2024	8436	816	5456	8436	8436
Standard Deviation	268.7006	431.5183	1406	204	979.9265	1406	1406
z-Test	0.521026	1.025449	1.049787	0.208333	2.344564	-0.00285	2.02596
Probability	0.5962	0.303	0.2938	0.8336	0.0188	0.992	0.0424
Observations	19	23	37	17	32	37	37
COD	0.015082	0.04953	0.043254848	0.0108802	0.217473	3.61E-06	0.1176463

Hake US CA results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.225296	-0.31052	-0.341979	-0.237874	-0.326331	0.010178	-0.309053
Correlation (corrected)	0.224859	-0.31475	-0.374116	-0.28934	-0.364308	0.008178	-0.313181
t-Test (n>10)	1.032028	-1.51959	-2.486793	-1.209075	-2.247225	0.050413	-2.032842
Degrees of Freedom	20	21	38	16	33	38	38
Critical 2-sided T-value (5%)	2.086	2.08	2.042	2.12	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.725	1.721	1.697	1.746	1.697	1.697	1.697
D-square value (calculated)	1372	2652.5	14305.5	1199.5	9470	10551.5	13954.5
D-square value (expected)	1771	2024	10660	969	7140	10660	10660
Standard Deviation	386.4639	431.5183	1706.96612	235.01702	1224.4999	1706.966	1706.9661
z-Test	-1.03244	1.456485	2.13566	0.98078	1.902818	-0.06356	1.930032
Probability	0.2984	0.1442	0.0324	0.3222	0.0562	0.9442	0.0524
Observations	22	23	40	18	35	40	40
COD	0.050562	0.099066	0.139962781	0.0837176	0.1327203	6.69E-05	0.0980823

Hake US CA results	2 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.183083	-0.30904	-0.379418	0.033701	-0.283422	-0.21616	-0.399442
Correlation (corrected)	0.182775	-0.31326	-0.41637	-0.014165	-0.326839	-0.21903	-0.404593
t-Test (n>10)	0.788737	-1.51163	-2.747728	-0.054867	-1.925515	-1.34689	-2.654531
Degrees of Freedom	18	21	36	15	31	36	36
Critical 2-sided T-value (5%)	2.101	2.08	2.042	2.131	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.734	1.721	1.697	1.753	1.697	1.697	1.697
D-square value (calculated)	1086.5	2649.5	12606.5	788.5	7680	11114.5	12789.5
D-square value (expected)	1330	2024	9139	816	5984	9139	9139
Standard Deviation	305.1229	431.5183	1502.442345	204	1057.8317	1502.442	1502.4423
z-Test	-0.79804	1.449533	2.307909	-0.134804	1.60328	1.314859	2.429711
Probability	0.4238	0.147	0.0208	0.8886	0.1074	0.1868	0.015
Observations	20	23	38	17	33	38	38
COD	0.033407	0.098132	0.173363977	0.0002006	0.1068237	0.047974	0.1636955

Hake US CA results	3 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.082456	-0.44392	-0.564486	-0.079044	-0.386089	-0.34412	-0.398708
Correlation (corrected)	0.082456	-0.44858	-0.608574	-0.132639	-0.430205	-0.34732	-0.404288
t-Test (n>10)	0.341137	-2.30003	-4.537353	-0.518286	-2.610226	-2.19115	-2.615039
Degrees of Freedom	17	21	35	15	30	35	35
Critical 2-sided T-value (5%)	2.11	2.08	2.042	2.131	2.042	2.042	2.042
Critical 1-sided T-value (5%)	1.74	1.721	1.697	1.753	1.697	1.697	1.697
D-square value (calculated)	1046	2922.5	13198	880.5	7562.5	11339	11799.5
D-square value (expected)	1140	2024	8436	816	5456	8436	8436
Standard Deviation	268.7006	431.5183	1406	204	979.92653	1406	1406
z-Test	-0.34983	2.082183	3.386913	0.316176	2.149651	2.064723	2.392248
Probability	0.7264	0.0366	0.0006	0.749	0.0316	0.0384	0.0164
Observations	19	23	37	17	32	37	37
COD	0.006799	0.201221	0.370362313	0.0175931	0.1850763	0.120628	0.1634488

