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Status of the eulachon *Thaleichthys pacificus* in Canada

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ABSTRACT

The anadromous eulachon (*Thaleichthys pacificus*) is a small species of smelt that spawns in the lower reaches of coastal rivers and streams from northern California to the southern Bering Sea. Nearly all eulachon spawning runs have declined from California to south-eastern Alaska in the last 20 years, especially since the mid-1990's. The causes of the declines are uncertain, and this paper reviews and comments on the main suggestions and explanations. Climate change is implicated as a cause of a general decline, but other factors cannot be overlooked, including local habitat alterations and bycatch in commercial trawl fisheries. The decline of eulachons is a concern for many First Nations, for whom the eulachon is of major cultural significance, especially as a source of an important traditional staple called 'grease'. The status of eulachons also concerns fisheries managers and the commercial fishing industry because eulachons are common as bycatch in shrimp trawls in some areas. The decline of eulachons has prompted specific management actions to limit eulachon bycatch, and such actions may reduce potential shrimp catches in some areas. The available biological information on eulachons is fragmentary and previously has not been synthesized into a single document. This paper attempts to pool and summarize the available biological information on eulachons prior to commenting on their biological status. Genetic evidence, which is subject to confirmation, indicates that eulachons constitute a single ESU (evolutionary significant unit) throughout their entire range. Other biological data, including data on meristic analyses and river-specific spawning times indicate that there is substantial local stock structure. This may indicate that although different eulachon stocks are genetically coupled, presumably through straying or mixing, different rivers (or estuaries) probably represent demographically uncoupled stocks. Therefore we point out that probably it is precautionary to assume that stock structure is geographically fine, until shown otherwise. The significance of the genetic data to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is that classification applies at the level of the ESU, or a significant part of it. Available evidence suggests that several rivers in the central coast of BC may be extirpated, while others have declined severely. Only the Nass maintains normal or near-normal runs, although the Fraser, while markedly lower in recent decades and especially since 1994, still has regular, but diminished runs. The Columbia River, with the world's largest eulachon run, declined sharply in 1993, and has remained low since. Apparently all runs in California have declined and several runs that once were large have not been seen for more than 20 years. Based on these observations, we suggest that the widespread decline in the southern part of the range warrants a COSEWIC classification of 'threatened' in Canadian waters. We further point out, however, that this status could change rapidly as the abundance of immature eulachons in southern offshore waters is substantially greater in 2000 than in the previous decade. If this offshore abundance is indicative of stronger spawning runs in future years, then the classification of 'threatened' may be too severe. On the other hand, the abundant offshore eulachons appear to be mainly from the 1999-year class, which probably will spawn in 2002, and may not contribute to stronger spawning runs in year 2001. We conclude with a plea for the development and implementation of policy for eulachon management, which will cover issues such as commercial fisheries for eulachons, forest industry interactions, dredging and habitat alteration in spawning areas, pollution of spawning rivers and bycatch in offshore trawl fisheries. In this regard, as a potential policy template, we include a short section of recommendations, modified to suit eulachons, from the recent draft of the DFO 'Wild Salmon Policy' paper.

RÉSUMÉ

L'eulakane (*Thaleichthys pacificus*) est un petit éperlan anadrome qui fraie dans le cours inférieur des cours d'eau côtiers, du nord de la Californie au sud de la mer de Béring. Depuis 20 ans, presque toutes les remontes d'eulakanes de la Californie au sud-est de l'Alaska ont diminué, surtout depuis le milieu des années 1990. Les causes de ce déclin sont incertaines; le présent document examine et commente les principales suggestions et explications à cet égard. Le changement climatique est considéré comme une cause du déclin général, mais il ne faut pas négliger d'autres facteurs, notamment les perturbations locales de l'habitat et la capture accessoire de l'eulakane dans les pêches commerciales au chalut. De nombreuses Premières nations s'inquiètent du déclin des populations d'eulakanes, car cette espèce revêt pour eux une grande importance culturelle, surtout en tant que source d'une graisse qui constitue un important aliment traditionnel de base. L'état des stocks d'eulakanes concerne aussi les gestionnaires des pêches et l'industrie de la pêche commerciale, car les prises accessoires d'eulakanes par les chaluts à crevettes sont courantes dans certains secteurs. Le déclin des populations d'eulakanes a poussé les gestionnaires à prendre des mesures précises visant à limiter les prises accessoires d'eulakanes, ce qui pourrait réduire les prises de crevettes dans certains secteurs. L'information biologique fragmentaire disponible sur l'eulakane n'a jusqu'ici jamais été synthétisée en un seul document. Le présent document tente donc de réunir et de résumer l'information disponible avant de commenter la situation biologique de l'espèce. Selon des données génétiques non confirmées, les eulakanes formeraient une seule unité évolutionnaire significative (UES) dans l'ensemble de leur aire de répartition. D'autres données biologiques, notamment sur les caractéristiques méristiques et la période de fraie propre à chaque rivière, montrent que la structure des stocks varie considérablement à l'échelle locale. Cela pourrait indiquer que, bien que les différents stocks d'eulakanes soient génétiquement liés (probablement en raison d'individus égarés ou d'un certain mélange entre les stocks), les stocks qui fraient dans différentes rivières (ou estuaires) ne sont pas liés du point de vue démographique. Nous soulignons donc que, jusqu'à ce que l'on dispose d'indications contraires, il serait sans doute prudent de supposer que la structure des stocks varie sur de petites échelles géographiques. L'importance des données génétiques pour le Comité sur la situation des espèces en péril au Canada (COSEPAC) réside dans le fait que la classification s'applique à toute l'UES, ou à une grande partie de celle-ci. Les données disponibles laissent croire que l'eulakane a disparu de plusieurs rivières de la côte centrale de la C.-B. et que d'autres populations ont connu un déclin important. La rivière Nass est la seule dans laquelle les remontes d'eulakanes persistent à des niveaux normaux ou qui s'approchent de la normale. Bien que les remontes dans le Fraser aient diminué sensiblement depuis quelques décennies, surtout depuis 1994, elles se produisent encore régulièrement. La plus importante montaison d'eulakanes au monde, celle du fleuve Columbia, a brusquement baissé en 1993 et est restée faible depuis. Toutes les remontes en Californie semblent avoir connu un déclin, et certaines remontes qui étaient très fortes n'ont pas été observées depuis plus de 20 ans. En nous fondant sur ces observations, nous suggérons que le déclin généralisé des populations d'eulakanes dans la partie sud de leur aire de répartition justifie que le COSEPAC désigne cette espèce comme « menacée » dans les eaux canadiennes. Toutefois, nous soulignons que ce statut pourrait changer rapidement puisque l'abondance d'eulakanes immatures dans les eaux du large au sud de leur aire a beaucoup augmenté en 2000 par rapport à la décennie précédente. Si cette abondance en haute mer indique que les remontés de géniteurs seront plus fortes dans les années à venir, le statut d'espèce « menacée » pourrait être exagéré. Par contre, la forte abondance d'eulakanes en haute mer semble être principalement constituée de la classe d'âge de 1999, qui se reproduira sans doute en 2002 et ne contribuera peut-être pas à des remontes accrues en 2001. Nous concluons en préconisant l'élaboration et la mise en œuvre d'une politique de gestion de l'eulakane qui portera sur des questions comme les pêches commerciales de cette espèce, les effets de l'industrie forestière, le dragage et la perturbation des frayères, la pollution des rivières de fraie ainsi que les prises accessoires dans les pêches au chalut en haute mer. En guise de modèle de politiques possibles, nous avons inclus une brève section de recommandations tirées de l'ébauche récente du document du MPO sur la politique du saumon sauvage et adaptées à la situation de l'eulakane.

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INTRODUCTION

OBJECTIVE

This document comments on information relevant to determining the biological status of eulachons. We attempt to be comprehensive but succinct. The document comments on the apparent declines in abundance of eulachons in different parts of the British Columbia (BC) coast, as well as certain US waters. The document lists and discusses potential explanations for the declining eulachon abundance and discusses the efficacy of potential mitigation efforts, particularly as they apply to habitat restoration and bycatch reduction.

The key issue in this document is whether the changes in eulachon distribution or abundance warrant concern about their sustainability in some or all parts of Canadian waters. Do eulachons require special legislative protection, of the kind available through a listing through the Committee on the Status of Endangered Wildlife in Canada (COSEWIC)? If so, should the listing category (i.e. threatened, vulnerable, endangered, etc.) be applied consistently throughout all parts of the range of eulachons within Canadian waters, or can the listing category vary among different putative stocks? A definitive answer to this latter question would require a definitive understanding about eulachon stock structure, and this is not available at the present time. There are, however, a number of independent studies which support alternate stock structure hypotheses that distinguish between the finest potential stock structure: (several stocks within single rivers) and the most coarse (one stock for the entire BC or for the entire Pacific coast). For each extreme, plus the several intermediate hypotheses (one stock for each river, or one stock for each major estuary, or one stock for each major coastal region) we discuss the implications for mitigation and precautionary management.

This document begins with a brief review of the growing awareness of the decline of eulachons. This is followed by a review of the biology of eualchons, including short sections on taxonomy and distribution, reproductive biology, life history, stock structure and assessment methods. A distinct section discusses factors that may affect the abundance of eulachons, including climate change, habitat deterioration, fisheries directed at eulachons and fisheries with incidental capture of eulachons. The latter sections briefly discuss the implications of precautionary management of eulachons, especially with respect to uncertainty about stock structure. The report concludes with sections describing the probable prognosis for eulachons and recommendations for species listing relative to criteria defined in COSEWIC.

This report does not attempt to describe or discuss the role or significance of eulachons to First Nations. This omission should not be interpreted as either an oversight or a refutation of this topic. Eulachons are of vital importance to many First Nations. In part, the preparation of this document reflects that concern.

BACKGROUND: THE DEVELOPING AWARENESS AND CONCERN ABOUT EULACHONS

Eulachons were of only marginal interest or concern to Fisheries and Oceans, Canada prior to 1990. Relative to other species, the scientific and technical literature is lean. Only a few scientific or biological papers are presented in peer-reviewed journals. One such paper, concerned with contaminants (mainly chlorophenols in the Fraser River) was published in 1990 (Rogers et al., 1990). Before 1990 there were only a few other documents but noteworthy is a comprehensive technical report on the biology of Nass River eulachons (Langer et al., 1977) and a technical report by Ricker et al. (1954) on eulachon catches in the Fraser River. None of these papers commented on the state of eulachon abundance, although in these and other papers, concerns were expressed about several issues including chemical contamination, the impacts of dredging and forest industry impacts. There were very few other papers from anywhere else within the known range of eulachons (Northern California to Southern Bering Sea).

In the early 1990's the Haisla First Nation (Kitimaat) expressed concerns about eulachons – for a number of reasons, including concerns about pulp mill effluent on the Kitimat River, the Kemano Completion Project impact on the Kemano River and general impacts of logging on other rivers in their territory.

In 1993, the Kemano Completion Project's impacts on Kemano River eulachons became an issue within the Department of Fisheries and Oceans, Canada (DFO). The Science Branch of DFO reviewed the consultant reports, made brief field investigations to the Kemano River and participated in the hearings. In August 1994, following the Kemano Completion Hearings, an 'Eulachon Workshop' was held sponsored by BC Forests Ministry, in Kitimat. This meeting was a precursor to the subsequent 'Eulachon Research Council Meetings'. The main participants and issues were the effects of the forest industry on eulachons. Later in the month, the Chief Forester of BC Forests wrote to the Regional Director of DFO requesting more work to be done on eulachons.

In 1994, the eulachon run in the Fraser River declined. Reductions in spawning runs also occurred in several other rivers but these declines were not recognized until several years later. The decline on the Fraser was immediately recognized, however, and this led to a number of meetings about Fraser River eulachons with stake-holders. This was followed, in 1995 with the start of a series of surveys to assess egg and larval eulachon as a means to (i) estimate spawning stock biomass and (ii) approximate locations in the river where spawning occurs.

In March, 1995 an 'Eulachon Research Council' meeting was held (on the Simon Fraser University Campus in downtown Vancouver). Again, the main representatives were from DFO, the Forest Industry and First Nations. There was a second meeting of the 'Eulachon Research Council, held at Terrace, in November 14-15, 1995.

In 1996, DFO Science Branch made a marine survey of the northern BC coast (mainly Gardner Canal) to confirm the distribution of larvae as indicators of spawning rivers. In 1997 this was extended to the lower coast (Dean Channel to Johnstone Straits). We also assembled information from incidental eulachon captured in other rivers to put a comprehensive overview together in a 1999 paper presented to PSARC (Pacific Scientific Advice Review Committee). We still have not surveyed the extreme north (Skeena estuary to Alaska) as a vessel was requested for 2000 but was not available. In 1996 we also collected samples throughout the BC coast, and elsewhere in support of a genetic study at the University of BC (UBC) for stock identification purposes. In November 1996 another meeting of the Eulachon Research Council occurred in Vancouver, mainly to discuss technical issues.

In 1997, data and information from the Columbia River catches were summarized and compared with incidental eulachon catches from annual offshore research shrimp surveys (Hay et al., 1997 a). This showed that the offshore eulachon abundance in 1995 had ‘crashed', in approximate synchrony with the Columbia and Fraser Rivers. In 1997, funding from the Forest Renewal of BC initiative (FRBC) supported a study of elemental analyses of eulachon otoliths as a means of differentiating eulachon stocks. (Report completed, and submitted to FRBC in 1998 and journal publication is in preparation). Also in 1997, following a pilot project in 1996, DFO initiated a coastwide survey of shrimp trawl bycatch, with the primary intent of estimating the amount of eulachon in the bycatch.

In March, 1998 there were two further meetings of the Eulachon Research Council (ERC): one in Terrace and another in Vancouver. These meetings included representatives of the First Nations, DFO Science Branch and management (including habitat managers), Forest Industry, First Nations, Academia, NGO’s (non-government agencies) and, for the first time, members from the Shrimp Industry.

In 1999, work continued on a number of areas, and two additional eulachon PSARC papers were completed: one updated estimates of eulachon bycatch for the years 1997 and 1998 (Hay et al., 1999) and another described the distribution of coastal eulachon stocks, based on coastal larval surveys (McCarter and Hay, 1999).

In 2000, a third eulachon bycatch paper was in preparation and 3 Eulachon Research Council meetings were held: (1) an Eulachon Forum on March 27, in New Westminster, (2) a meeting in Terrace on May 4 and (3) and a meeting in Bella Coola on May 12, 2000.

BIOLOGY: TAXONOMY, DISTRIBUTION AND HABITATS

THE TAXONOMIC STATUS AND GLOBAL DISTRIBUTION OF EULACHONS (FAMILY OSMERIDAE)

Eulachons are small (<25cm) silver fishes, one of about 12 species in the family Osmeridae (McAllister, 1963). The exact number of species (10-12) depends on the interpretation taxonomic status of species sometimes as identifies as 'sub-species', particularly within the genus *Hypomesus,* for which *H. pretiosus* has a subspecies in Japan *(H. p. japonicus)* and one in North America *(H. p. pretiosus)*. Similarly *Hypomesus transpacificus* has both a Japanese subspecies *(H. t. nipponenis)* and a North American subspecies *(H. t. transpacificus),* which is known as the Delta Smelt, and which is confined to the Sacramento River system in California. Within the USA, the Delta Smelt has been listed as a 'threatened' species based on reviews of the biology (Moyle et al., 1992). A representative drawing of an eulachon, as well as representatives of some other osmerid species are shown in Fig. 1.

Phenotypically, eulachons resemble small Pacific salmon, having an adipose fin and long extended anal fin. There are no fossils to confirm the antiquity of eulachons, but their close relationship to other groups within the Order Salmoniformes links them with representatives of the earliest forms of modern bony fishes. Most osmerid species are found in the North Pacific and it seems probable that the Pacific is the centre of origin for most. Only two species occur in the Atlantic, and both of these species also occur in the North Pacific and some Arctic areas, which may be evidence that only those smelt species that can tolerate sub-Arctic conditions were able to pass through the Arctic to Atlantic waters (McAllister, 1963). Within the Pacific, the distribution of eulachons, like most of the other species, is Boreal. Eulachons are found only on in the eastern Pacific, from northern California to the eastern Bering Sea (Fig. 2). Eulachons are not known in Russian waters (N. Naumenko, Pers. Comm). In North America, their distribution coincides closely with areas known as the coastal temperate Rain Forest (Simenstad et al., 1996) although there may not be any functional linkage.

THE COMMON NAME: EULACHON, OOLIGAN, HOOLICHONS, CANDLE FISH, ETC.

Thaleichthys pacificus is known by a number of common names of which 'eulachon' is the scientifically recognized common name. Common spelling, however, varies with 'ooligan' (nearly identical pronunciation) and 'hooligan' (pronounced with a hard 'h' as in 'hoot') among the most common. This latter pronunciation seems common in Alaska although American biologists often insert a 'y' at the beginning of 'eulachon' to pronounce it as 'yoolachon'. In our view the spelling and pronunciation are of little concern and do not lead to confusion with many other common names of smelts. It is our experience that other smelt species, particularly surf smelt, longfin smelts and capelin have been mistakenly referred to as eulachons, but this is not related to pronunciation or nomenclature.

We also note that the various First Nations each have different names for eulachons, none of which are even roughly similar to the sound or pronunciation of 'eulachons'. On the other hand the word eulachon is supposed to have an origin from 'Chinook' (Hart, 1973) the synthetic trading language made up of French, English and various First Nations Languages. If so, we point out that a literal translation of eulachon is close to the pairing of two distinct words 'heule' (or oil) and 'chan', which is similar to cane (as in a stick) or an abbreviated form of 'chandelle' (or candle). Therefore, if the word 'eulachon' had a French origin, it could have been used to mean 'oil cane' or 'oil candle'. Such terminology would be consistent with one of the common English names (candle fish) which is based on the observation, which we have confirmed, that dried specimens will burn like candles.

DISTRIBUTION IN BRITISH COLUMBIA: NUMBERS AND LOCATIONS OF SPAWNING RIVERS

Figure 3 shows all known eulachon spawning rivers according to a number that corresponds to a list, from north to south, in Table 1. For some rivers, Table 1 groups rivers that share common marine waters, particularly inlets. These groups will be referred to later, in a discussion of stock structure. Not all rivers shown in Table 1 receive spawning every year, but those that do are indicated as 'R', for regular spawning, in a separate column. This classification represents the most current assemblage of available information but the classification for some rivers may be incomplete because some rivers that are not indicated by an 'R' may have regular, or nearly regular spawning, and vice versa.

Even though there may be some subsequent additions to Table 1, it is clear that there are not a large number of eulachons in BC - with a total of 33 spawning rivers listed, of which only 14 are classified as having regular spawning. In contrast, there may be 10,000 different runs or populations of Pacific salmon (all species) over the same range (Slaney et al., 1996).

In some coastal areas, eulachon rivers are solitary, and represent the only known eulachon spawning river within a broad geographical areas (i.e. Fraser River or Nass) and in other areas, there are clusters of small spawning rivers, usually within an inlet (i.e. the Kitlope, Kowesis and Kemano in the Gardner Canal). Within such clusters, different rivers could be interpreted as representing different parts of the same biological stock. Therefore, Table 1 also shows a grouping by estuarine 'pools' or groups of adjacent spawning rivers. This pooling results in a total of 16 stock groups, of which only 9 groups include rivers have classifications of 'regular' spawning - for a maximum of 9 potential stocks, classified according to estuarine waters (Table 1).

Although the exact number and distribution of eulachon populations outside of BC is not well documented, there are not a large number. For instance, there may be almost 10,000 distinct salmonid populations over the same approximate range (Slaney et al., 1996). Eulachon populations in the southern Bering Sea, the most northerly extent of the range, appear to be relatively abundant. Eulachon also occur in a few Cook Inlet rivers. In south-eastern Alaska they are reported to occur in at least 6 rivers (Unik, Smeaton Bay, Bradfield, Stikine, Kenai, Yakutat and Taku). In total, over 35 rivers in Alaska are known to have either regular or intermittent eulachons spawning runs (S. Moffit, Pers. Comm). In Washington State, the main eulachon-spawning river is the Columbia, which may have had the largest spawning run in the world. There are only a few runs south of the Columbia, with the largest in the Klamath River, in northern California. Jennings (1996) reports on a citing of a dead eulachon (found in 1977) in 'Jolly Giant Creek' that drains into Humboldt Bay, California, (just south of 41^{o} latitude) and reports this as the most southerly record of spawning eulachons. To our knowledge, the most southerly record of eulachons in offshore waters is reported by Weinberg et al. (1994) who described species captured in offshore surveys of the continental USA in 1989. Eulachons are listed as occurring from 34^{o} 36' to 49^{o} 35' latitude (Weinberg et al., Table 2, page 29).

SPAWNING LOCATIONS WITHIN RIVERS

Within large rivers such as the Fraser and Columbia Rivers, spawning occurs over a wide range of areas and inter-annual changes in spawning locations have been noted (Samis 1977; Hay et al., 1997 b; Smith and Saalfeld, 1955). In the Columbia, there are several smaller rivers that drain into the mainstem of the Columbia, of which the Cowlitz River is one of the most important for eulachons. Using meristic analysis (including vertebral counts) Smith and Saalfeld (1955) investigated the possibility that each of these tributaries could have been a different run. Variation in spawning locations had been noted by local fishers, and there were concerns that industrial pollution was eliminating some of the runs in local tributaries. Similar concerns have been expressed about spawning-site variation within the Fraser River, and variation in spawning location has been documented in recent years (Hay et al., 1997b). In 1995, most of the spawning was above New Westminster but in 1996, most eulachon spawning was in the lower reaches, well below New Westminster (Hay et al., 1997 b). In 1999, most of the spawning in the Fraser watershed appeared to occur in the Pitt River, which drains into the Fraser just east of New Westminster (Hay, unpublished data). It is interesting to note that the larger watersheds, like the Fraser, Skeena and Columbia, often have eulachons spawning runs observed in tributaries, draining into the mainstems. In this regard, the geographic scales of large rivers are similar to some inlets, with lengths of 50-100 km of water traversed by eulachons before they reach smaller tributaries. For example, from an eulachon's perspective, there may be little difference between an inlet like the Gardner canal (which in March, is mainly fresh on the surface waters (McCarter and Hay, 1999) and a river like the Fraser. The inlets have approximately the same lengths and widths as the rivers, and both receive a number of small river tributaries, in which eulachons spawn. As eulachons swim up large rivers or inlets, perhaps they are really seeking some smaller river or stream, as the focus for their spawning sites.