UI Results- North	No LAG		
	Nass	Kemano	Bella Coola
Statistic			
Correlation (not corrected)	-0.03201	0.168696	0.298043
Correlation (corrected)	-0.03295	0.165795	0.289697
t-Test (n>10)	-0.2111	0.788561	2.324897
Degrees of Freedom	41	22	59
Critical 2-sided T-value (5%)	2.021	2.074	2.021
Critical 1-sided T-value (5%)	1.684	1.717	1.684
D-square value (calculated)	13668	1912	26548
D-square value (expected)	13244	2300	37820
Standard Deviation	2043.594	479.5832	4882.541005
z-Test	0.207478	-0.80904	-2.308634
Probability	0.8336	0.418	0.0208
Observations	43	24	61
COD	0.001086	0.027488	0.083924352

UI Results- North	2 yr LAG		
	Nass	Kemano	Bella Coola
Statistic			
Correlation (not corrected)	0.157186	0.126522	0.245902
Correlation (corrected)	0.156341	0.123474	0.238009
t-Test (n>10)	0.988507	0.583609	1.850092
Degrees of Freedom	39	22	57
Critical 2-sided T-value (5%)	2.042	2.074	2.021
Critical 1-sided T-value (5%)	1.697	1.717	1.684
D-square value (calculated)	9675.5	2009	25805.25
D-square value (expected)	11480	2300	34220
Standard Deviation	1815.147	479.5832	4493.306132
z-Test	-0.99413	-0.60678	-1.87273
Probability	0.3174	0.5418	0.0602
Observations	41	24	59
COD	0.024443	0.015246	0.056648284

UI Results- North	3 yr LAG		
	Nass	Kemano	Bella Coola
Statistic			
Correlation (not corrected)	0.306989	0.137826	0.155157
Correlation (corrected)	0.30624	0.134818	0.145653
t-Test (n>10)	1.983071	0.638177	1.101714
Degrees of Freedom	38	22	56
Critical 2-sided T-value (5%)	2.042	2.074	2.021
Critical 1-sided T-value (5%)	1.697	1.717	1.684
D-square value (calculated)	7387.5	1983	27465
D-square value (expected)	10660	2300	32509
Standard Deviation	1706.966	479.5832	4305.92224
z-Test	-1.91714	-0.66099	-1.17141
Probability	0.0548	0.5028	0.238
Observations	40	24	58
COD	0.093783	0.018176	0.021214796

UI Results- Central	No LAG			
	Kemano	Bella Coola	Klinaklini	Kingcome
Statistic				
Correlation (not corrected)	0.06087	0.261779	-0.047511	-0.048739
Correlation (corrected)	0.057592	0.252978	-0.068592	-0.07631
t-Test (n>10)	0.270579	2.008491	-0.500533	-0.432936
Degrees of Freedom	22	59	53	32
Critical 2-sided T-value (5%)	2.074	2.021	2.021	2.042
Critical 1-sided T-value (5%)	1.717	1.684	1.684	1.697
D-square value (calculated)	2160	27919.5	29037	6864
D-square value (expected)	2300	37820	27720	6545
Standard Deviation	479.58315	4882.541005	3772.2142	1139.33826
z-Test	-0.29192	-2.027735	0.349132	0.279987
Probability	0.7642	0.0424	0.7264	0.7794
Observations	24	61	55	34
COD	0.0033168	0.063997868	0.00470486	0.00582322

UI Results- Central	2 yr LAG			
	Kemano	Bella Coola	Klinaklini	Kingcome
Statistic				
Correlation (not corrected)	0.304783	0.257978	0.071793	0.107286
Correlation (corrected)	0.302358	0.249528	0.052058	0.084518
t-Test (n>10)	1.487822	1.945436	0.375907	0.472264
Degrees of Freedom	22	57	52	31
Critical 2-sided T-value (5%)	2.074	2.021	2.021	2.042
Critical 1-sided T-value (5%)	1.717	1.684	1.684	1.697
D-square value (calculated)	1599	25392	24351.5	5342
D-square value (expected)	2300	34220	26235	5984
Standard Deviation	479.58315	4493.306132	3603.6544	1057.83175
z-Test	-1.461686	-1.9647	-0.522664	-0.606902
Probability	0.1416	0.0488	0.5962	0.5418
Observations	24	59	54	33
COD	0.0914204	0.062264223	0.00271004	0.00714329

UI Results- Central	3 yr LAG			
	Kemano	Bella Coola	Klinaklini	Kingcome
Statistic				
Correlation (not corrected)	0.287826	0.153773	0.145803	0.257436
Correlation (corrected)	0.285186	0.144213	0.128489	0.238487
t-Test (n>10)	1.395596	1.09059	0.925267	1.36729
Degrees of Freedom	22	56	51	31
Critical 2-sided T-value (5%)	2.074	2.021	2.021	2.042
Critical 1-sided T-value (5%)	1.717	1.684	1.684	1.697
D-square value (calculated)	1638	27510	21187.5	4443.5
D-square value (expected)	2300	32509	24804	5984
Standard Deviation	479.58315	4305.92224	3439.69592	1057.83175
z-Test	-1.380365	-1.160959	-1.051401	-1.456281
Probability	0.1646	0.242	0.2892	0.1442
Observations	24	58	53	33
COD	0.0813311	0.020797389	0.01650942	0.05687605

UI Results- South	No LAG				
	Bella Coola	Klinaklini	Kingcome	Fraser	Columbia
Statistic					
Correlation (not corrected)	0.196444	-0.16434	0.027349	0.11835	0.172528
Correlation (corrected)	0.186857	-0.187794	0.001804	0.116844	0.170335
t-Test (n>10)	1.461007	-1.391927	0.010204	0.903686	1.327769
Degrees of Freedom	59	53	32	59	59
Critical 2-sided T-value (5%)	2.021	2.021	2.042	2.021	2.021
Critical 1-sided T-value (5%)	1.684	1.684	1.697	1.684	1.684
D-square value (calculated)	30390.5	32275.5	6366	33344	31295
D-square value (expected)	37820	27720	6545	37820	37820
Standard Deviation	4882.541005	3772.2142	1139.3383	4882.541	4882.541
z-Test	-1.521646	1.207646	-0.157109	-0.91674	-1.33639
Probability	0.126	0.2262	0.8728	0.3576	0.1802
Observations	61	55	34	61	61
COD	0.034915538	0.03526659	3.254E-06	0.013653	0.029014

UI Results- South 2 year lag

	Bella Coola	Klinaklini	Kingcome	Fraser	Columbia
Statistic					
Correlation (not corrected)	0.174313	0.119783	0.081885	-0.21905	0.198758
Correlation (corrected)	0.164904	0.101097	0.05846	-0.22136	0.197363
t-Test (n>10)	1.262278	0.732776	0.326046	-1.71371	1.519953
Degrees of Freedom	57	52	31	57	57
Critical 2-sided T-value (5%)	2.021	2.021	2.042	2.021	2.021
Critical 1-sided T-value (5%)	1.684	1.684	1.697	1.684	1.684
D-square value (calculated)	28255	23092.5	5494	41716	27418.5
D-square value (expected)	34220	26235	5984	34220	34220
Standard Deviation	4493.306132	3603.6544	1057.8317	4493.306	4493.306
z-Test	-1.32753	-0.872031	-0.463212	1.668259	-1.5137
Probability	0.1836	0.3788	0.6384	0.095	0.1286
Observations	59	54	33	59	59
COD	0.027193329	0.0102206	0.0034176	0.048998	0.038952