LOCATIONS AND PHYSICAL CHARACTERISTICS OF SPAWNING RIVERS

As first glance, there are few common features among the eulachon spawning rivers listed in Table 1. Some are large or turbid, with high sediment loads; others are small and clear. The high sediment loads are not necessarily unnatural, and occur in relatively undisturbed rivers in Alaska, such as the Twentymile River, draining into Cook Inlet (E. Kitto, Eulachon Research Council Minutes, 2000). In contrast, other eulachon spawning rivers, like the Kemano are clear.

There is, however, one factor common to nearly all rivers. Virtually all have spring freshets, which are characteristic of rivers draining large snow packs or glaciers. Indeed, most of the rivers shown in Table 1 can be traced to having some part of their headwaters occurring in glacier or snow pack areas. This observation also holds for most rivers in US waters, including Alaska (Steve Moffit, Pers. comm.). Perhaps, for this reason, there are no known eulachon spawning rivers found on any large coastal islands, including Vancouver Island, Queen Charlotte Islands, Kodiak or any of the small coastal island in northern BC or south-eastern Alaska.

MARINE LARVAL SURVEYS AS INDICATORS OF EULACHON SPAWNING RIVERS

Ichthyoplankton surveys have been shown to be effective at detecting *small*, spawning runs that might be missed by conventional fishing techniques (gillnet or seine nets) on adults. Substantial numbers of eulachon larvae can be caught in rivers where no (or negligible) adult spawning is observed. Further, the duration of the presence of larvae in adjacent estuaries seems to occur over a number of weeks, whereas the duration of spawning may be complete within days. A wide range of larval densities can also be measured using standard ichthyoplankton survey techniques, not only in rivers but also in estuaries, inlets and open ocean areas, during an 18-20 week period (April to August) 4 weeks after adult spawning has occurred. The basic technique is simple and requires a plankton net and a swept-volume procedure. Larval surveys are described later, and also in detail in Hay and McCarter (1997) and McCarter and Hay (1999).

ANADROMY: MARINE VERSUS FRESHWATER HABITAT

Eulachons are anadromous, spawning in the lower reaches of rivers, followed by a movement to the sea as small pelagic larvae. Although they spawn in fresh water rivers and streams, eulachons (*Thaleichthys pacificus*) are mainly a marine fish, spending over 95% of their lives in marine waters. This is based on an estimate of 4 weeks in freshwater as incubating eggs and larvae and another 4 weeks as returning spawners, for a total of about 8 weeks of freshwater residence in their lives. A 3-year-old eulachon (age 156 months) would then have spent 5.2% of its life in freshwater. A 4-year-old eulachon would spend only 3.8% of its life in freshwater.

HOMING: BIOLOGICAL IMPLICATIONS

If eulachons home to natal rivers, they must imprint to those rivers at earlier life stages. Presumably imprinting in eulachons, if it occurs, would involve the same physiological processes as salmonids, which specifically is the memorization of chemical characteristics of the water of the natal sites (Hasler, 1966). In the case of eulachons, such imprinting would have to occur either during the egg stage, while incubating in the sediments of various rivers, or during the short-duration of the larval stage, while in fresh water. Salmon, however, probably do not imprint during most of their egg stage, perhaps in part because of the limited exchange of water across the membranes of the egg capsule. Indeed, the inter-river transfer of fertilized salmon eggs, followed by imprinting of the alevin stages to the new river is a standard salmonid stocking technique. Therefore, the potential for imprinting during the egg stage of eualchons is not clear, and seems improbable. It follows that if imprinting occurs, then it must occur during the larval stage, but again we note that the duration of this stage, while it is in freshwater, is very short relative to that of salmonids. Also, an eulachon larvae is very small, about 6 mm in length and weighs only a few mg - which is less than 1% of the weight of a comparable salmonid and therefore may lack the necessary physiological tissue (i.e., olfactory rosette and associate nervous system memory capacity) as salmonids. For these reasons, imprinting during the freshwater larval stages seems unlikely. On the other hand, the larval stage may have a relatively long duration, perhaps several months or more, in the estuarine and marine waters adjacent to spawning rivers. This could be an opportunity to imprint during the juvenile stages, because the duration of the stage may be sufficient and the size and physiological development of the developing juveniles could be sufficient. If imprinting did occur at this time and place, however, it probably would be less precise than that of most salmonid imprinting. It is probable that imprinting would be specific only to estuarine waters, and not to that of specific rivers, either within estuaries (such as the Gardner Canal or Dean Channel), or to tributaries within large rivers, such as the Fraser or Columbia.

Distribution in the Sea: Marine Habitats and Offshore Distribution

The 2-3 year period between hatching and spawning appears to be spent mainly in near-benthic habitats in open marine waters. Based on analyses of distribution as bycatch in shrimp trawls, and as incidental capture during research trawls, eulachons appear to live near the ocean bottom in waters of moderate depth (20-150 m). They are rarely captured in the Strait of Georgia as adults, and the few instances of capture appear to be related to their spawning migration to rivers.

The distribution of larval eulachons in estuarine and marine waters has been described briefly by Barraclough (1967) and McCarter and Hay (1999) and is summarized briefly here in Figs. 4a-i. Barraclough's paper is interesting because he describes the distribution of young juveniles, and finds them in the Strait of Georgia. In contrast, studies of incidental eulachon bycatch in shrimp trawls (Hay et al., 1998 and 1999) found none in the Strait of Georgia. The mesh size of these shrimp trawls was larger than that of the small, experimental mesh used by Barraclough. Therefore, it is probable that young juveniles are found in many coastal waters, such as the Strait of Georgia, but their small size makes them difficult to detect. (Note: Readers should be advised that the small, juvenile stage is a difficult period for study among most marine fish, particularly when juveniles are sufficiently large to avoid slow moving, fine mesh, plankton nets, but still too small to be retained in mesh sizes common to commercial shrimp gear.)

The distribution of eulachons in the marine waters off BC has been compiled from review of all incidental catches of eulachons from research surveys, and is shown here for the first time in Figs. 5a-b.

Proximate Analysis

The scientific name for the Genus of eulachons (*Thaleichthys*) is derived from Greek, meaning 'rich fish'. This richness is in the form of very high oil content, which was the basis for the processing and extraction of eulachon 'grease', by First Nations. This high oil content has been recently confirmed in a comparative study of forage fished in Alaska and the Bering Sea (Payne et al. 1999) which found that eulachons have an oil content of about 20%. This was the highest of all species examined and about 4-5 times greater than most other species of comparable size. The biological reason for this exceptionally high oil content, however, is unknown.

Age Determination

Age validation of eulachons has been difficult. Most recent work has used otoliths, but age estimates from otoliths may not be reliable. This was the conclusion of Ricker et al. (1954) who compared scales and otoliths from Fraser River fish. Although neither scales nor otoliths provide clear indications of age, age estimates from otoliths were higher, by 1-2 years, than scales. This difference held for 3 different readers, who examined both scales and otoliths from the same fish. In fact, Ricker et al. (1954) tentatively concluded that most Fraser River spawning fish were mainly two-year-old fish, with most spawners at age 2 (~24 months), and a few spawners at age 3. Further, he suggested eulachons, like pink salmon, and may have had alternate weak and strong returns. Smith and Saalfeld (1955) aged Columbia River eulachons using otoliths and concluded most were age 3 (~36 months) with a few age 4, 5 and 2, but later DeLacy and Batts (1963) obtained older age estimates from otoliths. Results from recent analysis of otoliths of BC eulachons (Table 2) indicate that the fish are mainly age 4-6, but these data are suspect because there is no corresponding increase in size (length or weight) with the putative age (Fig. 6). Consequently, age data based on otoliths cannot be considered as reliable, unless they are verified from other means of analyses. The best estimates of age are based on analyses of size, and the modes from offshore samples. Samples from shrimp research surveys conducted in May, show that there are 2 distinct size modes (Fig. 7) that correspond to ages 1 and 2 (i.e. 12 and 24 months). There also are a few individuals that are smaller (age 0+, or a few months of age) and some distinctly larger, corresponding to ages 3 (~36 months). The modes shown in Fig. 7 are consistent with other data. For instance, a re-analysis of Barraclough's (1967) data (shown in Table 3) indicates that there also are several distinct modes in his data that correspond approximately with that seen in Fig. 7. The modes, however, are dynamic, because of rapid growth of eulachons in offshore waters. Another problem with modal analyses is the substantial inter-annual variation, and this also is seen in Fig. 7, which shows that the two modes in 1999 are shifted to the right (i.e. larger) than those in 1998. Yet another problem is the variation among areas with some areas, such as the inshore waters of Barkley Sound (Statistical Area 23) having mainly smaller eulachons (smaller size modes) and areas offshore (Statistical Areas 121-125) having mainly larger eulachons (larger size mode). Therefore, pooling size data over different areas and different years could diminish modal variation associated with age. For these reasons we analysed eulachon length data (n >30,000) collected in marine waters, mainly from 1997 to 2000, from samples taken by observers and research surveys (Fig 8a). These pooled data do not show the same sharp modal differences seen in Fig. 7. Still, some differences in modes can be seen in some areas, and the overall size composition, shown by length (cm) category and Statistical Area, shows the 2 main modes seen in Fig. 7. A clear bimodal distribution is seen, for instance, in Statistical Area 4 (northern BC) as well as other areas. The probable ages of these modes are indicated in Fig. 8b which shows an interpretation of the size ranges, consisting of mainly ages 1 and 2, with only a few at age 3. This size distribution is consistent with the view that most eulachons spawn at age 3 (36 months) with a few spawning at age 4. This is also seen in a comparison of the size distribution of eulachons taken in rivers with those from the sea (Fig. 9). Spawning eulachons in rivers are larger than those in the sea and correspond to the largest size modes seen in the sea. This also is consistent with the older age data based on scales (Ricker et al., 1954). Also, it matches with some preliminary observations that we have made in the laboratory, where we ground and polished some otoliths to clarify the rings, from spawning eulachons. In general, most were age 3. From these observations and analyses, we conclude that most eulachons spawn at age 3, with a few older (age 4 or 5) and younger (age 2) participants.

REPRODUCTIVE BIOLOGY

AGE OF SEXUAL MATURATION AND POST-SPAWNING MORTALITY

The age of sexual maturity is uncertain because age determination is uncertain (discussed later) but probably is about age 3 for most fish. Also, it is probable that nearly all eulachons die after spawning (similar to Pacific salmon). We observe substantial post-spawning mortality in most rivers. The best evidence for post-spawning mortality, however, is from teeth. Spawning eulachons in rivers have few teeth, probably because most have resorbed the calcium and other minerals prior to spawning, presumably for egg production. The resorption does not seem to be uniform among all bones in the jaw, with few eulachons retaining some teeth. In contrast, all eulachons captured in offshore marine waters have large pronounced teeth, and we have found no marine eulachons without teeth. This observation, combined with the observation that the largest eualchons are found in rivers, indicates that they do not return to the sea after spawning. We note, however, that Alaska researchers did observe teeth in spawning eulachons in the Cook Inlet area (E. Kitto, Pers. Comm.). This raises the possibility that the completeness of post-spawning mortality may vary geographically.

SEX RATIOS AND RELATIVE SIZES OF THE SEXES

Based on collections in the Fraser River, we observe that the lengths of males and females are approximately equal both in 1995 and 1996 (Table 4, from Hay et al., 1997b). Further, the overall sex ratio of spawning eulachons from the Fraser River is approximately equal, although some individual samples may have been predominately males, or female. Similar observations of some samples consisting of mainly one sex appears to have led to assertions that skewed sex ratios are the norm, but we have not seen this in our samples.

FECUNDITY

An external distinguishing feature between sexually mature male and female eulachons is the pelvic fin which is larger and longer in males. The tip of male pelvic fins usually, but not always, reaches the anus, while in females the fin will never reach the anus. The only sure way to sex eulachons, however, is to cut them open and look for an egg mass or gonads. Remarkably, we have occasionally found hermaphrodites (male and female gonads in the same fish), with 1 specimen observed in a sample of 210 eulachons.

The method for estimating eulachon fecundity follows that used for herring (Hay, 1985) and a brief description follows. Most fecundity samples are taken from ovaries that have been stored in formaldehyde after a fresh weight (gms), or thawed weight, is obtained. After storage and hardening of eggs, the whole fixed ovary weight is taken. Then 3 sub-samples of exactly 100 eggs are taken and weighed to the nearest mg on a microbalance. If the sub-sample weights agree within 5% then the mean weight is estimated from the 3 sub-samples to obtain an individual egg weight. From this, an estimate of total fecundity is obtained by dividing the total fixed ovary weight by the individual egg weight. (Note, this ignores the weight of maternal ovarian tissue, but this is small, probably < 5%). The estimate of relative fecundity is obtained for each individual by dividing the total fecundity by the body weight, to get an estimate of the numbers of eggs per gram, for females. The relative fecundity for different rivers is obtained by assuming that the weight of males is approximately equal to that of females, so the relative female fecundity, is divided by 2.

Fig. 10 shows the results of fecundity analysis of 624 eulachons (5 from Knight Inlet, 521 from the Fraser River from 1995-1999, 73 from the Kitimat, 3 from the Kemano and 22 from the Kowesas rivers). The size-specific fecundity of Fraser River fish was higher than that of Kitimat or Knight Inlet fish (Fig. 10a), but this may be misleading, because some of the fish from both locations may have been partially spent.

Fecundity increases with fish length, but the relationship is quite variable, with some small eulachons having high fecundities and vice versa. The relationship between fecundity and length (estimated for the Fraser River only) is shown in Figs. 10b-c. A quadratic equation, describing the relationship between standard length and fecundity provides a slightly better fit than a simple linear equation, with a r^2 of 56.5 and 58.0 respectively. This is higher than the relationship between fecundity and weight, for which r^2 is 49.9 for both a linear and quadratic equation. In general, for most spawning eulachons, the total fecundity is about 20,000-40,000 eggs.

The estimates of egg weight (Fig. 11) also vary as a function of length and the r^2 for a linear relationship between egg weight and length (59.5%) is nearly the same or greater than that between egg weight and log length (60.1%) (Figs. 11b-c). Estimates of relative fecundity (Fig. 12) indicate changes among years with 1997 and 1998 being higher (Note: no samples were available in 1999 because the proposed test fishery, the source of all samples, was not conducted. Samples for the year 2000 are available but have not yet been processed in the laboratory.). Relative fecundity will increase if there is a decrease in the proportion of somatic tissues, perhaps caused by lower condition factors (Hay, 1985; Hay and Brett, 1988). This was examined by first doing a linear regression of the length: weight relationship for data pooled among all years and comparing the distribution of residuals between years. Using this approach, fish that are relatively heavier at a specific length (i.e. higher condition factor) will have positive residuals, and vice versa. The distribution of residuals for 1997 and 1998 were significantly lower than the two previous years, indicating a decrease in condition in 1998 and 1999 compared to the 2 previous years (1995 and 1996).

SPAWNING TIMES

Among-river variation.

Eulachons spawn in the early spring, beginning in January and February in the Columbia River and extending to the late April and May in the northern rivers. Unlike many other small fishes, such as herring, the geographical variation in eulachon spawning time is not a simple relationship of earlier spawning in the south and later in the north, at least within BC waters. For example, the Fraser is the most southern BC river supporting eulachons, but it has the latest spawning times, mainly in April and May. In contrast, the most northern BC rivers, the Nass and Skeena, have the earliest times, beginning sometimes in late February and early March. If the entire range of eulachons is considered, however, the most southern runs (i.e. the California and the Columbia River runs are early, beginning in late January, whereas some of the Alaskan runs are much later (May), although not too dissimilar to the Fraser. The explanation for the differences in spawning times is unknown but, as noted later, the geographic variation in spawning times may be a key factor in the assessment of the status of eulachons.

Within-river variation.

There are sufficient data available from the Columbia, Fraser and Klinaklini rivers, and perhaps others, to confirm that there may be substantial differences in the timing of spawning. This is not a simple task, however, because it is complicated by possible variation in the duration of spawning. Therefore the annual 'timing' of spawning could be estimated as the time of first spawning, the time of peak (median) spawning, the mid-point (mean) in the duration of spawning, or perhaps even the date of the last spawning. Both Ricker et al. (1994) and DeLacy and Batts (1963) attempted to relate the timing of spawning to ambient water temperature, but the results were equivocal.

LIFE HISTORY STAGES

THE EGG STAGE

Eulachon eggs are small (<1.0mm diameter) and mildly adhesive. There is an outer membrane that serves as a sticky 'stalk' that anchors the egg (Fig. 13a). Single eggs or clumps of eggs stick to grains of sand or other debris that appear to 'anchor' eggs to the bottom. During river surveys some eggs often are collected in plankton nets (Pedersen et al., 1995; Hay et al., 1998). Most eggs are captured relatively soon after spawning, often during a burst of eggs that occurs immediately after spawning. Unfortunately, it is not clear if some of these eggs are alive or dead. It is not possible to field identify individual eggs in the murky Fraser River water. The samples are fixed immediately after collection so it has not been possible to separate eggs from debris to determine if the eggs are alive or dead. In experimental conditions, Columbia River eggs hatched over a period of 21-25 days when incubated at temperatures of approximately 8 °C (Parente and Snyder, 1970). It seems that in most rivers spawning occurs in fresh water, but not far above the upper extent of seawater, although in the Fraser or Columbia, this could be 50-100 km upstream. The duration of incubation is temperature-dependent (DeLacy and Batts, 1963) but at ambient temperatures of 4-5 C (perhaps typical of northern BC rivers), hatching occurs in about 4 weeks.

THE LARVAL STAGE

The larvae (Fig. 13b) are small (6-8 mm), elongated with a distinct yolk sac and oil globule and resemble many marine pelagic fish larvae. In most rivers, the larvae are flushed to sea rapidly, probably within minutes in some streams. Once in the sea, larval eulachons may be retained in low salinity, surface waters in estuaries for several weeks or longer.

Larval eulachon distribution in BC

Hay & McCarter (1997) describe surveys of Pacific herring larvae (*Clupea pallasi*) to comment on stock structure. Those surveys also have determined the distribution of larval eulachons and comment on the possibility that larval distributions from different rivers overlap and mix. In 1996 and 1997, surveys for eulachon larvae were conducted in nearly all BC mainland inlets, with emphasis on the locations nearest rivers that might serve as potential eulachon spawning areas. If substantial mixing of larvae occurs among rivers, then maintenance of genetic isolation between individual spawning sites would be unlikely unless eulachon larvae possessed homing mechanisms that allowed them to imprint precisely to each river. Small, undeveloped larvae, such as those captured near rivers during the surveys, are unlikely to acquire such imprinting capabilities.

Surveys conducted early in the season (April 14-25, 1997) showed larvae distributed closer to known, eulachon spawning rivers, while surveys that were conducted late in the season (May 27-June 7, 1996, Douglas Channel-Gardner Canal) showed eulachon larvae widely distributed along the entire lengths of inlets to open ocean areas. Fig. 4 shows detailed maps of larval eulachon densities represented by the size (areas) of each sampling station circle. A cross represents a station where no eulachon larvae were captured. Maximum larval densities are indicated below each figure. The highest recorded eulachon density (32.2 larvae/m^3) occurred at the head of Gardner Canal near the Kitlope River estuary. Eulachon larval densities decreased gradually in a seaward direction along most inlets until reaching the measuring resolution limit of the plankton nets (approximately 1 larvae per 100 m^3 of seawater filtered through the 57-cm diameter bongo net during a 6-minute tow).

Most larval eulachon were found adjacent to known, eulachon spawning rivers. The presence of eulachon larvae at the heads of some inlets surveyed, however, suggested the occurrence of eulachon spawning in nearby rivers not previously known to support eulachon spawning (Table 1). In some cases, there was uncertainty whether the captured larvae were recently flushed down from nearby, undocumented eulachon spawning rivers or were advected to the heads of these inlets from further distant but known eulachon spawning areas via deeper, landward currents controlled by estuarine circulation with possible Coriolis effect. Larval eulachon samples that were collected at the heads of particular inlets (Loughborough Inlet, Thompson Sound, Smith, Moses and Kynoch Inlets) were comprised mostly of small, newly-hatched larvae (3.6-8.0 mm) which supports the first explanation. Significant numbers of large (8-27 mm) and small (4.4-6.6 mm) eulachon larvae were collected in other more remote inlets (Khutze and Aaltanhash Inlets) which supports, but does not negate, the second scenario (for more explanation, see McCarter and Hay, 1999).

Larval samples collected at the heads of inlets, adjacent to known eulachon spawning rivers consisted predominantly of small, newly hatched larvae. Mean eulachon larval size (mm) generally increased at each sampling station in a seaward direction away from eulachon spawning rivers (Fig. 14). Larval eulachon collected at some stations along inlets, however, showed a wide range of larval sizes indicating mixing of small, newly hatched larvae from nearby rivers (i.e. Kemano or Kowesas River flowing into Gardner Canal) with much larger larvae, from more distant rivers (i.e. Kitlope River at the head of Gardner Canal). Larval mixing was also suggested between eulachon originating in the Kimsquit and Bella Coola rivers and between several eulachon spawning rivers in the Johnstone Strait Region.

Very few larvae were caught in the open, ocean entrances of the inlets (i.e. Queen Charlotte Strait). Other ichthyoplankton surveys conducted later in the year, however, have captured eulachon larvae in more open ocean areas. One hundred and twenty-eight eulachon larvae, 12-34 mm in size were captured late in July and early August at 31 sampling stations located in the centre of Chatham Sound and west of Porcher Island (Figure 4i) using the same bongo net gear and techniques (McCarter et al., 1986). No larval eulachon were captured during similar ichthyoplankton surveys conducted in May of 1985 or 1986 in nearshore areas around Moresby or Porcher Island (Hay & McCarter, 1997).

Larval eulachon: relative abundance

Estimated numbers of eulachon larvae determined by the area expansion of each measured density at each sampling station are shown in Table 5 for each region and year. Eulachon larvae were more abundant during the 1994 survey in the Johnstone Strait Region than those estimated in the same region during the 1997 survey. Rivers Inlet larval eulachon estimations were similar between the two years. Queen Charlotte Strait surveys captured few eulachon larvae but this region was not covered equally between the two years so comparisons may be invalid.