UI Results- South 3 yr LAG

	Bella Coola	Klinaklini	Kingcome	Fraser	Columbia
Statistic					
Correlation (not corrected)	0.109862	0.130745	0.051387	-0.14893	0.195777
Correlation (corrected)	0.099803	0.113141	0.027089	-0.15111	0.19465
t-Test (n>10)	0.750601	0.813208	0.150881	-1.14391	1.485028
Degrees of Freedom	56	51	31	56	56
Critical 2-sided T-value (5%)	2.021	2.021	2.042	2.021	2.021
Critical 1-sided T-value (5%)	1.684	1.684	1.697	1.684	1.684
D-square value (calculated)	28937.5	21561	5676.5	37350.5	26144.5
D-square value (expected)	32509	24804	5984	32509	32509
Standard Deviation	4305.92224	3439.69592	1057.8317	4305.922	4305.922
z-Test	-0.829439	-0.942816	-0.290689	1.124382	-1.47808
Probability	0.4066	0.3422	0.7642	0.2584	0.1388
Observations	58	53	33	58	58
COD	0.009960639	0.01280089	0.0007338	0.022833	0.037889

NOI Results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.16115	-0.211522	0.240912	0.07612	0.006842	0.456224	0.142227
Correlation (corrected)	0.159356	-0.218142	0.231651	0.05165	-0.015317	0.454767	0.140053
t-Test (n>10)	1.008058	-1.048428	1.797832	0.287957	-0.110468	3.855124	1.067903
Degrees of Freedom	39	22	57	31	52	57	57
Critical 2-sided T-value (5%)	2.042	2.074	2.021	2.042	2.021	2.021	2.021
Critical 1-sided T-value (5%)	1.697	1.717	1.684	1.697	1.684	1.684	1.684
D-square value (calculated)	9630	2786.5	25976	5528.5	26055.5	18608	29353
D-square value (expected)	11480	2300	34220	5984	26235	34220	34220
Standard Deviation	1815.147	479.58315	4493.306132	1057.8317	3603.6544	4493.3061	4493.3061
z-Test	-1.019201	1.014423	-1.834729	-0.430598	-0.049811	-3.474502	-1.083167
Probability	0.3078	0.3078	0.0658	0.66	0.9602	0.0006	0.2758
Observations	41	24	59	33	54	59	59
COD	0.025394	0.0475859	0.053662186	0.0026677	0.0002346	0.206813	0.0196148

NOI Results	2 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.125051	0.147609	0.252965	0.553886	-0.009775	0.158608	0.236097
Correlation (corrected)	0.123276	0.142764	0.243492	0.542388	-0.031489	0.156284	0.234646
t-Test (n>10)	0.755621	0.676551	1.861819	3.536102	-0.222771	1.173449	1.790158
Degrees of Freedom	37	22	55	30	50	55	55
Critical 2-sided T-value (5%)	2.042	2.074	2.021	2.042	2.021	2.021	2.021
Critical 1-sided T-value (5%)	1.697	1.717	1.684	1.697	1.684	1.684	1.684
D-square value (calculated)	8644.5	1960.5	23050.5	2434	23655	25962	23571
D-square value (expected)	9880	2300	30856	5456	23426	30856	30856
Standard Deviation	1602.748	479.58315	4123.30644	979.92653	3280.2961	4123.3064	4123.3064
z-Test	-0.770864	-0.707906	-1.89302	-3.083905	0.069811	-1.186912	-1.766786
Probability	0.4354	0.4776	0.0574	0.002	0.9442	0.234	0.0768
Observations	39	24	57	32	52	57	57
COD	0.015197	0.0203816	0.059288354	0.2941847	0.0009916	0.0244247	0.0550587

NOI Results	3 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.34588	0.26913	0.189833	0.439617	-0.077738	0.082587	0.066388
Correlation (corrected)	0.344446	0.264655	0.179	0.4256	-0.102299	0.080261	0.064533
t-Test (n>10)	2.201385	1.287238	1.336968	2.532762	-0.719869	0.591705	0.475211
Degrees of Freedom	36	22	54	29	49	54	54
Critical 2-sided T-value (5%)	2.042	2.074	2.021	2.045	2.021	2.021	2.021
Critical 1-sided T-value (5%)	1.697	1.717	1.684	1.699	1.684	1.684	1.684
D-square value (calculated)	5978	1681	23705.5	2779.5	23818	26843.5	27317.5
D-square value (expected)	9139	2300	29260	4960	22100	29260	29260
Standard Deviation	1502.442	479.58315	3945.417595	905.56796	3125.412	3945.4176	3945.4176
z-Test	-2.103908	-1.290704	-1.407836	-2.407881	0.549688	-0.612483	-0.492343
Probability	0.0348	0.1936	0.1586	0.016	0.5824	0.5352	0.617
Observations	38	24	56	31	51	56	56
COD	0.118643	0.0700423	0.032041	0.1811354	0.0104651	0.0064418	0.0041645

SST total avg Results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.08574	0.071522	-0.324557	-0.139496	0.052068	-0.38251	-0.176341
Correlation (corrected)	-0.08646	0.068078	-0.339932	-0.169482	0.033931	-0.38454	-0.183499
t-Test (n>10)	-0.59497	0.320057	-2.799829	-0.972806	0.249484	-3.35854	-1.504974
Degrees of Freedom	47	22	60	32	54	65	65
Critical 2-sided T-value (5%)	2.021	2.074	2	2.042	2.021	2	2
Critical 1-sided T-value (5%)	1.684	1.717	1.671	1.697	1.684	1.671	1.671
D-square value (calculated)	21280.5	2135.5	52599.5	7458	27736.5	69286	58953.5
D-square value (expected)	19600	2300	39711	6545	29260	50116	50116
Standard Deviation	2829.016	479.5832	5084.472539	1139.3383	3945.418	6168.853	6168.8532
z-Test	0.594023	-0.34301	2.534875	0.801342	-0.386144	3.107547	1.4326
Probability	0.5484	0.7264	0.011	0.418	0.6966	0.0018	0.1498
Observations	49	24	62	34	56	67	67
COD	0.007475	0.004635	0.115553765	0.0287241	0.001151	0.147873	0.0336719

SST total avg Results	2 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.15099	-0.14261	-0.307196	-0.291138	0.010304	-0.13981	-0.182627
Correlation (corrected)	-0.15195	-0.14735	-0.322541	-0.325366	-0.008639	-0.14156	-0.189139
t-Test (n>10)	-1.03132	-0.69875	-2.595093	-1.946461	-0.063489	-1.13506	-1.528838
Degrees of Freedom	45	22	58	32	54	63	63
Critical 2-sided T-value (5%)	2.021	2.074	2.021	2.042	2.021	2	2
Critical 1-sided T-value (5%)	1.684	1.717	1.684	1.697	1.684	1.671	1.671
D-square value (calculated)	19907.5	2628	47046	8450.5	28958.5	52157.5	54117
D-square value (expected)	17296	2300	35990	6545	29260	45760	45760
Standard Deviation	2550.156	479.5832	4685.498906	1139.3383	3945.418	5720	5720
z-Test	1.024055	0.683927	2.359621	1.672462	-0.076418	1.118444	1.461014
Probability	0.303	0.4902	0.0182	0.093	0.9362	0.2628	0.1416
Observations	47	24	60	34	56	65	65
COD	0.02309	0.021711	0.104032697	0.105863	7.46E-05	0.02004	0.0357736

SST total avg Results	3 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.33787	-0.03217	-0.242198	-0.251795	0.100068	-0.10761	-0.067033
Correlation (corrected)	-0.33906	-0.03646	-0.256515	-0.28497	0.082763	-0.1094	-0.072065
t-Test (n>10)	-2.39071	-0.1711	-2.003692	-1.681767	0.610275	-0.86664	-0.56892
Degrees of Freedom	44	22	57	32	54	62	62
Critical 2-sided T-value (5%)	2.021	2.074	2.021	2.042	2.021	2	2
Critical 1-sided T-value (5%)	1.684	1.717	1.684	1.697	1.684	1.671	1.671
D-square value (calculated)	21693.5	2374	42508	8193	26332	48380.5	46608
D-square value (expected)	16215	2300	34220	6545	29260	43680	43680
Standard Deviation	2417.189	479.5832	4493.306132	1139.3383	3945.418	5503.163	5503.1627
z-Test	2.266475	0.154301	1.844522	1.446454	-0.742127	0.854145	0.532058
Probability	0.0232	0.8728	0.0644	0.147	0.4532	0.3898	0.5892
Observations	46	24	59	34	56	64	64
COD	0.114964	0.001329	0.065799945	0.0812079	0.00685	0.011969	0.0051934