Larval eulachon depth distribution and capture avoidance

Most eulachon larvae were captured in surface waters between 0 and 15 metres depth. Considerably fewer larvae were caught at depths of 20-35 metres (See Tables 5a and 5b from McCarter and Hay, 1999 for details). In general, density estimates of larval eulachon were greater near the surface waters during night plankton tows than during daytime tows, but this conclusion is tentative because of 2 potential sources of error: (1) continuous advection of pulses of larvae through the sampling areas could obscure any relative pattern (2) an opening and closing device was not installed on the bongo frame such that depth contamination upon deployment of the nets to each fixed depth, would slightly inflate larval densities at lower depths. These influences, however, were considered minimal. Other sources of error could involve deflection of larvae near the stern wash of the vessel and capture avoidance by large, developed larvae in the undisturbed, surface waters off the starboard sampling side during daylight.

Mean larval eulachon lengths were significantly smaller in daytime catches than night catches. Larvae sampled in surface waters were also consistently smaller than those at deeper depths. Capture avoidance of large, developed larvae is a significant factor considering eulachon larvae greater than 30 mm in length are rarely captured in bongo net gear (McCarter et al., 1986). The turbidity of seawater filtered through the nets (milky colour from glacier-fed rivers) was also highly variable during the surveys. A particularly sharp border between turbid and clear water was observed midway along Gardner Canal where the canal makes a hairpin turn (Cornwall Point). Larval eulachon density estimates declined at this point and again where Gardner Canal joins Douglas Channel (Fig 14). Most surveys, however, were conducted early in the season when larvae were small (< 15 mm) and sampled with oblique tows (0-20 m variable sampling depths) so that deflection and capture avoidance by larger larvae in the surface waters was considered insignificant. Kitimat Arm fixed-depth plankton tows were conducted late in the season (June 4, 1996) when this frequently overlooked sampling bias can have a more influential effect on fixed-depth surface samples.

Larval surveys as indicators of spawning origins

Larval surveys made in the vicinity of potential rivers, 6-8 weeks following spawning, provide data to corroborate the existence of spawning runs in different rivers in the central coast of BC (McCarter and Hay, 1999). For most BC rivers known to have spawning runs, McCarter and Hay (1999) found larvae in the adjacent marine and estuarine waters. In some instances, additional concentrations of larvae that appeared to originate from small rivers that were previously unknown as eulachon runs (see Table 1).

The results of the surveys described in McCarter and Hay (1999) did not examine all potential areas of the coast as possible sources of eulachon larvae. For instance, these surveys did not investigate potential spawning sites around the Strait of Georgia, Vancouver Island or the Queen Charlotte Islands. These areas, however, were examined during other surveys directed at describing the distribution of Pacific herring larvae (Hay and McCarter, 1997). These other surveys were conducted in April and May and found virtually no eulachon larvae in these outer areas. This reinforces the conclusion that eulachon spawning is mainly confined to coastal rivers that have a distinct spring freshet (Hay et al., 1997a).

Larval survey information as contributions to the biology of eulachons

We observe that eulachon larvae mix and distributions overlap with other eulachon larvae originating from several eulachon spawning rivers. This occurred at the head of Knight Inlet, Dean Channel and Gardner Canal. In the central coast eulachon larvae disperse and mix with other plankton in coastal areas during an 18-20 week period (April to August) 4 weeks after adult spawning has occurred. Based on modal variation in length frequency data, larvae grow from approximately 3-4 mm in size to 30-35 mm in size during this period.

Oceanographic features measured during the surveys suggest that BOTH dispersion and retention mechanisms affect larval distribution. Clearly there is some dispersal of larvae as they discharge from the relatively small spawning areas in rivers (probably from an egg deposition area of between 0.1 and 1.0 km^2 in most rivers) to an area from 10-1000 km^2 for most larval distributions. On the other hand, larvae appear to be retained in inlets, and the larval eulachon distribution seems to be more oriented to fjords than the distribution of herring larvae, which are captured at the same time of year. Like herring larvae, however, relatively high larval eulachon densities, measured on the left sides of inlets (looking seaward), suggest an accumulation or retention effect (Coriolis effect) while larval samples collected at other stations showed a continuous dispersion effect due to estuarine outflow and wind and tidal influences (Hay and McCarter, 1997).

The larval rearing environment in BC’s deep, cold and remote inlets seems to be dominated more by physical factors than biological factors. The inlets and deep fjords surveyed are known to be relatively low in overall productivity as compared to the rich, productive offshore banks and adjacent nearshore areas exposed to open ocean. Therefore it is likely that some protection from predators is afforded in these inlets while eulachon larvae absorb their yolk sacs and gradually acquire the characteristics necessary to survive in open, ocean environments. Further, the confinement of eulachon larvae to the upper layers of relatively low saline water (resulting from estuarine circulation) would eliminate most stenohaline predators (i.e. most marine fishes and invertebrate predators). As a consequence, small spawning runs of eulachon may be more sensitive to ocean climate changes particularly those that impact the freshwater discharge than, for instance, large spawning runs of herring that deposit vast numbers of progeny usually near the centres of highly productive areas.

THE JUVENILE STAGE: AGES 8 WEEKS - 12 MONTHS

There is no precise definition of the 'juvenile stage' but within the scientific literature on marine fish, the term is often is used to describe a stage that has moved beyond the larval stage, in the sense that it has grown to a sufficiently large size to emerge from the ichthyoplankton (unlike larvae) and schooling behaviour has become evident. There also is an understanding that the juvenile stage involves the development of 'fish-like' characteristics (instead of elongated larval characteristics) and the development of lateral scales and pigmentation (whereas larval stages tend to be transparent). In general, this stage involves fish from about 3-10 cm.

The distribution and ecology of this stage, when fish are too large to be collected in ichthyoplankton gear, and too small to be retained in fishing nets, is poorly known. The meagre information available is from a few data reports on experimental 'two-boat trawl' surveys, mainly from the Strait of Georgia, and summarized by Barraclough (1967). This report is interesting on several counts because Barraclough describes eulachons as occurring in the Strait of Georgia, but they are not captured there by commercial shrimp gear (Hay et al., 1998 and 1999).

The distribution of juveniles is poorly understood, but it seems that individuals disperse to open, marine waters within their first year of life and perhaps within the first few months, because some (which may have been classified either as large larvae, or small juveniles) were taken off Porcher Island, in plankton nets, in July (McCarter and Hay, 1999).

THE OCEANIC, SUB-ADULT AND ADULT STAGE

The distribution (See Fig 6) of this phase is known from incidental capture in various research cruises conducted over many years. It is also known from analyses of bycatch in shrimp trawl gear (Hay et al., 1997a, 1998 and 1999) but these data are confined to limited areas of the coast where shrimp fisheries occur.

From the analyses of catches of eulachons in incidental research data we know that there is seasonal variation in eulachons catch rates (kg/hour) with most incidental capture taken in the summer months. The data and analyses, however, cannot distinguish between numbers of eulachons and total weight of captured eulachons. If the incidental capture consisted mainly of small eulachons in their first year of life (<12 months) then the capture rates by number may vary from that indicated in this figure. These analyses also indicate that eulachons are found in waters up to 500 m of depth but most are taken in the depth range of about 100 m (Figs. 15). This is determined from comparison of the incidental catch rate (kg/hour) as a function of 'bottom depth' or 'depth of net' (Fig. 15a, b). Although the data indicates that in some instances eulachon may have been captured at depths of neatly 500 m, but this is not certain, because eulachons may have been entrained into the nets, either on deployment (descent) or recovery (ascent). In other instances, eulachons were taken in very shallow water (< 10 m), although it is not clear if there is a change in size or age composition of eulachons with depth. A relationship is indicated in Fig. 7, which shows smaller size modes in Barkley sound contrasted to larger modes in offshore waters.

Eulachon catch rates (kg/h) appear to vary with season, and when compared by ANOVA, the differences are significant (Fig. 16) although there is a lot of variation in all months. Also, this analysis was conducted on data pooled over a number of years, and may have included different year classes of eulachons, so the results cannot be validated.

THE PRE-SPAWNING STAGE

A short period between the end of the summer prior to spawning and their arrival at the river constitutes the 'pre-spawning phase'. It may not warrant being called a distinct life-history stage but this classification is convenient, if not biologically distinct. During this time gonadogenesis occurs, and sexually maturing eulachons must segregate from the non-maturing component of the population and migrate to spawning rivers. Prior to entering the river, and like salmon, they probably hold in brackish water as they make the physiological changes that allow them to survive in freshwater. Because we now believe that eulachons are exclusively semelparous (explained below), somatic tissues are sacrificed for the benefit of gonads, and it appears that females (and perhaps males) resorb minerals from scales and some teeth.

This stage, is the period when eualchons tend to become conspicuous to predators, usually at river mouths. It also is the stage when eulachons are taken in traditional fisheries for grease, and this is the phase when much of the traditional knowledge applies. Traditional knowledge is particularly rich on aspects of the spawning biology of eualchons, including factors such as the tidal and river flow conditions that are most suitable, for eulachons. In many rivers, the precise within-river migration route is known, as well as the timing and capacity for variation.

THE SPAWNING STAGE

We do not know the duration of the spawning act, but we can assume that it is at least hours, and may last for a day or more. Spawning appears to occur mainly at night and involves groups of fish. In contrast to some marine fish such as herring, eulachons must closely synchronize the timing of spawning between sexes, because the duration of the viability of sperm in freshwater is short, perhaps only minutes.

THE POST-SPAWNING STAGE

After spawning, there is a large, post-spawning mortality that we believe is normal. M. Bailey (Katzie FN) describes the banks of the Fraser River as being 'white' with the carcasses of spent eulachons. This also occurs in other rivers, and has been directly observed by us in the Kemano River estuary. This stage may provide important sources of nutrition for many scavenger species, and particularly sturgeon in the Fraser River (See comments by M. Bailey and M. Roseneau, Eulachon Research Council Minutes, 1998 and 2000). Dead carcasses also could result in a short but substantial inoculation of nutrients to some inlets, and perhaps to the Strait of Georgia (Hay, 1998).

TROPHIC RELATIONSHIPS

Eulachons as prey

Concurrent changes in distribution and abundance have occurred with other species, some of which might be with predators or prey of eulachons. Changes in eulachon predation in the sea are not known or documented but there appears to be increased marine mammal activity in some rivers, especially in the Fraser, during eulachon spawning times. First Nations accounts of past gut analyses of sturgeon (*Acipenser*) indicate that eulachons were an important prey. Similarly, there may have been changes in the prey species consumed by eulachons, but there are few available data.

Eulachons have long been known to be a prey species for many marine fish, and are documented as prey in hake, *Merluccius productus (*Outram and Haegele, 1972), dogfish, *Squalus acanthias* (Jones and Geen, 1977), and Pacific cod, *Gadus macrocephalus* (Westrheim and Harling, 1983). Outram and Haegele (1972) found that about 5% of the hake off the lower west coast of Vancouver Island, examined over a 10 day period in 1970, on the lower west coast of Vancouver Island, contained eulachons. The potentially important significance of this is that hake biomass sometimes becomes very high. Although hake tend to eat mainly euphausiids, even modest predation by an abundant predator on a relatively scarce prey species like eulachons, may have a substantial impact on eulachons. Beamish and MacFarlane (1999) described a recent northward movement of hake, as they have expanded to waters of southeaster Alaska. As hake move into previously unoccupied habitats (at least within the last century) their substantial predatory biomass might have resulted in local depletions of eulachons. The significance of this is discussed later.

Eulachons are sometimes identified as prime prey for marine birds and marine mammals. Predation may be particularly intense just prior to spawning when pre-spawning eulachons concentrate in the lower reaches of rivers. We have observed seals and sea lions in upstream areas of the Fraser River (above New Westminster) during the eulachon spawning period. Also, Morton (2000) suggests that the whited-sided dolphin (*Lagenorhyncus obliquidens*) was feeding on eulachons in Knight Inlet.

At other times of the year, however, mammal predation may be lower, particularly as eualchons occupy relatively deep waters. For instance, Olesiuk et al. (1990) describes the feeding of harbour seals (*Phoca vitulina*) in the Strait of Georgia but the incidence of eulachons is very low relative to other species such as herring or hake. The Strait of Georgia, however may not be a representative location, as few eulachons appear to inhabit the Strait, except for the Fraser River spawning migrations. Olesiuk et al. (1990) make brief mention of diets in other locations in BC but no prey are identified explicitly as eulachons, but only as 'smelt'. Even then, the frequency is low.

Eulachons as predators

Cursory analyses of a few eulachon stomachs from offshore waters indicates they mainly consumed a particular euphausiid species (*Thysanoessa spinifera*) (C. Cooper, Pers. Comm) and there is other evidence that this euphausiid has declined in the last 5-6 years (R. Tanasichuk, Pers. comm.). It is not clear, however, if there are important ecological relationships between these species or if the apparent changes in *Thysanoessa* spp. are related to changes in eulachon abundance. We have found that eulachons in the sea have substantial teeth, from several different jaw bones (Fig. 17). Such dentition, as well as a relatively low gill raker count (Hart, 1973), indicates that eulachons are mainly particulate feeders and require teeth to grab and hold their prey. The low gill raker number indicates that filter feeding, as seen in herring and other osmerids, may not occur in eulachons.

We also note and confirm observations by Hart and McHugh (1944) that eulachon dentition in freshwater spawning fish is much reduced. This indicates that they probably stop feeding as they approach their spawning rivers, and resorb minerals in teeth (and probably scales) to assist with gonadogenesis. The additional significance of this observation is that we do NOT see toothless eulachons in the sea, which indicates that post-spawning mortality probably is complete.

ASSESSMENTS: POPULATION SIZE AND BIOMASS

RIVER ASSESSMENTS - LARVAL SURVEYS

There are few direct estimates of spawning biomass from any river in BC, but the available estimates were summarized by McCarter and Hay (1999) and shown here in Table 6. Similarly, there is very little catch data and most of the available data were recorded informally. Larval samples have been used to assess the abundance of Fraser River adult eulachon spawning biomass. Pedersen et al. (1995) and Hay et al. (1997b) estimated total larval production as the product of the mean larval density (numbers per m^3) and the river discharge (m^3 per second). The conversion from larval numbers to spawning biomass uses estimates of 'relative' fecundity. For the Fraser River, this was about 700 eggs per gram of spawning female or about 350 eggs/g (males included) from the spawning populations (i.e. spawning biomass = [mean larval density] x [discharge]/relative fecundity).

A few similar assessments have been made on other rivers, including one from the Nass, based on unpublished data from U. Orr (DFO) and presented in an appendix in McCarter and Hay (1999). Similarly M. Berry made a larval-based assessment of the Klinaklini River (Eulachon Research Council Minutes, 1998).

RIVER ASSESSMENTS - DIRECT OBSERVATIONS

Assessments have also been made based on direct observations and estimates of the dimensions of pre-spawning or spawning eulachons in rivers (Triton, MS 1991). This was done by aerial surveys from helicopters and, after adjusting for differences in structure and density of schools, resulted in an estimate of 3.2 million spawners (~150 tonnes). Obviously this method requires relatively clear water and logistical support. Even when directly observed, the estimates could be coarse, although with experience and corroborative information, this method may have application in a few non-turbid rivers (Kemano River, Triton, MS 1990 and 1991). As a method for broader application, however, this approach has limited potential for application in most rivers. Another approach is a direct estimate of the numbers of deposited eggs, followed by back-calculation of the numbers of spawners required to deposit the eggs. This technique is broadly used in fisheries biology, and is the basis for Pacific herring stock assessments. Triton (MS 1991) made such an estimate on the Kemano River in 1991 and estimated a total of 1.7 million fish (80 tonnes), about half of the estimate made by visual counting of pre-spawning adults. Both approaches have substantial scope for error, and it would be desirable to have a detailed description of the error, and some estimate of confidence provided for these estimates.

RIVER ASSESSMENTS - CPUE INDICES

Typical analyses of catch and fishing effort data has not been done for eualchons, although there may be an opportunity to apply such approaches on several rivers that have accumulated reliable data sets. One interesting instance is the Kitimat River, where samples have been collected systematically with gillnets for about 10 years (Beak Consultants, MS 1998). Although these data have not yet been systematically analysed to show temporal trends, they did indicate that the run in 2000, and 2 previous years, was virtually non-existent (D. Ferrara, Eulachon Research Council Minutes, 2000). There also are catch data from controlled 'test-fishing' sets for the Fraser River, collected since 1995. There is a systematic record of catch data for the Nass River (G. Barner, Eulachon Research Council Minutes, 2000) and a long time series from the Columbia (Hay et al, 1997a; Bargmann, Eulachon Research Council Minutes, 2000). In the Columbia River catch data are available since the 1930's and may provide an approximate index of spawning escapement.

OFFSHORE ASSESSMENTS

Indices of biomass of eulachons in selected offshore areas can be estimated based on catch rates of nets of known area (and volume) and expanded to estimate the biomass density of the entire survey area (Hay et al., 1997a). An index of offshore biomass decreased sharply in 1993 and 1994, corresponding to sharp declines in Columbia River catches (Hay et al., 1997a). This apparent coherence of the Columbia River catch data and the offshore biomass index (for all years up to 1996) led Hay et al. (1997a) to speculate that eulachons offshore of the west coast of Vancouver Island may have originated from the Columbia River. Although this is possible, it is not substantiated, and there are other explanations. The offshore biomass index is shown in Table 7, for years 1973 to 2000, but we advise readers that there are some changes in the numbers between this report and those presented by Hay et al. (1997a). The changes are associated with the size of the area over which biomass estimates were extrapolated. The numbers shown in Table 7 are based on areas optimzed for biomass estimation of shrimp, but the temporal trends are very similar between these data and those present in Hay et al. (1997a). Since 1998 these offshore surveys also have estimated a biomass index of eulachons for the central coast. Further, based on data from length frequency analyses, and assumptions that the main length modes correspond to distinct age classes (see Fig. 7), the relative abundance of the 2 main age classes has been estimated both for the west coast of Vancouver Island and the Queen Charlotte Sound areas (estimates presented later).

MARINE LARVAL SURVEYS AS INDICATORS OF EULACHON SPAWNING BIOMASS

Variation in vulnerability and catchability of adults can be a problem with assessment techniques that use seines, trawls, gillnets or traps. Ichthyoplankton catchability, however, is relatively constant, as most targets are small (< 15 mm), oceanographically dispersed and unable to avoid the nets. For these reasons, larval fish samples may be better 'unbiased' estimates of the population than samples from other gear types. Variations of standard ichthyoplankton surveys are currently used to assess the abundance of Fraser River adult eulachon spawning biomass (Hay et al., 1997b). Surveys described in McCarter and Hay (1999) however, were conducted primarily to assess distributions, not biomass. The main limitation of the data is that we cannot estimate the egg and larval mortality between egg deposition and larval capture. For these reasons, the estimates of total larval numbers are not a reliable index of spawning biomass. Still, because of the conservation concerns about eulachons, we felt it could be useful to estimate total numbers and then show the approximate estimate of the spawning biomass required to produce the estimated numbers of larvae. The conversion from larval numbers to spawning biomass uses estimates of relative fecundity of about 350 eggs per gram of spawning female or about 700 eggs/g from the spawning populations (males included). Using this conversion, the biomass required to produce the larval eulachon numbers are shown in Table 4.

We are certain that these estimates of spawning biomass are too low, because as calculated, they assume complete survival between the time of egg deposition and the larval period when they were captured. In some cases this could be 8 weeks or more. Therefore, any assumption about negligible egg or larval mortality during this period would be unreasonable. Instead, it is probable that total mortality during this period could account for most of the larvae (i.e. 90% or more). We have only a few estimates of the biomass from rivers in the central coast of BC (Table 7). An estimate was made for the Kitimat River in 1993 (Pedersen et al., 1995) of about 23 tonnes (based on an estimate of the number of discharged larvae of 5.7×10^9 and a relative fecundity of 250 egg/g). From aerial surveys, Triton Consultants (MS 1991) estimated a mean spawning escapement of 4.96×10^6 fish plus 1.875×10^6 fish taken in the fishery. At an approximate mean weight of about 50g/fish, the total spawning run (before catch) would have been about 340 tonnes, and this estimate was regarded as conservative because it did not include fish that entered and left the river prior to the survey, or after the survey. In 1991, eulachons may have spawned in other rivers in the Gardner Canal, such as the Kitlope and Kowesas, and their spawning biomass is unknown. Therefore, we can only guess at the total biomass but it seems probable that the upper Gardner Canal, which drain 3 major eulachon rivers (Kemano, Kitlope and Kowesas) could support eulachon spawning populations of 500-1000 tonnes or more. If so, the 1997 estimate of spawning biomass from the larval surveys of 113 tonnes (which includes the Kitimat and Kildala Rivers) would represent about 10-20 % of the spawning biomass in 1991. By presenting these estimates we do not mean to imply that there was a decrease in biomass between 1991 and 1997, and we do not mean to suggest that any conclusions can be drawn about larval survival. Rather, we only suggest that the numbers of larvae that we estimated in the surveys are not unreasonable, relative to the rough estimates of available spawning biomass.

Larval surveys in estuarine waters provide very approximate and conservative estimates of spawning biomass. These estimates, however, indicate that central coast eulachon populations are small, with a low, total biomass. This is corroborated by a comparison of single point population biomass estimates made for certain years at different rivers, and by a comparison of catch data among different rivers, including the Fraser, Nass and Columbia Rivers, which were outside the range of the survey.

HISTORICAL AND PRESENT STATUS OF EULACHON FISHERIES IN BC

Eulachon populations have supported small commercial fisheries on the Columbia and Fraser Rivers for most of this century. There was a relatively large commercial fishery for eulachons on the Nass River in the early 1900's and at that time, the eulachon was the fifth most important commercially landed species in BC. This has changed so that, except for the Fraser River, the present fisheries are conducted mainly by First Nation's people for the production of grease and as a source of food. In the 1940's and 1950's, the commercial fishery on the Fraser River was mainly for a source of food for fur animals and for small local markets for human consumption. The price was low, however, so it is not clear if the historical catches reflected eulachon abundance (or catchability) or markets, or both. The limited commercial value probably accounts for the minimal attention paid to this species since the 1940's.

During the last 20 years nearly all runs in the southern part of their range (California to mid-BC) have declined. In 1994, there was a sudden sharp decline in spawning runs in 3 southern rivers: the Fraser, Columbia and Klinaklini (Knight Inlet) and perhaps in a few other rivers. This 1994 decline led to the continuing closure of the only two commercial eulachon fisheries (Fraser and Columbia Rivers).

The status of eulachons has also changed in other rivers. During the last two decades a run of eulachons in the Kitimat River was impacted from industry (Mikkelson et al. 1996). The size of the spawning run diminished and the spawning fish became chemically tainted by effluent and rendered unpalatable. Since the 1950's, another important eulachon spawning river, the Kemano, has had changes in discharge volume as a consequence of diversion of the Nechako River into the Kemano. It is not clear, however, if this change has been deleterious to eulachons. There have been apparent declines in other rivers but the explanations are uncertain. Forestry-induced impacts are possible, particularly as logging might affect the hydrology of spawning streams, but this has not been thoroughly investigated. Concurrently, there have been changes in the marine habitats of eulachons. One change is the rapid growth of the shrimp trawl fisheries, and eulachons have long been known to be part of the discarded bycatch. Furthermore, there have been some striking changes in the ocean climate, but the direct effects of this on eulachons have not been determined.

The increasing scarcity of eulachons in these and other rivers have concerned many people, especially some First Nations, for whom the eulachon is a very important species. Climate change, as a general explanation for the declines, is consistent with all of the available information about this species, but many people do not readily accept this explanation. Instead, most explanations for changes in eulachon distribution and abundance tend to be related to local concerns, and usually involve habitat damage caused by logging or industry, or bycatch in other fisheries.

EULACHON SPAWNING BIOMASS AND CATCH DATA FROM BC RIVERS

There are very few biomass estimates available, and most are available only in informal reports. In nearly all instances, these estimates are available for only a single year on the Nass, Skeena, Kitimat, Kemano, Oweekeno (Wannock), Kingcome, Klinaklini and Fraser rivers. The available catch data are shown for each river, by year, from 1929 to 1996. For the purposes of comparison, we present data from 3 rivers, the Nass, Fraser and Columbia rivers, which were outside the sampling areas of the larval surveys. Table 7 shows catch data from the Bella Coola and Klinaklini (listed as 'Knight' because some catch may also come from the adjacent Franklin River). In addition, we present data from a biomass index estimated for offshore areas in southern BC (Hay et al., 1997a). The purpose of showing these additional data is simply to provide a perspective of the relative scale of central coast rivers relative to other rivers. We stress, however, that catch data provides only an indication of minimal spawning biomass, and can be misleading if improperly interpreted.

STOCK ISSUES - BIOLOGICAL AND GENETIC DIFFERENCES

MERISTIC VARIATION

One of the first attempts to examine inter-population variation with eulachons was with meristic analyses - specifically the analysis of vertebral counts. Separate studies were conducted in the Columbia River (DeLacy and Batts, 1963) and in BC (Hart and McHugh, 1944). DeLacy and Batts (1963) failed to find any meaningful differences in runs within the Columbia river based on vertebral counts. To date these independent but comparable data sets have not be examined together. In the preparation of this report, we recompiled the data presented in these original studies (Table 8) and provide a new set of analyses. As shown in Table 8 there are data available for 4 separate years in each of the Columbia and Fraser rivers, so we can compare both inter-annual variation within rivers, and inter-river variation (provided that inter-annual, intra-river variation is not great).

The results are shown in Fig. 18, with relatively lower vertebral numbers for the Columbia and Fraser rivers, and higher numbers for more northern areas identified by Hart and McHugh (1944) as (1) Rivers Inlet, (2) Kingcome-Kingcome inlets and (3) the Nass. The results were compared both by parametric and non-parametric statistical analyses (Table 9). Inter-annual differences within the Columbia River were small but significant, but inter-annual differences within the Fraser were not significant. When pooled among years, there were no significant differences between the Columbia and Fraser rivers, but the differences among all rivers were highly significant, which was the original conclusion reached by Hart and McHugh (1944).

From Fig. 18 it is clear that mean vertebral numbers are higher in the north, which is consistent with trends for clinal increases of meristic series with latitude (Lindsey, 1962). It also is consistent with the early work of Tanning (1952) that shows that meristic series vary as a function of temperature, and that variation in vertebral number can be environmentally induced.

Both the late spawning Fraser River eulachons and early spawning Columbia River eulachons would incubate in warmer temperatures than some of the northern rivers, where spawning may occur under ice. The differences in meristic variation in Fig. 18 do not demonstrate that the populations are genetically distinct - but they do suggest that mixing of eulachons in offshore waters, if it occurs, is not so great as to obscure the differences between vertebral number.

CHEMICAL - ELEMENTAL ANALYSIS OF OTOLITHS

Background

A project completed in 1998 employed elemental analyses of otoliths in an attempt to determine if eulachons mix between different rivers. The results have been presented in a final report (Carolsfeld and Hay, 1998) to the BC Science Council and are in preparation for publication. The use of the technique requires the assumption that there are distinctive elemental compositions of estuarine waters close to spawning areas that are likely to leave a unique chemical signature in the core of bony tissues of fish. If chemical deposits of the watersheds leading to the different estuaries are distinct, then fish that spent their larval period in a particular spawning ground should all carry a distinctive elemental signature in the core of bony tissues like otoliths that are not resorbed. Elemental Analysis with Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICPMS) is a procedure that permits the evaluation of this elemental signature by vaporising the area of interest of the tissue with a laser and then analysing the elemental composition of the vapour with mass spectrometry. A comparison of the LA-ICPMS analysis of the larval portion of the bony tissue of adult eulachon collected on different spawning grounds should thus indicate if fish are returning to their natal spawning grounds or are emigrating from other areas.

Elemental analysis of fish tissues for stock identification with LA-ICPMS is a relatively new procedure pioneered by Elemental Research Inc. (North Vancouver, BC) that has been used for several species (Campana et al., 1994; Wang et al., 1994) but still requires standardisation and adaptation specific to each new species studied. For the eulachon, this included: (1) selection of tissues to be studied, (2) development of preparative and handling techniques for the selected tissues, (3) evaluation of contamination introduced by the preparative techniques, (4) selection of elements to be measured, and (5) evaluation of biological information represented by the analysis. We looked at otoliths and opercular bones as potential tissues to be analysed with eulachons, and developed cleaning, grinding and mounting procedures that are suited to the eulachons. Scales are the tissue of choice for elemental analysis in some other fish species, but we found that the scales of eulachons are too loosely attached to be of use, since most of the frozen samples of eulachons examined were devoid of scales.

Sources of samples

Eulachons were collected during the spawning season in the Klinaklini, Kowesis, Franklin, and Kitimat rivers on the BC central coast in 1995, and from spawning schools in the Fraser River in 1995 and 1996 (Fig. 3). In addition, eulachon bycatch samples were collected in the shrimp trawl fishery in 1995 off the west coast of Vancouver Island and the central coast (Fig. 1). All fish were frozen shortly after capture and stored frozen until processing 3-4 months later. Evaluation of stock distinction was carried out with a single otolith from random samples of 20 fish from each of the rivers and offshore areas indicated above, as well as a further 30 fish collected from the Fraser River in 1996 for evaluation of inter-annual differences. In addition, the second otoliths of a sample of 10 of the fish collected in the Fraser River in 1995 were analysed to investigate variation of the otolith composition within a fish. All of these otoliths were analyzed with a single spot in the centre of the otolith core, presumed to represent larval life of the fish. The sequence of analysis of the definitive otolith samples was blocked with stock identity to allow statistical correction for and evaluation of machine variability between analysis sessions. Discriminate analysis was done using SYSTAT© statistical package, both with hypothesised groupings of the sampling area and analysis sessions. This analysis was also carried out with data pooled among the central coast "stocks". Subsequent analyses by a Scanning Electron Micrography showed that the laser ablation crater in the otolith was generally 80-120 μm in diameter and of an undetermined depth. This diameter corresponded quite well with the diameter of the otolith primordium, but in the periphery represented about 40-60 days of life, as judged by the 2 μm width of the presumed daily growth increments. However, not all of the crater was necessarily analysed during LA-ICPMS, as most of the edges looked fractured rather than burned.

Selection of elements

An initial suite of 45 elements was used in our preliminary work. Of these, 38 were selected for further utility, based on relative abundance, large or small ratios in abundance in outlying portions of the otoliths, or significance in stock discrimination of other species. During the analytical phase of the work, we identified 7 elements with a strong signal, 9 with a periodically strong signal, and 5 with a relatively weak signal that was useful only in data of the first three of the five analytical sessions. Fourteen of the remaining elements/isotopes were found to have too weak a signal for analytical use and three were found to have a highly unpredictable background variation.

Results - Discriminant Analysis

Correct classification into our hypothesised stock groupings was influenced by data pre-processing and the sequence of submission of samples for analyses. At the beginning of this project, we hypothesized that elemental composition of otoliths from fish collected on different spawning grounds would provide distinctive multivariate group signatures coincident with spawning stock identity. Alternatively, lack of such grouping could indicate straying of fish between the different spawning sites, although this would require additional evidence. Surveys of larval eulachon distributions show that there is broad overlap of larval distributions in most inlets and fjords (McCarter and Hay, 1999).

Samples of otoliths were prepared and submitted for analyses in 'blocks', with about 18 otoliths per block. Each block contained samples from all river systems. A single session would analyses all otoliths and there were 5 sessions. The preliminary results indicated that otoliths could be separated both by the river or location of origin and by session date. If we had submitted the samples according to location, so that the samples analyzed from each session corresponded exactly to a single location, then we would not have been able to distinguish between variation associated with the session date from sample location. Indeed, we found that both location and sample data provided a basis for grouping the samples and this posed a dilemma. Can we conclude that there is significant variation among the some rivers when we know that there are other significant sources of error? Alternately, can we examine the apparent sources of analytical variation (mainly date) and determine if this is sufficient to confound the (tentative) conclusion that there are some partial elemental differences among stocks? To address this issue, our statistical analysis were exploratory in nature, both in terms of developing an optimised discriminant model to produce the hypothesized grouping and in terms of evaluating the validity of the procedure and its application. In this process, we passed through several stages of analytical processing.

Considerable overlap in the distinction of our groups still existed (Fig. 19), leading us to the conclusion that either the elemental analysis was not an appropriate procedure for eulachons stock analysis or there is considerable straying between rivers. Examination of the classification matrix suggested that more expansive groupings of the rivers may be indicated. We thus pooled the fish into north coast (Kitimat and Kemano/Kowesis), lower central coast (Klinaklini and Franklin) and Fraser fish and found that correct classification of these fish within this discriminant model was considerably better, and the backstepping model optimization improved correlation with jack-knifed classification as well. When we entered the replicate otoliths of the Fraser River fish used to build the model, they grouped with high fidelity with the original Fraser River fish, and offshore fish grouped as an interesting balance between the two central and north coast fish pools. However, otoliths from fish captured in 1995 in the Fraser River unexpectedly did not group well with 1996 samples from the Fraser River. The Fraser River 1995 otoliths were distinctly high in ^{138}Ba. This could be a marked inter-annual variation in elemental composition of eulachon otoliths from this river, which could create considerable problems for reliable stock identification with this technique. Alternatively, these otoliths may have become contaminated during storage or processing.

Conclusions

Elemental analysis of otoliths has interested some researchers as a tool for stock identification, but the application of the technique is controversial, mainly because of uncertainties or error associated with the technique. Our results reflect both sides of the controversy. On the one hand, we see evidence of significant variation in the analytical technique, mainly due to variable background noise that varied with the date of analyses. On the other hand, we also see significant differences among river systems. Further, because of the sequence in which we prepared and submitted the samples for analyses, we were not prepared to conclude the variation associated with technical procedures was sufficient to render the other sources of variation (i.e., river origin) as meaningless.

In summary, we concluded that using elemental analysis, some distinction of eulachon stocks is possible, but that either: 1) the elemental signature is too weak in the fish to allow full separation of the stocks, 2) background noise and machine variability obscures the biological signal, 3) fish stray considerably between the rivers and/or 4) inter-annual differences between fish of a single stock are as great or greater than stock differences. The analyses suggested that that straying is more pronounced between closely adjacent rivers, as would be predicted by the hypothesis of straying for data homogeneity. It is clear, however, that using elemental analysis as a stock separation technique still requires considerable caution. The variability between analysis sessions further indicates that unless a means is found to correct for such differences properly, the general application of LA-ICPMS elemental analysis to stock identification of any fish species can only be carried out on complete sample sets including all stocks in question. Thus, all unknown samples would need to be analyzed together with standard samples for classification, rather than being compared to data gathered from the standard samples at some other time.

GENETIC VARIATION

The biological uniqueness of different eulachon populations or runs remains uncertain. Recent genetic evidence, based on mitochrondrial DNA (McLean et al., 1999) and a limited amount of micro-satellite DNA analyses (McLean, 1999) indicates that there are few differences between any rivers in BC and virtually none between geographically adjacent rivers. There was a clear demonstration of a degree of 'isolation by distance' with the greatest differences seen between the most geographically separated stocks. The lack of apparent genetic variation among different spawning populations led to the tentative conclusion that eulachons consist mainly of one large genetic unit (or ESU - 'evolutionary significant unit'). Based on these results, presented by McLean (1999) and McLean et al. (1999), the probability of finding future genetic variation among eulachon populations is low. These genetic results are consistent with results from other approaches, such as the elemental analyses of otoliths from different populations, and earlier studies examining meristic differences (Smith and Saalfeld, 1955). We caution, however, that these genetic results require corroboration and further study. Still, the general (but still preliminary) conclusions from the genetic and otolith chemistry analyses are that there are few if any differences among eulachon populations.

It is possible that the identification of new alleles using nuclear DNA could prove interesting and useful. If distinct geographic differences in genetic variation could be demonstrated, then there may be a number of different ESU's and COSEWIC classifications that would require re-evaluation: one for each genetically distinct population.

BIOLOGICAL VARIATION

In contrast to the relatively low degree of apparent genetic variation in eulachons, and in addition to the meristic variation described above, there are some other biological differences among rivers. The mouth of the Columbia (at about 46º N) and Fraser (at about 49º N) rivers are separated by 3º of latitude, or about 180 Nautical miles (north to south) or approximately 280 nm by water. The nearest neighbouring populations are located each at the heads of long fjords. The Homathko River is at the head of Bute Inlet and the Klinaklini and Franklin rivers, (separated by only a few miles) are at the head of Knight Inlet. The Homathko and Klinaklini rivers are separated from the Fraser by about 150 and 215 nm respectively, and from each other by about 145 nm. The distances between these rivers are roughly similar to the distances between each river and the estimated offshore concentrations found during research surveys (Hay et al., 1997 a), although we cannot match an eulachon taken from an offshore area to any particular spawning river. If there are no genetic differences among populations from different rivers, then among-river differences in spawning time (particularly between the Fraser and Columbia rivers) and other differences among rivers (Hart and McHugh, 1944) probably reflect some form of local non-genetic adaptation to local environmental regimes. If so, these are differences that should not be ignored relative to conservation issues.

Spawn timing

Although we do have a compete set of data on spawning times for all rivers, there are distinct differences, with the Columbia being among the earliest, mainly in late January and February (Smith and Saalfeld, 1955; DeLacy and Batts, 1963; Bargmann, in Eulachon Research Council Minutes, 2000), and the Fraser River as the latest, mainly in April and May (Ricker et al., 1954, Hay et al., 1997b). Eulachon in northern BC rivers are mainly early spawners, with the Nass and Skeena beginning in late February or March, and most of the rivers in the Douglas Channel or Gardner Canal area, occurring in March. The Klinaklini River, at the head of Knight Inlet, is relatively late, (Stacy, MS 1996), but still earlier than the Fraser. The spawning range of nearly 3 months between two adjacent rivers, would appear to require that the populations of eualchons spawning in each river are adapted to either a late, or an early spawning time.

Spawning population regularity

Although we do not have reliable spawning biomass data for all rivers, we know that some, like the Nass, have been quite steady, or reliable, over time. Others fluctuate sharply. The apparent lack of coherence between the Nass and many of the other rivers where populations have declined indicates that the factors affecting survival of Nass River eulachons differs from those of other rivers. Probably, such variation would require the maintenance of distinct biological differences among populations derived form each river.

It is well established that there are biological differences among many different salmon runs so it is difficult to rule out the potential for similar types of variation among eulachons. Based on concepts developed from observation of spawning of Pacific salmon, the timing of spawning runs of eulachons should be biologically adapted to each river. If so, and if the same model is applied to eulachons, then each population would be adapted to each river. Therefore, until we better understand both the biological and genetic variability (or lack of it) among different eulachon populations, we should not ignore any population differences among different watersheds used for spawning.

CONTRIBUTIONS OF LARVAL SURVEYS TO UNDERSTANDING STOCK STRUCTURE

The distribution of larval eulachons is consistent with known oceanographic factors that may affect their distribution, particularly estuarine circulation. The distribution of small eulachon larvae also has implications for understanding eulachon stock structure. We suggest that the smallest geographical area that can support a ‘unique’ eulachon stock is a marine estuary, and not necessarily a river, although this depends on the relative proximity of each river to each estuary or shared estuary. This suggestion is based on the observation that eulachon larvae spend very little time (minutes – hours) in rivers and substantially longer time in estuaries or inlets, as we observed from ichthyoplankton studies. The duration of larval residency in estuaries may be sufficient for geographic imprinting to occur. We suggest, therefore, that the most appropriate management unit for eulachons is the estuary, not necessarily the river. This recommendation only has application in a few instances where more than one river drains into an estuary. Specifically, we suggest that eulachons spawning in the Kitimat River may be the same population that spawn in adjacent rivers and streams at the head of Douglas Channel. Similarly, the populations spawning in Gardner Canal rivers (Kemano, Kitlope and Kowesas rivers) may be biologically identical, and able to switch among rivers. The same conclusions may apply to eulachon in Dean Channel, Rivers Inlet, Smith Inlet, Kingcome Inlet and Knight Inlet. If so, the total number of eulachon populations should not be listed according to the numbers of spawning rivers but by the numbers of available marine estuaries. This tentative conclusion is consistent with recent genetic and otolith chemistry analyses of eulachons.

The close proximity of different potential spawning rivers casts doubt on the capability for adjacent rivers to maintain distinct biological stocks. For instance, following the basic salmon life-history model, it is not unreasonable to assume, *a priori,* that eulachons may home to individual rivers. Imprinting at an earlier life history stage, however, must precede homing. Salmonid imprinting may occur at several stages, and the first stage is thought to involve some form of olfactory recognition of chemical constituents in the water just after hatching. Imprinting is not thought to occur during the egg stage, presumably because of the relative impermeability of the egg capsule. Therefore, if these constraints applied to eulachons, there would be no imprinting during the 2-4 week egg incubation stage. If eulachons imprinted after hatching, they probably would have to do it rapidly, because in most instances they are rapidly advected to estuarine or marine waters. Given the flow rates in some eulachon-bearing rivers, the time of freshwater residence of newly hatched eulachon larvae would be measured in minutes or, at most, hours. This would provide very little time for larvae to imprint, compared to the much longer time (days, weeks and months of gravel residence) of salmonids. Further, eulachon larvae weigh only a few mg, whereas salmonid alevins are thousands of times larger, and presumably have more biological capability (tissue and sense organs) for imprinting. Therefore, we suggest that it is unlikely that eulachons imprint during their freshwater egg and larval stages. On the other hand, our larval distribution data indicates that larvae reside in estuaries and inlets for considerable periods, weeks and perhaps months, and may be retained there by estuarine circulation. This resident time could provide an opportunity to imprint, but if so, the imprinting would be to estuarine waters and not necessarily to the water discharged from specific rivers. Therefore we suggest that estuaries may be an important criterion for population configuration and that the numbers of different spawning runs could be determined (or limited) by the numbers of different estuaries. It also follows that annual variation in discharge volumes might lead to changes in the relative sizes of the eulachon spawning runs among rivers.

EVIDENCE FOR STRAYING

During 1993, when the eulachon run in the Columbia decreased substantially from previous year, there was an unprecedented spawning run of eulachons in a tributary of the Chehalis River system, just north of the Columbia (P. McAllister, Pers. Comm, and Hay et al., 1997a). It seems reasonable to assume that these eulachons were associated with the Columbia River and strayed to a different river. Similarly, Hart (1973) briefly describes an anomalous eulachon spawning in the Somass River, on the west coast of Vancouver Island which had not occurred before as a "mistake". An observation was also made of eulachons spawning in the Nimpkish River, on the north end of Vancouver Island - another anomalous occurrence. On the other hand, there is reference to eulachons spawning in the Squamish River, which is geographically close to the Fraser. In Kitimat, eulachons sometimes spawn, unpredictably, in small streams close to the Kitimaat Village - an event that is rare, but not unprecedented (J. Kelson, Pers. Comm). Similarly, eulachons apparently spawn in the Queet River, Washington State, every few years (G. Bargmann Pers comm.). Therefore, there appears to be rare but genuine acts of 'straying' where eulachons spawn in areas where previous spawning has not be reported.

SYNOPSIS - POPULATION STRUCTURE

The genetic evidence, based on mitochrondrial and micro-satellite analyses (McLean, 1999; McLean et al., 1999) indicates that there are few differences between any rivers in BC and virtually none between geographically adjacent rivers. These results are consistent with those of other approaches, such as the elemental analyses of otoliths from different populations (Carolsfeld and Hay, 1998). The general (but still preliminary) conclusions from the genetic and otolith chemistry analyses is that there are few if any genetic differences among eulachon populations in spite of the many striking biological differences among different populations. The most apparent is simply the geographical discontinuity of different spawning runs, different spawning times and the apparent 'homing' of each run to individual rivers. In some rivers such as the Kitimat or Kemano, the time of spawning is relatively early, beginning in early March and in others such as the Fraser, or Klinaklini, the timing is later, beginning in late April or May.

This apparent 'genetic' homogeneity and 'biological' heterogeneity among eulachons from different rivers is not necessarily unexpected, or indicative of sampling error. Rather, the results indicate that there is sufficient straying among populations to maintain them as 'genetically coupled'. As pointed out by Waples (1998) and others, even low rates of straying will prevent the development of genetically unique populations - so the different major eulachons stocks probably are genetically 'coupled'. In short, we tentatively concur with the conclusions of McLean et al. (1999) that eulachons occur only as one geographically large 'evolutionary significant unit'. Although we tentatively conclude that there are no stock-specific genetic differences among eulachons, this conclusion will be further tested with more research, emphasizing micro-satellite DNA analysis. If this new work finds unique genetic differences, then we may be forced to revise this conclusion, and recognize multiple 'ESU's.

The conclusion that there only is one ESU has major significance to the COSEWC classifications. COSEWIC classifications apply at the level of the ESU, so the challenge for this report is to provide only a single classification (described later) that applies to all eulachon populations. This single COSEWIC classification, however, does not precluded the requirement that the major stocks behave as different demographic units, and these units need to be recognized and managed as distinct units. The obvious biological differences among some rivers are evidence of the existence of separate eulachons stocks, but stocks that probably are demographically 'uncoupled'. The maintenance of these separate demographic units, or 'management units' is the responsibility of DFO, as the key agency with legislated accountability for eulachons.