SST 3 mo avg Results

	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.15245	0.086087	-0.32273	-0.35134	-0.12936	-0.4824	-0.18806
Correlation (corrected)	-0.15501	0.08049	-0.3398	-0.38912	-0.15244	-0.48618	-0.19659
t-Test (n>10)	-1.07572	0.37876	-2.79864	-2.38955	-1.13346	-4.48554	-1.6165
Degrees of Freedom	47	22	60	32	54	65	65
Critical 2-sided T-value (5%)	2.021	2.074	2	2.042	2.021	2	2
Critical 1-sided T-value (5%)	1.684	1.717	1.671	1.697	1.684	1.671	1.671
D-square value (calculated)	22588	2102	52527	8844.5	33045	74292	59541
D-square value (expected)	19600	2300	39711	6545	29260	50116	50116
Standard Deviation	2829.016	479.5832	5084.473	1139.338	3945.418	6168.853	6168.853
z-Test	1.056198	-0.41286	2.520615	2.018277	0.959341	3.919043	1.527837
Probability	0.2892	0.6744	0.0114	0.0434	0.337	0	0.126
Observations	49	24	62	34	56	67	67
COD	0.024029	0.006479	0.115467	0.151417	0.023238	0.236373	0.038648

SST 3 mo avg Results 2 yr LAG

	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.06606	-0.3971	-0.27667	-0.43789	0.03474	-0.16891	-0.08131
Correlation (corrected)	-0.06772	-0.43629	-0.29345	-0.47487	0.014964	-0.17208	-0.08853
t-Test (n>10)	-0.45534	-2.74282	-2.33781	-2.58778	0.109978	-1.3865	-0.70541
Degrees of Freedom	45	32	58	23	54	63	63
Critical 2-sided T-value (5%)	2.021	2.042	2.021	2.069	2.021	2	2
Critical 1-sided T-value (5%)	1.684	1.697	1.684	1.714	1.684	1.671	1.671
D-square value (calculated)	18438.5	9144	45947.5	3738.5	28243.5	53489.5	49480.5
D-square value (expected)	17296	6545	35990	2600	29260	45760	45760
Standard Deviation	2550.156	1139.338	4685.499	530.7228	3945.418	5720	5720
z-Test	0.448012	2.281149	2.125174	2.145188	-0.25764	1.351311	0.650437
Probability	0.6528	0.022	0.0332	0.0316	0.7948	0.1738	0.5092
Observations	47	34	60	25	56	65	65
COD	0.004586	0.190345	0.086115	0.225501	0.000224	0.02961	0.007837

SST 3 mo avg Results	3 yr LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.24875	-0.18717	-0.23523	-0.49649	0.016405	-0.12751	-0.03357
Correlation (corrected)	-0.25192	-0.19418	-0.25129	-0.53968	-0.00384	-0.1307	-0.03972
t-Test (n>10)	-1.72672	-0.92847	-1.96011	-3.62636	-0.0282	-1.03807	-0.31296
Degrees of Freedom	44	22	57	32	54	62	62
Critical 2-sided T-value (5%)	2.021	2.074	2.021	2.042	2.021	2	2
Critical 1-sided T-value (5%)	1.684	1.717	1.684	1.697	1.684	1.671	1.671
D-square value (calculated)	20248.5	2730.5	42269.5	9794.5	28780	49249.5	45146.5
D-square value (expected)	16215	2300	34220	6545	29260	43680	43680
Standard Deviation	2417.189	479.5832	4493.306	1139.338	3945.418	5503.163	5503.163
z-Test	1.668673	0.897655	1.791443	2.852094	-0.12166	1.012054	0.266483
Probability	0.095	0.3682	0.0718	0.0042	0.8966	0.3078	0.7872
Observations	46	24	59	34	56	64	64
COD	0.063462	0.037707	0.063148	0.291259	1.47E-05	0.017084	0.001577