In this regard, we suggest that the default position for conservation and management should be to treat each river (or 'river complex' such as the Gardner Canal rivers) as a biological entity, or management unit, worthy of recognition and protection. This suggestion acknowledges that these units may be geographically smaller than the smallest genetically significant (or evolutionary significant) area. This position is risk-averse and has precedent in the management of number of fisheries on marine fish with extensive genetic ranges, such as the Pacific Halibut (*Hippoglossus stenolepus*). This species, which extends over the entire north-eastern Pacific, from California to the Bering Sea, is fished by quotas that are set for much smaller geographical (and political) units (Anon., 1987). This action prevents or limits local depletions by conserving biomass in all areas.

FACTORS AFFECTING ABUNDANCE OF EULACHONS

RIVER FISHERIES DIRECTED AT EULACHONS

There are two main fisheries targeting on eulachons: commercial and First Nation. The small commercial fishery in the Fraser River (closed since 1997) and the larger commercial fishery in the Columbia have been under severe restrictions for several years (G. Bargmann, Pers. Comm.). The total catch of the commercial fishery on the Fraser was only about 20-30 tonnes, although it once was much larger, taking up to 500 tonnes per year. There was a commercial fishery on the Nass River in the early 1900's, and the catches were substantial, perhaps several thousand tonnes. The Columbia River catch is relatively large, at several thousand tonnes. This catch has been maintained for decades at fairly consistent levels. Other river fisheries are conducted by First Nations for their own requirements, of which the rendering of eulachon oil to 'grease' is most important. The significance of the First Nations fishery transcends the collection of fish biomass for consumption. Rather, the collection, rendering and subsequent distribution of grease are an integral part of coastal First Nations culture, and so in some ways it is inadequate to refer to the First Nation's use of eulachons simply as a 'fishery'. The catching, subsequent processing and distribution of eulachons carries much more significance. Unfortunately, this aspect often is not understood or appreciated by many.

The total catches of first Nations are not available for all rivers, but some data are available. Nass River catches are usually about several hundred tonnes. Similarly, the Haisla catches in the rivers within Gardner Canal may take about 100 tonnes per year. Estimates for rivers in the central coast also are modest, perhaps 20-30 tonnes per year. Catches from the Klinaklini River may take 50-100 tonnes per year (Stacey, in Eulachon Research Council Minutes, 1998). In short, the total eulachon harvest by both First Nations and the small Fraser River commercial fishery is modest. Potential future work could be directed at obtaining better estimates of past First Nations' catches, because the ratio of raw eulachons to grease production is known (Kuhnlein et al., 1982). Similarly, there are estimates of the grease consumption per capita so it may be possible to estimate, approximately, the probable catches of previous years.

HABITAT CHANGES WITHIN RIVERS

Three important eulachon rivers have been subjected to contamination by pollution from industry. This is well documented in the Fraser River (Rogers et al., 1990), the Columbia (Smith and Saalfeld, 1955) and the Kitimat River (Mikkelson et. Al. 1996, Beak Consultants, MS 1998).

There may be other rivers subject to industrial pollution, but there are no available data to support this. Perhaps what is important about pollution, relative to the recent declines of eulachons, is that these rivers have been polluted for a considerable period. Although the pollution may be deleterious for eulachons, (see Rogers et al., 1990) their exposure to pollution preceded their recent declines. There were still strong runs in all rivers when pollution may even have been worse than it is today. Therefore, although industrial pollution is a concern, and may have contributed to long-term declines in some rivers, it probably cannot account for the recent sharp declines in eulachons.

PHYSICAL CHANGES TO EULACHON SPAWNING HABITAT - DREDGING

Dredging of eulachon spawning areas, during the eulachon spawning period continued in the Fraser River until the late 1990's. The entrainment of spawning eulachons was documented by Tutty and Morrison (1976) and estimated at 17,417 spawning eulachons (~0.9 tonnes) from March until June 1976 (See Table 5 in Tutty and Morrison). Probably the direct loss of about 1 tonne of eualchons may have been small relative to potential deleterious impacts on survival of eulachons eggs - either from the direct effect of entrainment of spawned eggs, or the silt-induced smothering of eggs deposition in waters downstream of the dredging operations. Therefore we are unable to estimate the impact of dredging, although we can conclude that it probably cannot explain the decline in the Fraser or other rivers, because the Fraser had a relatively strong spawning run in 1996 (Hay et al., 1997b). Regardless, we strongly recommend that continued dredging be limited to the non-spawning season for eulachons. It also would be desirable to have some definitive analyses of the impacts of removal of bottom sediments that might be related to potential eulachons spawning habitat.

FOREST-RELATED OPERATION

Effects on river hydrology

Impacts of extensive logging in the vicinity of fish-bearing streams is better known for salmonids, but there are potential impacts on eulachons as well (Tchaplinsky, in Eulachon Research Council Minutes, 2000). The most plausible impact is a change in the volume and discharge patterns of rivers draining forested areas. There appear to be a number of potentially suitable rivers that eulachons do not use for spawning. Therefore, a concern is that logging may render presently utilized spawning habitat into non-utilized habitat. This could come from subtle changes in water flow or changes in suitable spawning sediments. There are valid concerns, worthy of future diligence relative to habitat protection, but these probably cannot explain the recent decline in eualchons. Rather, in some ways it seems that eulachons are both fussy about their habitat and carefree, spawning in turbid, polluted mud-bottomed areas. The factors that induce eulachons to spawn in these areas remain unknown.

Direct physical effects

Log handling and booming in rivers was a concern in past years, but now is a concern only in some rivers such as the Fraser. Debris from booming may have direct deleterious impacts on eulachon eggs, although the extent of spawning beneath booming areas is not clear.

Booming in marine habitats

Log booms in some marine areas may affect both eulachon larvae and juveniles. Perhaps the greatest concerns are in the headwaters of estuaries, where debris, and associated anoxic water, could accumulate behind sills. Indeed, perhaps there are no deleterious impacts of booming in marine or estuarine waters, but that remains to be demonstrated. Until it is, caution should prevail.

OFFSHORE TRAWLING AND BYCATCH

In offshore areas, eulachons often are captured and killed as bycatch during trawling operations. In particular, small mesh shrimp trawls sometimes have significant bycatch of eulachons (Hay et al., 1998 and 1999). In response to concerns about eulachon bycatch in shrimp trawls, a coast-wide observer program was started in 1997. Estimates of the total catch of eulachons are complicated by many variables in the data. There are several types of shrimp fishing gear deployed in the industry, which operates during different seasons and many different fishing areas, some of which have no eulachons, such as the Strait of Georgia. Further, the data used to make the estimates consists of relatively large, complex databases from on-board observers, logbooks of fishing effort, and 'hailed' catch rates. The distribution of commercial fishing effort for 1997 and 1998 is summarized in Fig. 2, and also shows the key eulachon spawning rivers, as defined in Fig. 3.

Although we point out that the estimates of total bycatch are only approximate, in general the magnitude of bycatch when compared to the probable sizes of eulachon spawning runs in rivers, is not large. For instance, there probably was about 15-20 tonnes taken by both gears types in 1997 and 1998, off the west coast of Vancouver Island. In contrast, in most years the Fraser River eulachon spawning stock probably is at least several hundred tonnes and in some years, such as 1996, perhaps several thousand tonnes (Hay et al., 1997 a). On the other hand, in the Queen Charlotte Sound area, the estimated bycatch was relatively large in 1997 and estimated at 61 tonnes (see Table 8 for Otter trawlers in 1997, in Hay et al., 1999), although subsequent analyses with a more complete data set have revised this estimate upwards to about 94 tonnes (N. Olsen, Pers. Comm).

We do not know the spawning biomass of eulachon in the rivers adjacent to the Queen Charlotte Sound area, but probably it is not high, even when runs are considered to be normal. Based on observations and surveys of similar sized rivers in the Gardner Canal (i.e. the Kemano and Kitlope), the main rivers in Smith Inlet and Dean Inlet may have eulachon spawning biomass populations of similar size or several hundred tonnes each, when runs are at 'normal' sizes. When runs are low, the spawning biomass may be much lower. For instance, Pedersen et al. (1995) estimated the 1993 spawning biomass of the Kitimat River at about 20 tonnes. If similar biomass levels occurred in 1997 in the central coast areas, then the impact of a 76 tonne bycatch is a concern.

Although the shrimp trawl industry probably has not caused the recent decline in eualchons, we cannot rule out the possibility that it could be a factor in limiting the recovery of certain stocks.

This is a specific concern in 2000 for central coast (or Queen Charlotte Sound) stocks, some of which may have had no runs for the last 2 years (1999 and 2000). In this regard, there are limits on the industry called 'action' levels, which are bycatch limits (in tonnes) set for specific shrimp management areas. If these limits are reached, shrimp fishing must cease, even if the landed shrimp catch is below the allowable quota. This happened for the first time in 2000, on the west coast of Vancouver Island.

As pointed out in Hay et al. (1999) a dilemma about bycatch levels is that the otter trawl vessels have the lowest overall bycatch of non-target species, but the highest rates of capture of eulachons. Some bycatch rates are very high, and estimated at over 25 kg/hour in the central coast in 1997 (see Table 8 in Hay et al., 1999). These high rates may have been anomalies, however, as bycatch rates were lower on the west coast of Vancouver Island (~11 kg/hour) in 1997. Eulachon bycatch rates in Queen Charlotte Sound were substantially lower in 1998 (highest for the coast was 6.2 kg/hour) although the explanation for the reduction is not clear. In part it could have reflected both a positive response by industry, in avoiding areas with high eulachon bycatch rates, but it also could reflect an overall decrease in the abundance of eulachons. It is interesting to note that average estimates of eulachon catch rates in bottom trawls throughout the Gulf of Alaska are approximately similar to the estimates made in BC. Compared by depth ranges Alaskan catch rates were 2.9 kg/hour from 1-100m, 15.1 kg/hour from 101-200 m, and 3.2 kg/hour from 200-400m (Ronholt et al., 1978 - Table XI-4. page 298).

Although the shrimp industry is striving to develop methods and approaches to further reduce or eliminate bycatch, their progress on this issue is undetermined. A positive action made by the industry in 2000 was the mandatory use of bycatch reduction grids (Clayton, Eulachon Research Council Minutes 2000). It is not clear, however if these devices are as effective at reducing bycatch of eulachons as they may be for bycatch reductions of other species. Further data and analyses are required to determine the efficacy of grids at reduction of eulachon bycatch.

Finally, we note that within the last decade there has been a substantial increase in the total shrimp fishing effort, increasing from approximately 4,000-6,000 fishing days in the 1980's to 15,000 days or more in the mid and late 1990's (Convey et al., 2000). In this regard, we reiterate that we do not attribute the widespread decline of eulachons to bycatch in the shrimp trawl fishery. That generality notwithstanding, we remain concerned that without effective measures to reduce eulachon bycatch, continued or expanded shrimp fishing in areas of reduced eulachon spawning abundance such as the central coast, could have deleterious impacts on long term abundance levels in those areas.

OCEAN CONDITIONS

Although they spawn in fresh water rivers and streams, eulachons are mainly a marine fish, spending over 97% of their total life in marine waters. Except for a brief period of a few months as pelagic larvae and juveniles, they live close to the bottom, on the shelf. Therefore eulachons probably are very susceptible to changes in ocean conditions. Throughout much of their range, from northern California to the southern Bering Sea, ocean climate has changed during the last few decades. (A full discussion of this topic is beyond the scope of this paper but interested readers could examine sources like Beamish (1995), McFarlane et al. (2000) or DFO (2000)).

The simplest description of impact of climate change is an increase in sea surface temperatures off the coast of BC (until 1999) but there have been other changes, including changes in the geographical and temporal distribution freshwater runoff, salinity, and increases in sea levels. Among the key scientific debates on this issue are (i) the best criteria to measure and assess such changes and (ii) whether changes in ocean conditions are part of natural fluctuations, perhaps occurring as repeatable or predictable 'regimes' (Ware and McFarlane, 1989). Although changes in ocean climate may account for changes in eulachon populations (Hay et al., 1997a) the mechanisms of such change are uncertain. Although relative temperature changes have been significant, the absolute changes are small (~ 1^oC) and therefore do not pose any unprecedented thermal limits to the habitation of eualchons throughout most of their range.

Probably the impact of climate change on eulachons is mediated through changes in food composition and availability, or in the distribution and abundance of eulachon predators. In this regard, as a possible example, we elaborate on an earlier suggestion that a predator like hake (*Merliccius productus*) may affect eulachons. The recent change in the distribution of hake (Fig. 23) corresponds roughly to the apparent decline of eulachons, beginning in the south and moving northwards. Probably hake predation is most intense on the smallest, youngest (age 1+) eulachons so the effect of intense predation may not be felt for 2 or 3 years. Although this suggestion is speculative, and provided only as an example of how climate change may affect eulachons (through changes in hake distribution) we note that the 1999 year class (observed in 2000 as age 1+) in southern BC waters appears to be strong relative to previous years. At the same time the abundance of hake in the same waters in 2000 was lower in the summer of 2000 (M. Saunders, Pers. Comm). Although we do not understand these relationships well now, the general topic of the effect of ocean conditions on fish populations is receiving a lot of attention, so it is likely that our understanding may improve in the future.

SYNTHESIS: COSEWIC CLASSIFICATIONS, RISK AND BIOLOGICAL IMPLICATIONS

COSEWIC CLASSIFICATIONS , BIOLOGICAL AND MANAGEMENT IMPLICATIONS

The rationale of COSEWIC, and basic COSEWIC procedures and classifications are defined in an Environment Canada (see web site http://www.cws-scf.ec.gc.ca/sara/strategy/index.htm) as follows: *"The main function of COSEWIC is to assess the level of risk extinction for wildlife species based on the best available scientific, Aboriginal traditional and community knowledge on the status of these species. This assessment will be based on biological factors and use rigorous assessment criteria, followed by classification into categories based on level of risk. COSEWIC's assessments of the status of species will be published in a public registry established by SARA."*

The present document represents a first step in the process of a COSEWIC listing, and part of the purpose is to assess the eligibility of eulachons for a possible listing. To determine the eligibility of a species, COSEWIC first determines if the taxonomic classification of the species is valid and if the species is endemic in Canadian waters. For eulachons, these are not concerns, and the first parts of this document provides affirmative evidence to all of these questions, although as we point out later, there is uncertainty about the genetic structure of eulachon populations. The other COSEWIC-related objective of this paper is to provide information that will assist with a COSEWIC classification, if required. There are seven COSEWIC classifications or categories: (1) extinct, (2) extirpated (species no longer present in the wild in Canada), (3) endangered, (4) threatened, (5) species of special concern, (6) species not at risk and (7) data deficient. The classification of 'endangered' applies to species that are at risk of imminent extinction or extirpation. Category 6, species of special concern, includes species that may be vulnerable, but not considered to be threatened. Those classified as 'threatened' are at risk of becoming endangered if no action is taken to reverse factors leading to becoming endangered and extinct. Our suggested classification is provided later, after a brief discussion of some of the biological issues and considerations about the categories, as they apply to eulachons.

Geographical ranges of the classification

Presently eulachons appear to be declining in much of their southern range, in nearly all areas from mid- to southern BC but this is not necessarily the case for northern populations, including Alaska. (Moyle et al., 1995; Hay et al., 1997a; Eulachon Research Council Minutes, 2000). The geographic pattern of southern declines includes most of the known range of eulachons. In a previous version of this document, we attempted to apply a COSEWIC to each of the 14 main rivers (Table 11). A reviewer of an earlier draft of this report pointed out that the COSEWIC classification should apply over broad ranges, especially if there are no demonstrable genetic differences among the individual spawning rivers. One problem with the geographically broad classification, however, is that much of the range is in US waters, from Washington to northern California in the south, and Alaska in the north. Therefore, the classification we use (indicated later) applies mainly to Canadian waters, although based on available information, we recognize that all populations south of BC are at a period of low abundance.

COSEWIC classifications and life history stages

For the purposes of establishing clear criteria for COSEWIC classification, we suggest that the presence, absence or relative abundance of spawning eulachons is the best and most defensible criterion of their status. Further, estimates of abundance in the sea, while interesting and useful for other purposes, does not provide a defensible evaluation of the status of individual populations or of the species as a whole. In the sea, eulachons may be ubiquitous, although the presence or absence varies in time and space. For instance we noted earlier that eulachons have been found in marine waters off of California in recent years, even though spawning populations in rivers are absent or negligible. The same situation may occur in British Columbia where some eulachons occur in Queen Charlotte Sound, but not in the adjacent spawning rivers. Therefore, we suggest that within the range of coastal British Columbia the occurrence, or lack of it, in spawning rivers and not marine waters, should be basis of a COSEWIC classification. We point out, however, that the presence or absence, or relative abundance of spawning eulachons may be determined, after the fact, by assessment of eggs or larvae. In these instances, these life history stages also provide information useful for COSEWIC classifications. This criteria is similar to that applied to Pacific salmon, which share many common characteristics with eulachons, including a very similar body form and closely related taxonomic status (same Order: Salmoniformes), as well as similar life history, which includes anadromy, the deposition of demersal eggs in substrates and semelparity. There are many examples of declines in salmon spawning in l coastal rivers streams, even though the adjacent marine waters may have abundant numbers of salmons migrating to or from other rivers, in other areas. The same conceptual model may apply to eulachons. Therefore the apparently high abundance of eulachons in offshore waters may not necessarily be indicative of strong future spawning stocks (perhaps the 'potential') in those adjacent rives.

What is at risk: species and genetic diversity or stocks or populations?

Several eulachon runs have not materialized for 2 years, and this is a concern for a fish where most individuals spawn at age 3 and then die. The apparent declines or losses of specific populations of eulachon, however, may not necessarily result in permanent loss of genetic diversity because, from a genetic perspective, there may be only one ESU, or large inter-mixing population genetic unit throughout the range of eulachons (McLean et al., 1999). This does not imply that eulachons are thoroughly mixed as individuals. The apparent lack of inter-population genetic differences may occur as a result of very low straying rates, sufficient to maintain virtual genetic homogeneity, but insufficient to prevent formation of relatively unique but non-genetic differences among populations in different major rivers systems. These include demographic differences as well differences in factors such as spawning time, vertebral number, size at age, otolith chemistry, etc.

If there are no genetic differences among eulachon populations, and if the factors which are deleterious to eulachons are irreversible or not preventable, we must ask 'what is at risk' or what could be lost and would such a loss be permanent? If not, can we estimate the duration of the loss? Here is our answer: Based on known distribution and biological characteristics of each population, we suggest that what could be lost are a number of well-established eulachon spawning populations, as well as some which are 'ephemeral' and occurring only intermittently in some rivers. Further, we suggest that this already may have occurred in California since the 1970's. In BC we believe that there are about a maximum of about 14 such 'established rivers' and perhaps another 19 which may be intermittently occupied, or ephemeral (See Tables 1 and 11). The estimate of 14 'established populations' requires some qualification, because it could be lower, around 8 or 9, if we allow that there probably is only one major population in each large estuary. Each 'established' population appears to maintain the capacity to home and perhaps to colonize, or re-colonize adjacent rivers - many of which are the intermittent populations, that are not used for spawning each year. Therefore the loss of an established population probably would result in the loss of the adjacent, less well-established populations.

If the differences among populations are not genetically distinct, then the loss of a population probably is not permanent, unless the loss of populations is due to permanent changes in essential habitat. Therefore the duration of the loss of an established population would probably be a function of the time required to re-colonize the river or estuary. Re-colonization time would depend on migration rates, and we do not know these for eulachons. Never-the-less, we will speculate as follows. Barring loss of key habitat, the loss of an eulachon population from the middle of its range, while surrounded by robust populations on all sides, would probably be short, perhaps a few years at most. This speculation is based on accounts from First Nations, and others, that sometimes an eulachon run fails, for a year or two, but then returns. In contrast, the loss of populations that are geographically remote, or on the edge of the range, such as those in California, may require much longer time to recover, perhaps many decades, or longer. This speculation is based on (i) the observation that in California eulachons have effectively disappeared for the last 20 years; and (ii) an undocumented historical account that in the 19th century, eulachons once disappeared from the Columbia River for about 30 years (D. Stacey, Pers. Comm).

MANAGEMENT IMPLICATIONS FROM OFFSHORE ESTIMATES OF EULACHON BIOMASS

Evidence of recent increases in eulachon abundance from offshore trawl surveys, while interesting and encouraging, is not definitive, because we do not know if any, some or all of the offshore eulachons will spawn in adjacent coastal rivers. Also, one of the years with the highest offshore biomass index (1992 with an offshore index of 3016) was followed by the sharp decline in catches in the Columbia River in 1993, and the apparent sharp decline in the Fraser River, and other BC rivers, in 1994. The key years are marked with arrows in Table 7. Columbia River catch data shown in Table 7 were provided by the Washington Dept. of Fish and Wildlife (in units of thousands of pounds, and were converted to metric tonnes for this report).

As shown in Table 7, between 1999 and 2000, there was an observed increase in the abundance of eulachons on the lower west coast of Vancouver Island, from a biomass index of 460 tonnes in 1999 to 3163 tonnes in 2000 (N. Olsen, Pers. Comm.). Most of the observed increase in 2000 was in the smaller size class, probably representing the 1999 year-class that will spawn in year 2002 as mature 3-year-old fish. Therefore, this increase in abundance may not be manifested into increased spawning biomass in 2001, unless it is in the form of precocious fish spawning at age 2. Further, and as discussed above, the spawning destination of these eulachons is unknown, although their geographic proximity is closest to the Columbia and Fraser rivers. Further, there is a precedent (as shown from the 1992 offshore index) for not necessarily having higher spawning biomass in rivers in the next 1-2 years.

The estimated offshore abundance in the central coast (Queen Charlotte Sound) in 2000 at 473 tonnes was similar to estimates made in 1999 (579 tonnes) and 1998 (473 tonnes) (N. Olsen, Pers. Comm). Mainly these Queen Charlotte Sound eulachons are in the larger size mode, equivalent to the age 2+, or fish that probably will spawn in the next year. A bycatch of 94 tonnes, as estimated from the 1997 fishery, if applied to the offshore abundance of eulachons estimated from 1998-2000 of about 500 tonnes, would indicate a total catch of about 25% of the spawning eulachons vulnerable to shrimp nets in the area. Such an estimate of catch rate is high, because eulachons likely occur in areas beyond the biomass survey area. Nevertheless, even at half this amount, this is far too high to be acceptable as a bycatch rate, particularly when some eulachons may be subject to a later fishery in the spawning rivers.