Seal/Sealion Results	No LAG						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	-0.2	-0.00074	-0.252658	-0.613636	-0.16117	-0.09778	-0.59146
Correlation (corrected)	-0.2	-0.01114	-0.31151	-0.675538	-0.22566	-0.09929	-0.60027
t-Test (n>10)	-0.70711	-0.0417	-1.795549	-2.897281	-1.15815	-0.54655	-4.11077
Degrees of Freedom	12	14	30	10	25	30	30
Critical 2-sided T-value (5%)	2.179	2.145	2.042	2.228	2.06	2.042	2.042
Critical 1-sided T-value (5%)	1.782	1.761	1.697	1.812	1.708	1.697	1.697
D-square value (calculated)	546	680.5	6834.5	461.5	3804	5989.5	8683
D-square value (expected)	455	680	5456	286	3276	5456	5456
Standard Deviation	126.1943	175.5752	979.926528	86.232245	642.4765	979.9265	979.9265
z-Test	0.72111	0.002848	1.406738	2.035202	0.82182	0.544429	3.293104
Probability	0.4654	0.992	0.1586	0.0414	0.4066	0.5824	0.001
Observations	14	16	32	12	27	32	32
COD	0.04	0.000124	0.09703848	0.4563516	0.05092	0.009859	0.360319

Seal/Sealion Results	2 Year lag						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0	-0.13824	-0.266496	-0.49011	-0.40202	-0.15735	-0.58633
Correlation (corrected)	-0.0022	-0.14497	-0.314154	-0.570118	-0.46057	-0.16022	-0.59555
t-Test (n>10)	-0.00763	-0.54822	-1.812453	-2.403893	-2.59437	-0.88905	-4.06058
Degrees of Freedom	12	14	30	12	25	30	30
Critical 2-sided T-value (5%)	2.179	2.145	2.042	2.179	2.06	2.042	2.042
Critical 1-sided T-value (5%)	1.782	1.761	1.697	1.782	1.708	1.697	1.697
D-square value (calculated)	455	774	6910	678	4593	6314.5	8655
D-square value (expected)	455	680	5456	455	3276	5456	5456
Standard Deviation	126.1943	175.5752	979.926528	126.1943	642.4765	979.9265	979.9265
z-Test	0	0.535383	1.483785	1.767116	2.049881	0.876086	3.26453
Probability	0.992	0.5892	0.1362	0.0768	0.0404	0.3788	0.001
Observations	14	16	32	14	27	32	32
COD	4.85E-06	0.021017	0.098692736	0.3250345	0.212121	0.025671	0.354677

Seal/Sealion Results	3 Year lag						
	Nass	Kemano	Bella Coola	Kingcome	Klinaklini	Fraser	Columbia
Statistic							
Correlation (not corrected)	0.095604	-0.31765	-0.231305	-0.298077	-0.46688	-0.07286	-0.56782
Correlation (corrected)	0.09461	-0.32447	-0.278111	-0.365998	-0.54873	-0.07611	-0.5778
t-Test (n>10)	0.329214	-1.28348	-1.585837	-1.304384	-3.2819	-0.41809	-3.87754
Degrees of Freedom	12	14	30	11	25	30	30
Critical 2-sided T-value (5%)	2.179	2.145	2.042	2.201	2.06	2.042	2.042
Critical 1-sided T-value (5%)	1.782	1.761	1.697	1.796	1.708	1.697	1.697
D-square value (calculated)	411.5	896	6718	472.5	4805.5	5853.5	8554
D-square value (expected)	455	680	5456	364	3276	5456	5456
Standard Deviation	126.1943	175.5752	979.926528	105.07775	642.4765	979.9265	979.9265
z-Test	-0.34471	1.230242	1.287852	1.032569	2.380632	0.405643	3.161462
Probability	0.7264	0.215	0.197	0.2984	0.0168	0.6818	0.0016
Observations	14	16	32	13	27	32	32
COD	0.008951	0.105278	0.077345728	0.1339545	0.301108	0.005793	0.333856