Another aspect of this issue deserves mention although it only serves to complicate the issue. One is the set of observations that there was a relatively strong eulachon spawning run in a number of central coast rivers in 1998, and this was also observed in some Gardner Canal rivers

(Eulachon Research Council Minutes, 1998 and 2000). Such a strong 1998 spawning run ***followed*** the relatively high eulachon bycatch in the Queen Charlotte Sound in 1997. Of course, we do not know the age or size composition of the 1997 bycatch, but if it was the same as observed in 1999 or 2000, then it was mainly fish of age 2+, or an age which should have spawned in 1998. If so, it would appear that the large 1997 bycatch in Queen Charlotte Sound was not sufficient to preclude a strong spawning runs in a number of Gardner Canal rivers in 1998. On the other hand, if the 1997 bycatch consisted mainly of small, age 1+ eulachons, which would have spawned in 1999, we point out that there was only a negligible spawning in 1999.

POPULATION CLASSIFICATION

Using the previous information on eulachon biology, and records of eulachons populations as recorded in the minutes of Eulachon Research Council meetings in 1998 and 2000, we have attempted to classify each of the 14 eulachon populations according to different levels of concern. Note that these are NOT COSEWIC categories, but the collective synthesis of these classifications may serve as a support for a COSEWIC designation for eulachons. Each of these categories is explained in more detail in Table 10, which also indicates ***suggested*** remedial activity required to address the concern and criteria for levels of concern.

Code	Criteria
1	Absent for >10 years
2	Absent for 2 or more years following low years and/or absence in adjacent rivers
3	Absent for 1 year following previous low years and 1 or absent runs in adjacent rivers
4	Low returns for 2 or more years and low or absent runs *in* adjacent rivers
5	Low returns for 2 consecutive years
6	Absent or low return for 1 year following 2 or more years of normal return
7	Normal

Each of the main 14 rivers was classified (Table 11) according to the codes shown in Table 10. As shown in Table 11, the classification was based on (1) general information presented at various sections of this report and (2) recent information taken from reports presented in the 2000 Eulachon Research Council meetings, or personal communication.

Only the Nass River is classified as 'normal', (Code 7 in Table 10) because its runs do not appear to have declined. It is not clear, however, if the Nass run is large as it was in the early 1900's, when very large catches were taken. The Skeena River is classified with only a low level of concern, and this may be too weak, but we have very little data of information from the Skeena. Of the 5 rivers in the Douglas Channel and Gardner Canal area, all are classified as having a high level of concern (code 3) except for the Kitimat River which is classified warranting an extreme level of concern (code 2). This is because the spawning run in the Kitimat River has been run low for years, and has been negligible for the last 2-3 years. The rivers in the Dean Channel and Smith Inlet all are classified as warranting a code 2 (extreme concern) because spawning has been negligible or non-existent for the last 2 years, which is an extreme concern for a fish which appears to mainly live to age 3. The Klinaklini River in Knight Inlet is classified as a code 3 (high level of concern) because the run is much diminished in recent years. The Fraser River run warrants a classification of code 4, or moderate concern. This run has occurred every year, but has been diminished in recent years (although based on preliminary analyses, the 2000 run appears to be stronger than that of previous years).

Table 12 shows a brief overview of some main eulachon spawning rivers in the USA. The format of the Table 12 follows that of Table 11, but we do not show a code or comment on mitigation.

As stated above, the genetic evidence indicates that there is only a single eulachon genetic population throughout the entire coast of BC (or even the Pacific). Based on accounts of individual rivers, eulachons have been virtually extirpated from the part of their range (south of the Columbia River) and nearly every spawning run in the mid-part of their range (Columbia River to the southern Gulf of Alaska) has shown significant declines (See Fig. 2), with failed spawning runs for 2 years in some rivers. Based on decline of catch data in the Columbia River (which probably is roughly indicative of spawning biomass) and the much reduced spawning runs in the Fraser River in recent years, we may conclude that only a fraction of the eulachon spawning biomass that once existed (say 50-100 years ago) is still present. Therefore we suggest that the evidence indicates a combination of widespread extirpation in the southern range and a drastic decline in the mid-part of the range. The extreme northern part of the range (western Alaska and the southern Bering Sea) remains uncertain. NOAA (National Ocean and Atmospheric Administration) websites indicate a pattern of decadal scale decline in all forage fishes, including eulachons, although in 2000 there are indications of substantial increases in the western Gulf of Alaska near Kodiak (B. Wilson, NOAA, Pers. Comm.). *We suggest that such a pattern would justify a COSEWIC classification of* ***threatened*** *in all areas south of Alaska, and perhaps even including parts of south-eastern Alaska.*

There is one more important distinction to be made about a classification for eulachons, especially compared to some of those recently applied to salmonids. In most salmonids, what is at risk is a single genetically unique population, which taxonomically, is only the sub-category of a sub-species. If eulachons were at risk of extinction throughout their entire range - and we are not suggesting that such a risk is imminent - but rather, what would be at risk is an entire, unique genus and species (*Thaleichthys pacificus*), one species of fewer only about a dozen in the entire Family Osmeridae. The loss of such genetic material, which probably has been unique for millions of years, would be a loss indeed, and unprecedented in modern times in the North Pacific.

RECOMMENDATIONS

PROGNOSIS

Recently the BC Provincial Ministry of Environment, Lands and Parks on their 'blue' list - which may be the approximate equivalent to the COSEWIC classification, listed eulachon as a 'species of special concern'. That is, a species that is considered 'vulnerable', but not yet in a position of being threatened or endangered. Washington State has classified eulachons as a 'State candidate species' or one which the Washington Department of Fish and Wildlife will review for possible listing as a 'State endangered, threatened or sensitive species'. California has put eulachons on the State's 'Watch list' as a species that may be in some form of potential risk (Moyle et al., 1995). In contrast, a recent attempt to classify eulachons as endangered by a US Federal agency was rejected. This effort originated from private sources within the US and was based mainly on the decline of eulachons in the Columbia River. The responsible review agency was the National Marine Fisheries Service (NMFS) within NOAA (National Ocean and Atmospheric Administration), the main federal research and management agency for waters under federal US jurisdiction. Although the petition was rejected, NMFS scientists did indicate there was cause for concern over the recent decline in the Columbia River and indicated that NMFS would reconsider its decision if more information became available. In part, the decision for the rejection of this application, which cited recent work conducted in BC, was that eulachons are subject to natural cycles, and this may be a period when they are at a low point in the cycle. This view may be correct, but we point out that such a view is in contrast to those adopted for salmonids, where many different sub-groups are recognized as being at risk of extinction. In effect, this decision was mainly determined using assumptions about different life histories of salmon and eulachon, with eulachons being considered mainly marine and having small pelagic larvae. Long-term cycles in marine species are common and we now understand that some species, such as the California sardine, may have decadal scale fluctuations in abundance (for examples, see Bakun, 1996 and references therein). What may have been overlooked in this situation (i.e. the NMFS decision not to list eulachons) were the similarities between salmon and eulachons, especially the fact that both are anadromous. It is possible that both the application for the classification, and the subsequent review, were made on the basis of incomplete information and data. We hope that some of those deficiencies are rectified in the present report, but we acknowledge that we still may not have included, or placed the correct amount of attention, on various aspects of the biology and life history of eulachons. In the final section, we use the recently drafted Canadian 'Wild Salmon Policy' (Anon., 2000) as a template for developing management policy for eulachons. In this respect, we emphasize the similarities between salmon and eulachons.

CLIMATE REGIME SHIFTS AND EFFECTS ON EULACHONS

If the recent changes in eulachons are mainly climate induced, and if there is a return (‘regime shift’, etc.) to a slightly cooler period (see DFO, 2000) then we may see a return of large spawning runs in some rivers. Perhaps we have already seen this in the form of relatively high estimates of offshore biomass in 2000. If the recent (1999) change is temporary, then any recoveries may be temporary. Regardless, some of the concerns about the present status of eulachons may diminish, and rapidly. Alternately, changes in ocean climate could continue (See Beamish, 1995 and papers therein) and the recent decline in eulachons may not be reversed in the long-term. The present state of low abundance could remain static or abundance could decline further, with functional extirpation of some runs. The most southern rivers may be the most vulnerable. If so, it is possible that there would be widespread pressure, from First Nations and others, to reverse this situation though proactive programs. From various public meetings we know that proactive proposals are usually river-specific and include suggestions to remove marine mammal from rivers (as one of the alleged causes of eulachon decline), and to reduce habitat damage and pollution. While repairing habitats would not hurt, it may not foster a rapid ‘recovery’ of eulachons. Undoubtedly, the issue of bycatch would become more strident, with accusations that trawl fleets are the cause of the problem, and that DFO is at fault for not acting more promptly to reduce and eliminate bycatch. Probably, the bycatch of eulachons in the Canadian shrimp trawl fleet is not the cause of the eulachon decline, although it is not part of the solution. The rapid elimination of bycatch, while essential, may not be accompanied by an immediate recovery of eulachons.

PARTNERSHIPS AND INTERNATIONAL CO-OPERATION

DFO, in conjunction with various partners in industry and First Nations, other government agencies and NGO's, should do everything reasonable to ensure that activities adverse to eulachons are reduced or eliminated. Most of these are readily identified, and include logging in key eulachon watersheds, industrial pollution of spawning rivers and continued bycatch reduction in trawl fisheries.

Research to further identify and define the problems and issues should be supported in a reasonable way. That is, there should be a distinct but gradual expansion in the support for eulachon research and assessment projects. Key partners in NGO's should be identified and asked to contribute to solutions.

Active collaboration with US investigations, in Alaska, Washington, Oregon and California should be encouraged, and perhaps partially funded. In part, such collaboration could be fostered by an international meeting with representation of key researchers and agencies to discuss eulachon-related issues. Recently there has been renewed interest in Alaska in eulachons. In the Copper River, Alaska eulachon may have increased suddenly in 1998 (E. Brown, Pers. Comm.) followed by a decrease in 1999 (S. Moffit, Pers. Comm.). There appears to be a substantial population in the Bering Sea, although the spawning origin of these Bering Sea eualchons is unknown. (S. Moffit, Pers. Comm.).

SUGGESTION FOR POLICY ON EULACHONS: WILD SALMON POLICY AS A TEMPLATE

Finally, there is an urgent requirement for the development and implementation of coherent management policy for eulachons. In this regard, the recent DFO document (Anon., 2000) on proposed Wild Salmon policy may be a useful guide. For that reason, we include a short discussion of the most salient aspects below.

The are several principles of the recent 'Wild salmon' draft policy document that are directly applicable to eulachons, and we note that, in many ways eulachons are like Pacific salmon: they are closely related taxonomically - in the Order Salmoniformes. Further, Like salmonids, eulachons are anadromous, semelparous, migratory and have demersal eggs that incubate in fresh-water substrates. They life span is approximately similar in duration (2-5 years). Therefore we suggest that the first 4 of the 6 major principles of the Wild Salmon Policy document are directly applicable to eulachons. The last 2 principles are concerned with artificial propagation of salmonids, and these principles do not apply to eulachons, so we do not retain them here. First, dropping the word 'Wild ' (because all eulachons are wild) and substituting the word 'eulachon' for 'salmon', the applicable principles are shown below, with additional comments added by us (in Italics)

1. Eulachons will be conserved by maintaining diversity of local populations and their habitats. *It is important to note that the policy designers refer to 'local populations' and not units based on genetic distinction. In the case of eulachons, local populations would be those that have a history of repeated runs (i.e. the 14 main rivers identified in Table 1, although it is probable that some alterations (additions and deletions) could be made to this list in the future.*

2. Eulachons will be managed and conserved as aggregates of local populations called 'conservation units'.
*In the case of eulachons, the population aggregates could correspond to the major estuaries, as suggested by McCarter et al. (1999). With further information and understanding, these units could be modified in the future, but for the present time, we suggest that the 9 major estuarie*s, *as identified in table 1, constitute the best definition of eulachon conservation units.*

3. Minimum and target levels of abundance will be determined for each conservation unit.
For each conservation unit, minimum target levels could be identified by reference to past catch data, as estimates of approximate run strength. Using this, for instance, the Fraser River would be expected to routinely have hundreds, and perhaps several thousand tonnes of spawners. Similarly, the Nass River would also be expected to have routinely large runs, perhaps reaching a thousand tonnes, or more. In other rivers, estimate of past run strength could be estimated, approximately, by estimating approximate grease consumption or production in historic times. (Kuhnlein et al. 1982, Stewart 1975)

Minimum target levels will require some application of assessment techniques. Presently there are not routine assessment methods available for potential 'conservation units'. Only 1 river, the Fraser, presently has annual assessments, although several others have had occasional assessments (Table 1). Present assessment methods used on the Fraser are time-consuming and expensive. If applied to other areas of the coast, they would require a substantial cost, both in terms of human and financial resources, as well as a significant administrative effort required for the co-ordination of data collections from many remote sites. This is not to advocate that such work not be done, but rather to point out, that there may be other alternatives. This could include one or combinations of activities, such as periodic larval surveys to assess distribution. Alternately, perhaps simple indices of larval density in rivers would provide reliable results. In other circumstances, it appears that simple test fishing on the Fraser River (Kim West, Unpublished data) would suffice.

4. Fisheries will be managed to conserve eulachons and optimize sustainable benefits.
This principle, if followed, has implications for both (1) the present shrimp fishery, particularly in the central coast area; (2) the Fraser River commercial eulachon fishery and (3) some First Nation fisheries, where there have been concerns about high catch rates, that are not sustainable, in some rivers.

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Table 1. List and classification of known and probable eulachon spawning areas, and adjacent marine areas, estimated from larval surveys (McCarter and Hay, 1999) and information from Eulachon Research Council Minutes (1998 and 2000), and other documents. The column headed by 'R/I' indicates rivers where spawning is mainly regular, 'R' (occurring most years), irregular (I) or unknown (?). The next column, headed 'A/C' indicates whether assessments are done annually (A) and whether they are regular A_r or irregular A_i , and whether annual catch data (C) is indicated as recorded regularly (C_r) or irregularly (C_i). The next column indicates whether the river is routinely fished by First Nations (FN) or a commercial Fishery (Co). Estimated river size and spawning run sizes are roughly estimated by width as very small (V, < 5m), small (S, ~10m), medium (M, >20m), or large (L, >100m). The column 'estuary' shows common estuarine waters for different rivers.

	Eulachon Spawning Areas	*R/I*	*A/C*	*FN/Co*	*Size*	*Estuary*	*Marine areas*
1	Nass	R	A_i,C_r	FN	M-L	PI - 1	Portland Inlet
2	Skeena	R	A_i	FN	L-S	CS - 2	Chatham Sound
3	Kitimat River	R	A_i,C_r	(FN)	S-M	DC - 3	Douglas Ch - Kitimat Arm .
4	Kildala River	R		FN	S-S	DC - 3	Douglas Ch - Kitimat Arm
5	Giltoyees Inlet	I			V-V	DC - 3	Douglas Ch.
6	Foch Lagoon	I			V-V	DC - 3	Douglas Ch.
7	Kitlope River	R		FN	M-M	GC - 4	Gardner Canal - head
8	Kowesas River	R		(FN)	S-S	GC - 4	Gardner Canal - Chief Matthew's Bay
9	Kemano/Wahoo River	R	A_r,C_r	FN	M-M	GC - 4	Gardner Canal - Kemano Bay
10	Khutze River	?			V-V	*NC* -	Princess Royal Ch. - Khutze Inlet
11	Aaltanhash River	?			V-V	*NC* -	Princess Royal Ch. - Aaltanhash Inlet
12	Kainet or Lard Creek	?			V-V	*NC* -	Kynoch Inlet - Mathieson Ch.
13	Bella Coola River	R		FN	M-M	DC - 5	Dean Ch. North Bentick Arm
14	Kimsquit, Dean Rivers	R		FN	M-M	DC - 5	Dean Ch.
15	Noeick River	?		FN	S-S	DC - 5	South Bentinck Arm
16	Taleomy River	?		FN	S_S	DC - 5	South Bentinck Arm
17	Skowquiltz River	?		FN	S-S	DC - 5	Dean Ch. - west side
18	Cascade Inlet	?		FN	V-V	DC - 5	Dean Ch.
19	Kwatna River	?		FN	S-S	DC - 5	East side Burke Channel
20	Chuckwalla/Kilbella	R		FN	M-M	RI - 6	Rivers Inlet - Queen Charlotte Strait
21	Wannock/ Oweekeno	R	A_i	FN	M-M	RI - 6	Rivers Inlet - Queen Charlotte Strait
22	Clyak River, Moses Inlet	?			S-S	RI - 6	Rivers Inlet-Moses Inlet
23	Hardy Inlet (unknown source)	?			S-S	RI - 6	Rivers Inlet
24	Nekite River, Smith Inlet	?			S-S	SI -	Smith Inlet
25	Kingcome River	R	A_i	FN	M-M	KI - 7	Kingcome Inlet
26	Kakweiken River	?			S-S	*JS* -	Thompson Sound - Johnstone Strait
27	Klinaklini River	R	A_i,C_i	FN	L-M	KI - 8	Knight Inlet
28	Franklin River	?		FN	S-S	KI - 8	Knight Inlet
29	Port Neville	?			V-V	*JS* -	Johnstone Strait
30	Stafford/Apple Rivers	?			V-V	*LI* -	Loughborough Inlet
31	Homathko River	I		(FN)	M-S	*BI* -	Bute Inlet - Johnstone Strait
32	Squamish River	I		(FN)	M-S	*GS* -	Howe Sound
33	Fraser River	R	A_r,C_r	FN,Co	L_L	GS - 9	Georgia Strait

Table 2. Ages of eulachons estimated from otoliths, and believed to be incorrect, showing the numbers at age for all samples from river and offshore (marine) locations. Note that there are few age 3 and many age 5 and 6 fish. There is no corresponding increase in length with age, and these age designations do not correspond with either length frequency modes (Fig. 6), or with earlier age analyses (Ricker et al., 1954) and they probably are not reliable.

	AGE					
	2	3	4	5	6	All
Rivers						
Fraser-R	5	103	195	147	14	464
Klinaklini	0	2	20	32	5	59
Franklin	0	1	27	24	3	55
Kemano-R	0	1	2	14	36	53
Kitimat-	0	44	29	50	19	142
Kowesas-	0	0	7	45	38	90
Offshore						
Goose-Gr	1	11	22	41	10	85
Nootka-G	0	0	5	31	6	42
Pachena-	5	11	8	3	0	27
PearlRk-	7	11	9	8	0	35
Tofino-G	0	55	45	44	5	149
All	18	239	369	439	136	1201

Table 3. Length frequency by month for juvenile eulachons collected in different areas of British Columbia (data from Barraclough, 1967). The dashed ovals represent estimated year classes or cohorts joined by arrows. In this instance we distinguish among 3 separate cohorts, with the top arrow representing fish that are in their first year of life, between 2 and 10 months of age. The middle arrow represents fish in the second year, between approximately 12 months (February) and 16 months of age. The lower arrow represents eulachons in their third year, between 24 and 28 months of age. These analyses follow the same simple approach used by Barraclough (1967) who identified several more year classes than we see here. Our analyses are based on additional data however, so we recognize that there are 2 distinct size modes in offshore samples (Figs. 7-8). Also, we know from river and marine larval surveys that eulachons during their first year of life are approximately within the size range seen here. Further, we also recognize from analyses of offshore eulachon size data, that there are significant inter-annual differences in eulachon growth rates. Therefore any attempt to pool samples from different areas or different years will not results in sharp distinction among cohorts.

Length (cm)	**Feb**	**Mar**	**April**	**July**	**Aug**	**Nov**	**Dec**	**All**
2			3					3
3			2					2
4								
5	2					44	2	48
6	13					17	4	34
7	3		2			1	1	7
8	11	21	13			1	2	57
9	7	3	3		1	1	1	25
1	1	1	1	5	15			23
11	2	2	1	5	1			11
12		1	1	4				6
13			3	4	1			8
14	1		5	5				11
15			4	2				6
16			1					1
17				1				1

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Table 4. Biological features of adult eulachon from the Fraser River in 1995 and 1996. The summary data provided are the number sampled, Arithmetic Mean plus or minus Standard Error and Range for each parameter (from Hay et al., 1997b).

Females	***1995***	***1996***
Standard length (mm)	287 156 ± 0.60 123 - 189	218 155 ± 0.72 133 - 195
Weight (g)	287 43.35 ± 0.55 24.2 - 78.3	218 42.75 ± 0.67 26.95 - 96.17
Ovary weight (wet, mg)	N/a	200 9.64 ± 0.19 3.37 - 23.46
Preserved ovary weight (mg)	106 15.08 ± 0.37 5.38 - 26.72	100 13.81 ± 0.41 6.16 - 32.3
Egg weight (mg)	106 0.51 ± 0.01 0.36 - 0.68	100 0.44 ± 0.01 0.30 - 0.68
Fecundity (number of eggs)	106 29896 ± 744.90 11685 - 50350	100 31679 ± 917.76 12680 - 72704
Relative fecundity (egg/g) RF	106 678 ± 11.66 384 - 907	100 714 ± 10.68 419 - 968
GSI (gonad to somatic weight)	108 4.29 ± 0.13 3.18 - 16.08	200 4.57 ± 0.05 3.28 - 9.39

Males	***1995***	***1996***
Standard length (mm)	265 158 ± 0.68 138 - 196	241 156 ± 0.67 136 - 203
Weight (g)	265 42.81 ± 0.61 25.4 - 94.7	240 40.84 ± 0.61 25.5 - 92.4

Table 5. Estimates of the spawning biomass required to produce the numbers of eulachon larvae (estimated in from Table 4 in McCarter and Hay, 1999). The number of larvae (scientific notation) in each region and year using a simple area expansion method during *VECTOR*, April 25 - May 5, 1994, *R. B. YOUNG*, May 27 – June 7, 1996 and *VECTOR*, April 14 – 25, 1997 ichthyoplankton surveys. Only surface waters (0-20 m depth) were examined during the surveys (See McCarter and Hay, 1999 for details).

Survey Date:	Apr 25-May 5, 1994			Apr 14-25, 1997			May 27-Jun 7, 1996
Survey Region:	Johnstone Strait	Queen Charlotte Strait	Smith & Rivers Inlets	Johnstone Strait	Smith & Rivers Inlets	Burke & Dean Channels	Douglas Channel & Gardner Canal
Ocean Surface Area (m^2)	1.76E+09	3.59E+09	6.30E+08	1.22E+09	3.58E+08	1.06E+09	1.75 E+09
Estimated number of Eulachon larvae	3.76E+10	2.33E+08	1.70E+09	1.69E+10	2.26E+09	1.31E+09	3.94E+10
Estimated Eulachon spawning biomass (tonnes)	107.43	0.66	4.86	48.28	6.46	3.74	112.57

Table 6. List of eulachon spawning biomass estimates for specifc years and ranges of catches (t for short tons and mt for metric tonnes) estiamted for different rivers in BC, showing the source(s) of information (adapted and updated from McCarter and Hay, 1999). *(Author's comment: the report of a 4500 ton catch*, reported as 90,000 cwts (or units of hundred pounds) in 1929 in the Nass seems to be high, perhaps by a factor of 10. The next available report, for year 1931, was for 9,000 cwts, or about 450 tonnes. This latter estimate seems more reasonable in veiw of the maginute of catches in other years, and the single biomass estimate, made in 1983, of 1700 tonnes for the Nass.).*

River	Period/Year	Biomass	Catch	Source
Nass	early 1900's		~500 tons/y	Nisga'a Fisheries, MS, 1990
	1929		4500 tons*	Stacey, MS 1996
	1931		450 tons	Stacey, MS 1996
	1954		500 tons	Stacey, MS 1996
	1970-71		150-200 tons	Langer et al., 1977
	1983	1700 mt	239 mt	Orr, 1984 MS and McCarter and Hay, 1999
	1989		105 t	(Nisga'a Fisheries, MS, 1990)
	2000		168 tons	Barner, 2000, Eulachon Research Council Minutes
Skeena	1997		3 mt	Lewis, MS 1997
Kitimat	1993	23 mt		Pederson et al., 1995
Kemano	1991	340 mt	~120 tons	Triton, MS 1991
Klinaklini	1996	~120 mt	50-100 tons	Berry, MS 1996; Stacey, 1998
Kingcome	1997	14 mt		Berry, MS 1998
Wannock	1997	nil		Berry, MS 1998
Bella Coola	1944-1996	Max ~70 tonnes		Stacey, MS 1996, and Table 7, this report.
Fraser	<1950	100-500 tons		Ricker et al., 1954
Fraser	>1990's	50-1700 mt	20-30 tonnes	Hay et al., 1997b

Table 7. Summary of catch data from BC rivers, and an 'offshore index' estimated from analyses of eulachon densities captured in a time series of data collected during offshore shrimp surveys (from unpublished data from N. Olsen, DFO). The dark arrows indicate year of high offshore biomass (1992, 2000) and the light arrow shows a year (1993) when catches declined in the Fraser and Columbia rivers (see text for discussion). The asterisks indicate years when no data was available, and 'nr' (not recorded) indicates years when a catch of unknown size was observed. Bella Coola River (catches provided from unpublished data provided by Russ Hilland, DFO, Bella Coola, BC).

Year	Nass (tons)	Bella Coola (tons)	Knight (tons)	Fraser (tonnes)	Columbia (tonnes)	Offshore Index (tonnes)
1929	450	*	*	*	*	*
1930	45	*	*	*	*	*
1938	*	*	*	*	520.80	*
1939	*	*	*	*	1548.20	*
1940	*	*	*	*	1541.25	*
1941	*	*	*	50.14	1265.90	*
1942	*	*	*	152.74	1343.00	*
1943	*	*	*	154.79	1988.65	*
1944	80	nr	*	65.70	1134.25	*
1945	*	~8	*	73.87	2859.65	*
1946	*	~10	*	115.71	1638.00	*
1947	*	nr	135.0	231.10	772.45	*
1948	*	20.0	*	112.80	1987.05	*
1949	*	8.5	70.0	102.70	1666.80	*
1950	*	44.0	100.0	36.20	741.25	*
1951	*	10.0	20.0	189.30	758.45	*
1952	*	12.3	27.5	421.00	637.45	*
1953	2250	41.7	*	158.60	855.50	*
1954	1750	69.4	*	151.60	942.15	*
1955	*	7.6	*	238.80	1118.55	*
1956	575	6.2	*	235.50	841.95	*
1957	267	5.6		33.20	789.50	*
1958	260	8.4	*	92.10	1308.20	*
1959	250	7.0	45.0	132.00	878.05	*
1960	300	0.3	60.0	84.00	586.10	*
1961	350	2.0	*	216.90	526.15	*
1962	450	2.8	70.0	178.20	736.80	*
1963	300	8.4	*	159.30	538.55	*
1964	*	22.4	*	105.50	420.90	*
1965	20	11.8	100.0	87.80	455.35	*
1966	66	9.2	*	101.90	514.15	*
1967	35	11.5	100.0	86.80	500.40	*
1968	415	10.6	100.0	46.00	473.75	*
1969	260	7.8	80.0	29.80	541.85	*
1970	250	9.2	40.0	71.70	591.95	*
1971	200	16.8	20.0	34.50	888.35	*
1972	300	6.7	50.0	53.20	821.75	*
1973	200	12.3	40.0	53.10	1217.20	329
1974	*	10.6		75.30	1180.90	
1975	*	12.0		27.70	1038.80	987
1976	*	50.0	*	36.70	1537.55	1076
1977	*	35.0	50.0	32.20	876.50	2240
1978	300	25.0	*	38.60	1340.15	1269
1979	*	19.8	*	22.30	578.35	1157
1980	*	33.0	*	24.40	1605.75	1304
1981	*	38.5	*	21.20	836.15	992
1982	*	22.0	*	13.70	1105.00	2139
1983	239	30.5	*	10.80	1365.20	291
1984	*	30	*	11.80	249.00	
1985	*	nr	*	29.20	1019.00	1419
1986	*	nr	*	49.60	1919.40	
1987	*	nr	*	19.30	947.85	1822
1988	*	nr	*	39.50	1433.85	1937
1989	105	nr	*	18.70	1533.40	932
1990	8	nr	*	19.90	1392.10	1502
1991	*	nr	*	12.30	1475.20	1252
1992	***	***nr***	***	***19.60***	***1836.90***	***3016*** ←
1993	*	nr	*	8.70 ←	256.95 ←	1301
1994	*	20.0	*	6.10	21.70	181
1995	135	22.0	*	15.50	220.00	280
1996	nr	nr	*	63.20	4.55	522
1997	147	nr	*	closed	29.30	721
1998	*	nr	*	closed	6.00	324
1999	*	0	*	closed	10.45	460
2000	***168***	***0***	***	***closed***	0.00	***3163*** ←

Table 8. Comparison of vertebral numbers among rivers and among years within rivers. Data for Canadian Rivers is from Hart and McHugh (1944) and the Columbia River data is from DeLacy and Batts (1963).

	Vertebral number								
River (inlet) - year	65	66	67	68	69	70	71	72	All
Fraser - 1935	0	2	16	28	6	1	0	0	53
Fraser - 1939	0	6	86	172	39	3	1	0	307
Fraser - 1940	0	4	61	91	40	2	0	0	198
Fraser - 1941	0	15	114	183	42	1	0	0	355
Knight - 1940	1	3	34	102	84	19	0	0	243
Rivers - 1940	0	1	16	45	20	6	0	1	89
Nass - 1940	0	1	12	72	86	12	1	0	184
Columbia - 1953	0	10	128	241	74	8	0	1	462
Columbia - 1955	1	13	116	150	46	3	0	0	329
Columbia - 1956	1	23	150	303	80	8	0	0	565
Columbia - 1960	1	4	68	89	32	3	0	0	197

Table 9. Parametric (Test 1) and non-parametric (Tests 2-3) comparisons of the numbers of vertebrae (a) among years, within the Columbia River, (b) among years, within the Fraser River, (c) between the Fraser and Columbia Rivers, with data from separate years pooled and (d) among all rivers, with data pooled among all years. The single and double asterisks represent levels of significance at the 0.05 and 0.01 levels respectively.

Comparison between years within the Columbia

Test 1. Analysis of Variance: (df = 3,1549; F = 2.88)	$p = 0.035$*
Test 2. Kruskal-Wallis test, adjusted for ties: (H = 8.22, df = 3)	$p = 0.042$*
Test 3. Mood Median Test: (χ^2 = 11.02, df = 3)	$p = 0.012$*

Comparison between years in the Fraser

Test 1. Analysis of Variance (df = 3,909; F = 2.32)	$p = 0.074$
Test 2. Kruskal-Wallis test, adjusted for ties (H = 5.49, df = 3)	$p = 0.139$
Test 3. Mood Median test: (χ^2 = 3.04, df =3)	$p = 0.385$

Comparison between Fraser and Columbia

Test 1. Analysis of Variance (df =1,2464; F = 0.29)	$p = 0.590$
Test 2. Kruskal-Wallis test adjusted for ties (H = 0.26, df = 1)	$p = 0.612$
Test 3. Mood Median test: (χ^2 =0.00, df = 1)	$p = 0.945$

Comparison among all rivers

Test 1. Analysis of Variance (df=4,2977, F=59.76)	$p < 0.001$**
Test 2. Kruskal-Wallis test adjusted for ties (H = 216.51, df = 4)	$p < 0.000$**
Test 3. Mood Median test: (χ^2 = 87.44, df = 4)	$p < 0.000$**

Table 10. Codes for levels of concern for in eulachon spawning runs in rivers that normally support spawning eulachons (with 1 as the greatest concern). The next two columns show the ***suggested*** remedial activity required to address the concern and criteria for levels of concern.

Code	Definiton and suggested remedial actions (in Itlaics)	Criteria
1	Intense long-term remedial action *(Long-term catch and bycatch prohibition, habitat restoration)*	Absent for >10 years
2	Intense protective action of uncertain duration *(Assessment, catch and bycatch prohibition, habitat protection and restoration as required)*	Absent for 2 or more years following years with low *biomass* and/or absence in adjacent rivers
3	Monitoring and moderate protection (A*ssessment, intense catch and bycatch restrictions and, monitoring; habitat evaluation and restoration as required)*	Absent for 1 year following previous low yearsand/or low *biomass* or absent runs in adjacent rivers
4	Monitoring and moderate protection *(Assessment, moderate catch and bycatch restrictions, habitat evaluation and restoration as required)*	Low returns for 2 or more years and low or absent runs *biomass in* adjacent rivers
5	Monitoring, evaluation *(Catch and bycatch monitoring, habitat evaluation)*	Low returns for 2 consecutive years
6	Monitoring *Catch monitoring*	Absent or low return for 1 year following 2 or more years of normal return
7	No concern, *No action*	Normal or abundant runs

Table 11. Comments on rivers classified as having regular runs according to the observed status of the 1999 and 2000 runs, indicating the source(s) of the information and other comments related to data on catches and biomass assessment. Unless otherwise indicated, the source 'ERC 2000' refers to the notes of the Eulachon Research Council Minutes (2000).

River(s)	***Eulachon Spawning Areas - Rivers***	***Level of con-cern***		***Status of 1999/2000 run***	***Source(s)***	***Comments on data and availability***
1	Nass (A, C)	**6**	1. Nass R.	Normal catch in 2000 (168 t) but required increased effort	Glenn Barner, Nisga'a FN (ERC 2000)	Catch and effort monitored annually since and presented in reports. (one rough biomass assessment in 1993 (see McCarter 1999)
2	Skeena (A)	**5**	2. Skeena R.	(1) No typical signs in 2000 (2) 2000 worst year ever (24 years)	(1) Uriah Orr, DFO, Prince Rupert (ERC 2000 and Pers. Comm.) (2) Don Roberts, Kitsumkalum FN (ERC 2000)	Limited data available. Several years of larval density surveys, One year of biomass assessment (A. Lewis, MS, 1997)
3	Kitimat River (A, C)	**2**	3. Douglas Ch	Non-existent 1998-2000)	Dennis Ferara, Beak Consultants (ERC 2000 and Beak Consultant reports)	Test fishing and CPUE data available from Beak since 1991. One year of biomass assessment (Pedersen et al., 1995),
4	Kildala River	**3**	3. Douglas Ch	TBC - Negligible	Mark Bowler, Haisla Fisheries Commission (ERC 2000)	
4	Kitlope River	**3**	4. Gardner Ca.	TBC - low	Mark Bowler, Haisla Fisheries Commission (ERC 2000)	
6	Kowesas River	**3**	4. Gardner Ca.	TBC - low	John Kelson and Mark Bowler, Haisla Fisheries Commission (ERC 2000)	Some potential biomass data available but not reported
7	Kemano/Wahoo River (A, C)	**3**	4. Gardner Ca.	negligible in 1999, low in 2000 (Haisla catch ~ 3 t)	Dan Bouillon, Alcan (ERC 2000) (ERC 2000)	Catch data available for ~10 years, plus several years of biomass assessments.
8a 8b	Bella Coola River and south Bentink Arm - observation 1) Bella Coola River -	**2**	5. Dean Ch.	(1) No runs in seen 1999 or 2000 (2) Small run seen in flats in 1999 but Nothing in 2000	(1) Archie Pootlass and Andy Siwallace, Nuxa'lt FN (ERC 2000) (2) Pers. Comm. Russ Hilland, DFO, Bella Coola	Unpublished continuous catch data available 1944-1988, and 1993-94

	observation 2					
9	Kimsquit, Kwatna, Dean Rivers	**2**	5. Dean Ch.	No runs in 2000	Archie Pootlass and Andy Siwallace, Nuxa'lt FN (ERC 2000)	
10	Chuckwalla/Kilbella	**2**	6. Rivers In.	None seen in 1999 or 2000	Frank Johnson and Frank Hanuse, Oweekeno FN (ERC 2000)	
11	Wannock (A)	**2**	6. Rivers In.	No runs in Wannock or other rivers in 1999 or 2000	Frank Johnson and Frank Hanuse, Oweekeno FN (ERC 2000)	Unpublished larval data on Wannock in 1999 confirms low run (< 100 kg)
12	Kingcome River	**3**	7. Kingcome In	No run year in 2000	Robin Dawson, Tsawataineuk FN, Kingcome Inlet	
13	Klinaklini River	**3**	8. Knight In.	None or poor in 2000	Maxine Bruce, Kwakiiutl Territorial Fisheries Commission	Partial time series of catch data available, and 1 year of biomass assessment
14	Fraser River	**4**	9. Fraser R.	Late, but probable improved run improved run - based on test sets and in 2000	D. Hay (ERC 2000) and , Kim West (Pers. Comm) and Hay, (unpublished data)	Catch time series available since 1940's, Test fishing data available and annual larval biomass assessments available since 1995

Table 12. Comments on rivers in the USA. (A) Northern rivers in south-eastern Alaska, believed to have regular runs and (B) rivers in California, Washington. Most comments are based on personal communication between the sources and the senior author (Hay).

River(s)	***Eulachon Spawning Areas - Rivers***	***Status of 1999/2000 run***	***Source(s)***	***Comments on data and availability***
A				
1	Stikine	No commercial harvest in 1998 and some participants have commented that it has failed for 3 years. 2000 run unusual - either very early (and missed) or non-existent	Brian Lynch, Alaska Dept. of Fish and Game, Petersburg.	
2	Unuk (and Chickamin)	run in 2000 'did not occur'.	Scott Walker, Alaska Dept. of Fish and Game, Ketchikan	About 12 commercial fishers. Maximal catches capped at 25,000 pounds)
3	Chilkoot and Chilkat	TBC no run in 2000	Randy Bachman, Alaska Dept. of Fish and Game, Haines, Petersburg.	
4	Twentymile River, Cooke Inlet	run normal in 2000	Beth Kitto, US Forest Service, Girdwood, Alaska	
B				
	Redwood Creek	no run in 2000 - and no eulachons seen since mid-1980's	D. Anderson, US Dept. Interior, California Dept. of Parks and Recreation	Few quantitative data available, but had a large run at one time and used as subsistence fishery by Native Americans
	Klamath and Mad rivers, California	No runs in 200 or recent years	Report from Calif. Dept. of Fish and Game, Fish species of special concern, 1993	"massive runs" documented in 1970s, with that spawned with apparent regularity and supported . subsistence and small commercial fishery
	Columbia River, Washington	Catches declined in 1993 and have remained low since. The commercial fishery was closed in 1997 and 1998.	Greg Bargmann, Washington Dept. of Fisheries (ERC 2000) and Pers. Comm; also Hay et al., 1997a.	The largest run in the world, with catches documented since late 1800's, but no biomass data.

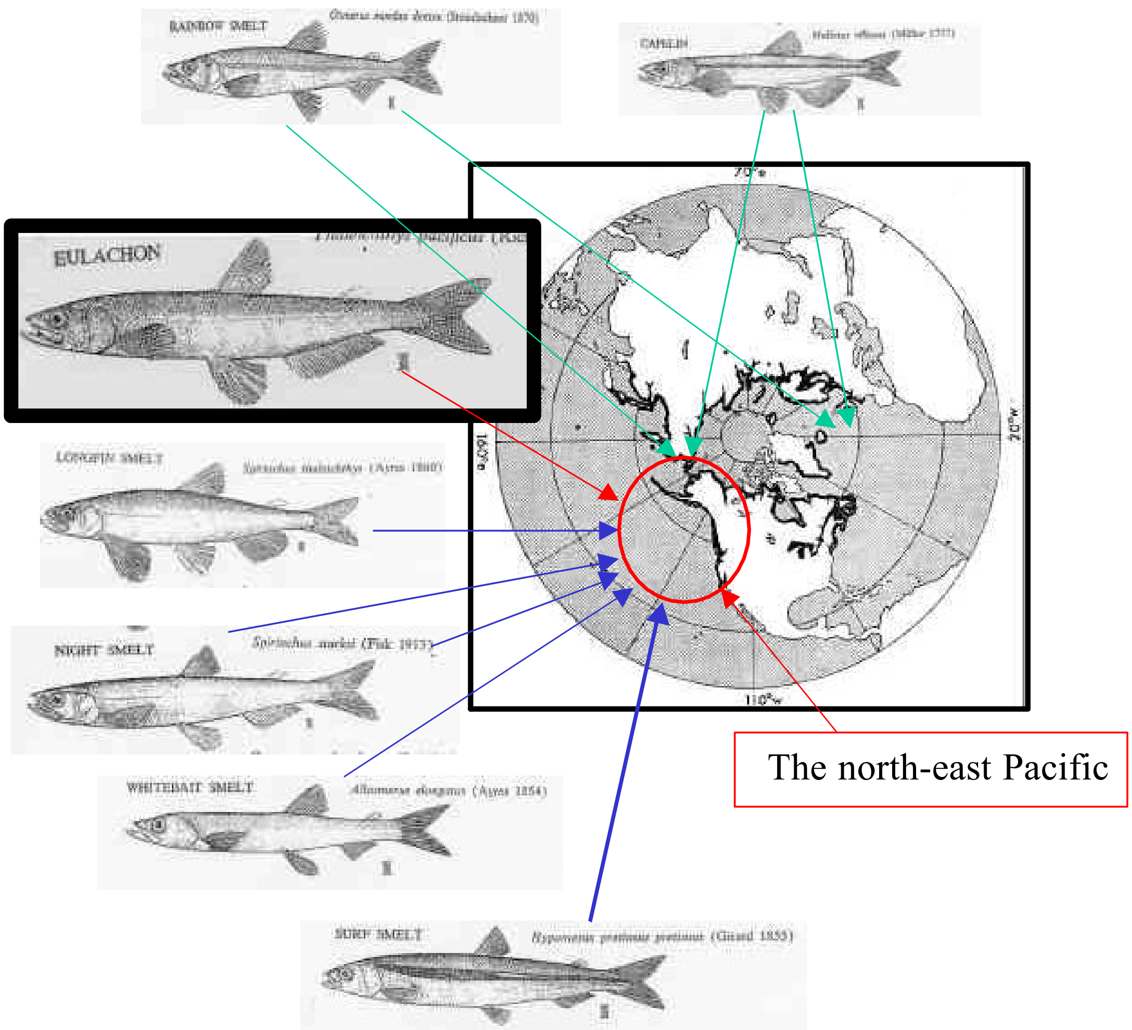

Fig. 1. A drawing of an eulachon, showing the global distribution and some representatives of some other osmerids. The distinctive features of eulachons include the partially concentric rings on the operculum, the long anal fin and low gill raker number. Distribution of smelts (Osmeridae). The drawings of smelt are adapted from Hart (1973).

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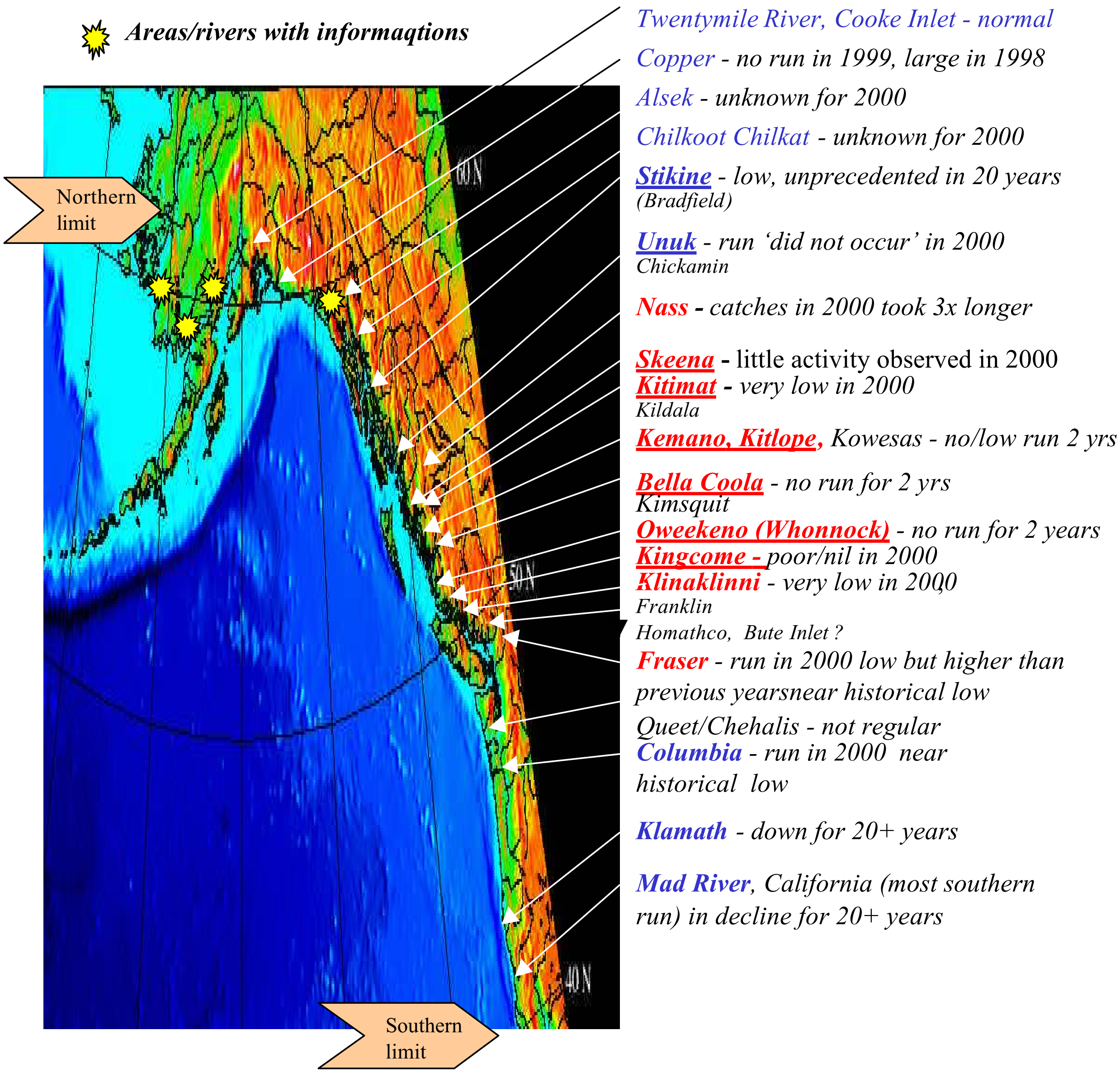

Fig. 2. Distribution, southern and northern limits, and recent comments on river-specific status of eulachons in 1999 and 2000. Eulachon runs in all rivers under observation are indicated with bold font. Rivers with no apparent no runs in 2000 are underlined. Other runs were not observed in 2000.

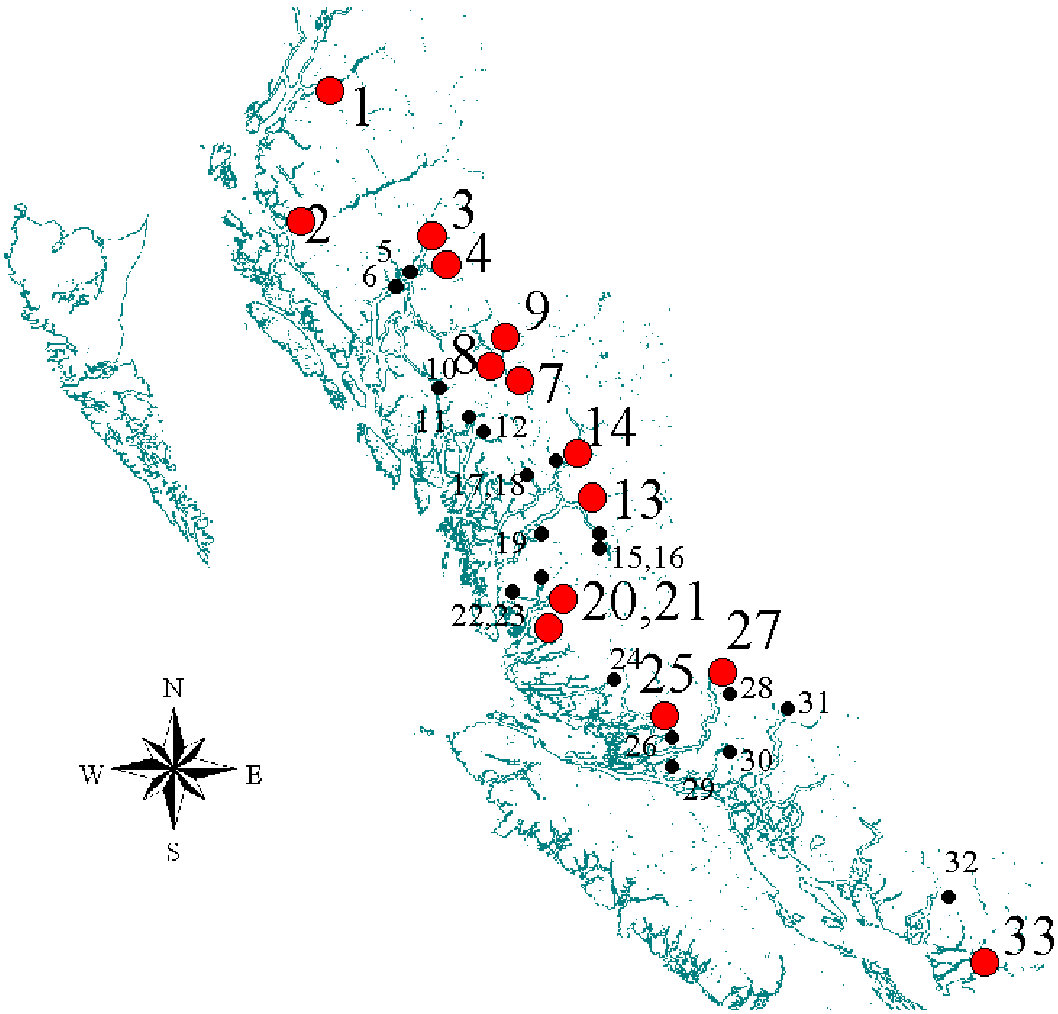

Fig. 3. Known eulachon spawning rivers in BC. The small circles represent every known spawning river indicated in Table 1. Many of these rivers, however, do not have regular inter-annual spawning. Those that are believed to be regular are indicated with large symbols and numbers, others are shown with small symbols and numbers.

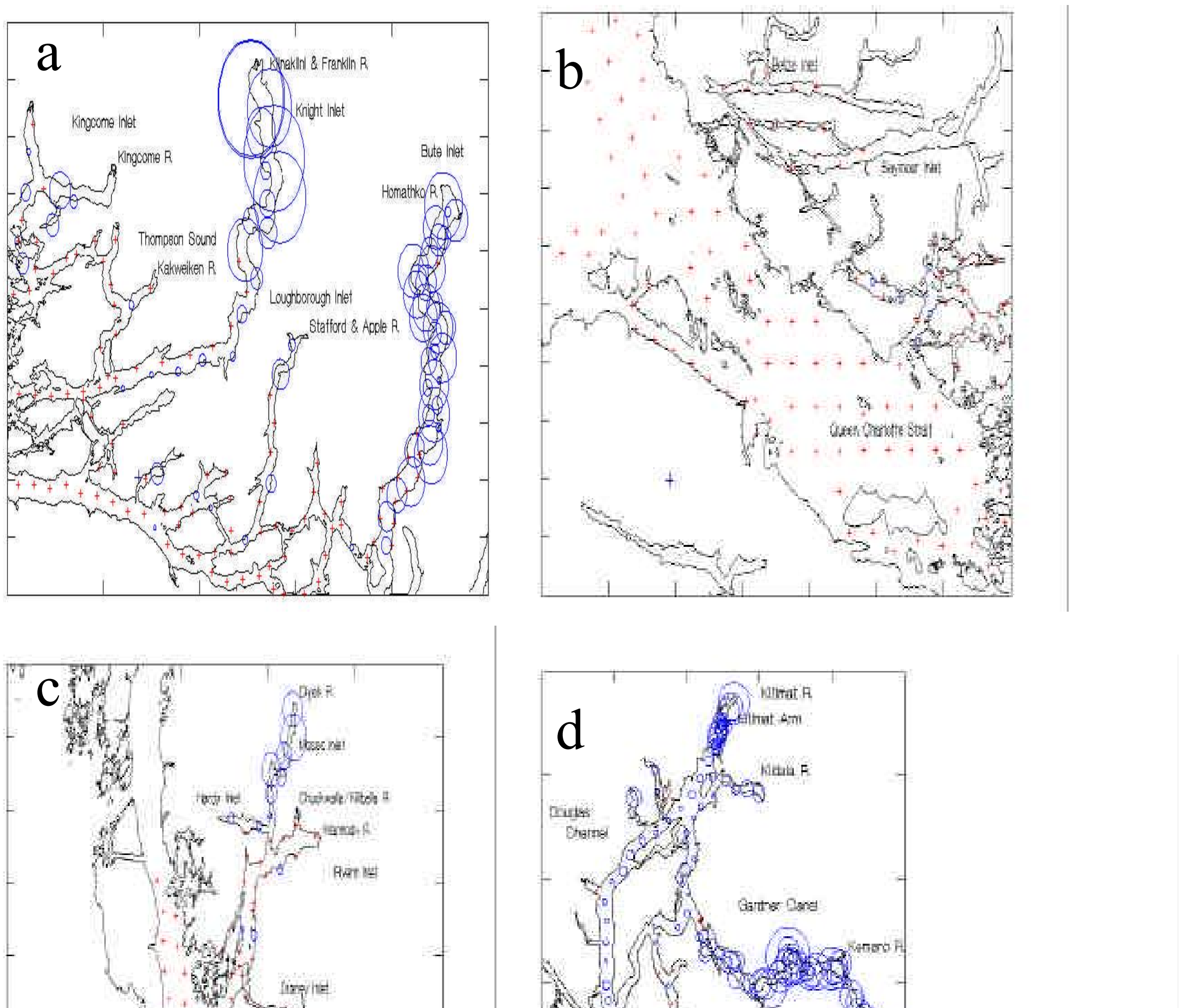

Fig. 4. **Larval eulachon** density map of (a) Johnstone Strait Region (JS) during April 25 – May 5, 1994 (Maximum density = 21.3 larvae/m3). (b) Queen Charlotte Strait Region (QS) during April 25 – May 5, 1994 (Maximum density = 0.1 larvae/m3). (c) Rivers Inlet Region (RI) during April 25 – May 5, 1994 . Maximum density = 4.0 larvae/m3). (d) Douglas Channel Region (DC) during May 27 – June 7, 1996 (Maximum density = 32.2 larvae/m3). In all figures, a red cross indicates a station where no eulachon larvae were captured.

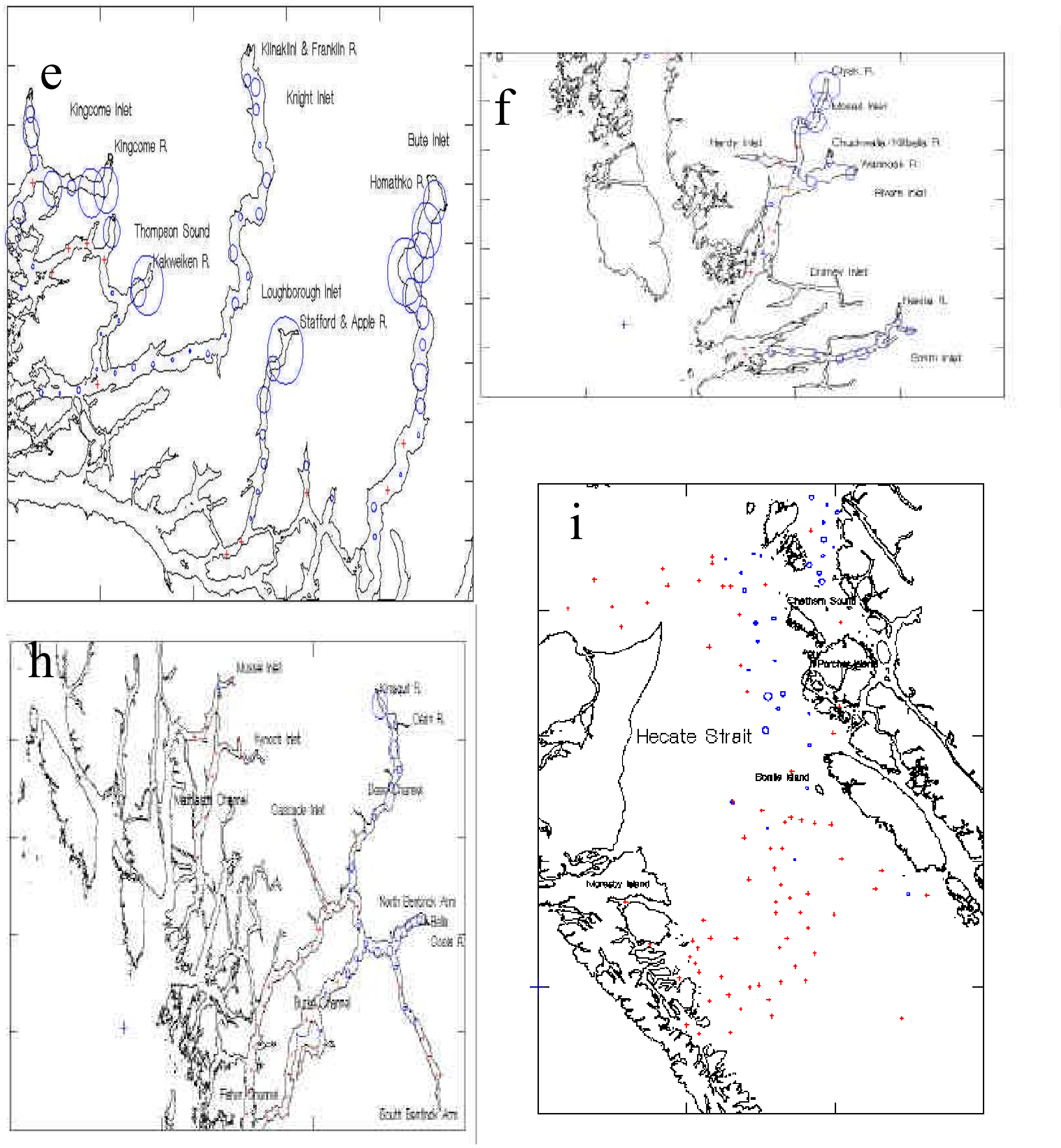

Fig.4 ***Continued***. (e) **Larval eulachon** density map of the Johnstone Strait Region (JS) during April 14 – 25, 1997 (Maximum density = 6.5 larvae/m3). (f) Rivers Inlet Region (RI) during April 14 – 25, 1997 (Maximum density = 3.6 larvae/m3). (g) Burke and Dean Channel Region (BD) during April 14 – 25, 1997 (Maximum density = 1.4 larvae/m3). (h) Hecate Strait during G.B. REED cruise, July 22-August 8, 1985. In all figures, a red cross indicates a station where no eulachon larvae were captured.

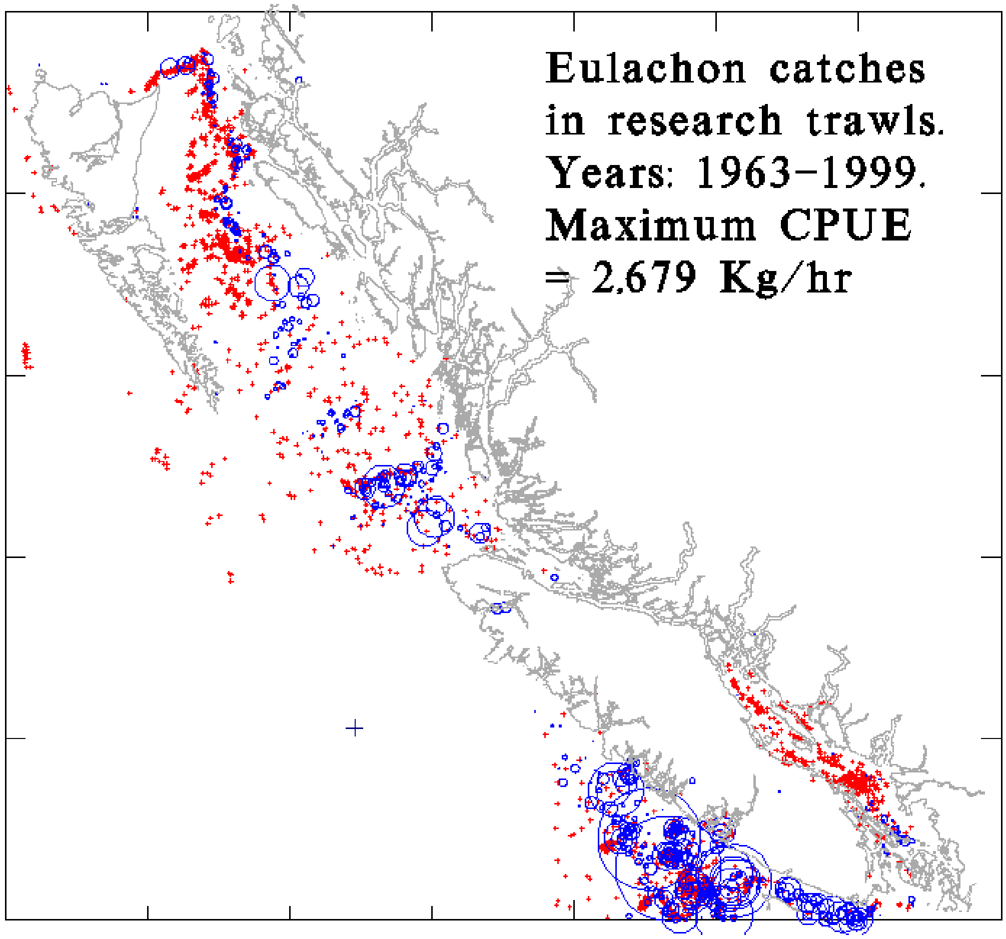

Fig. 5. Offshore distribution of eulachons, as determined from Research surveys. The sizes of the circles in proportional to the largest catch rates, which were approximately 2700 kg/hr.

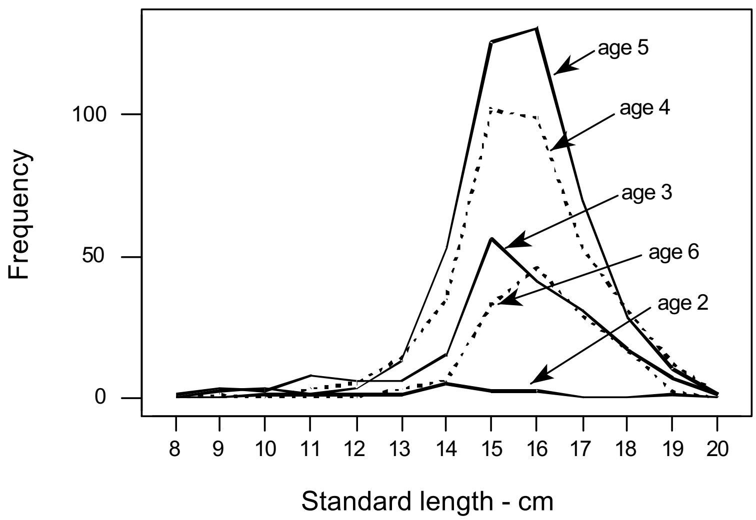

Fig. 6. Problems with age determination from otoliths. The lengths of different ages do not increase, and some small fish have ages estimated from otoliths at age 5 or 6, and some large eulachons have small ages. For these and other reasons, ages estimated from otoliths probably are not reliable (See text for more discussion).

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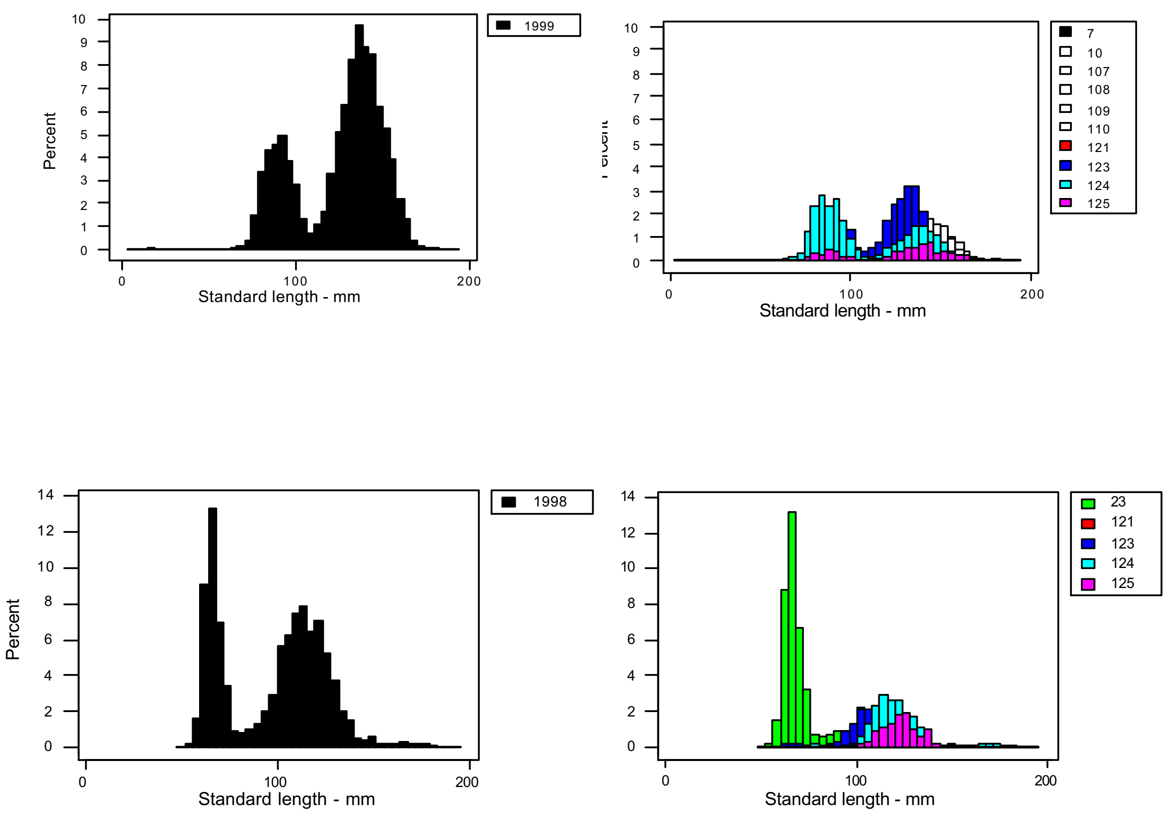


Fig. 7. Offshore eualchon Size modes - indications of age. The size modes of eulachons in May, 1997 and 1998, as determined from research surveys of shrimp on the lower west coast of Vancouver Island. There are two distrinct modes, which correspond to ages of approximalt 1 and 3 years (~12 and ~24 months). There are a few representatives of smaller (presumably young-of-the-year at ages of several months or less) and older (age 3 and 4) individuals. Note that the modes between 1997 and 1998 vary, indicating slightly different inter-annual growth rates. The different shading indicates the geographic areas wheer the eualchons were captured. Note that he smallest mode was taken mainly inside Statistical Area 23, in nearshore, shallow waters.

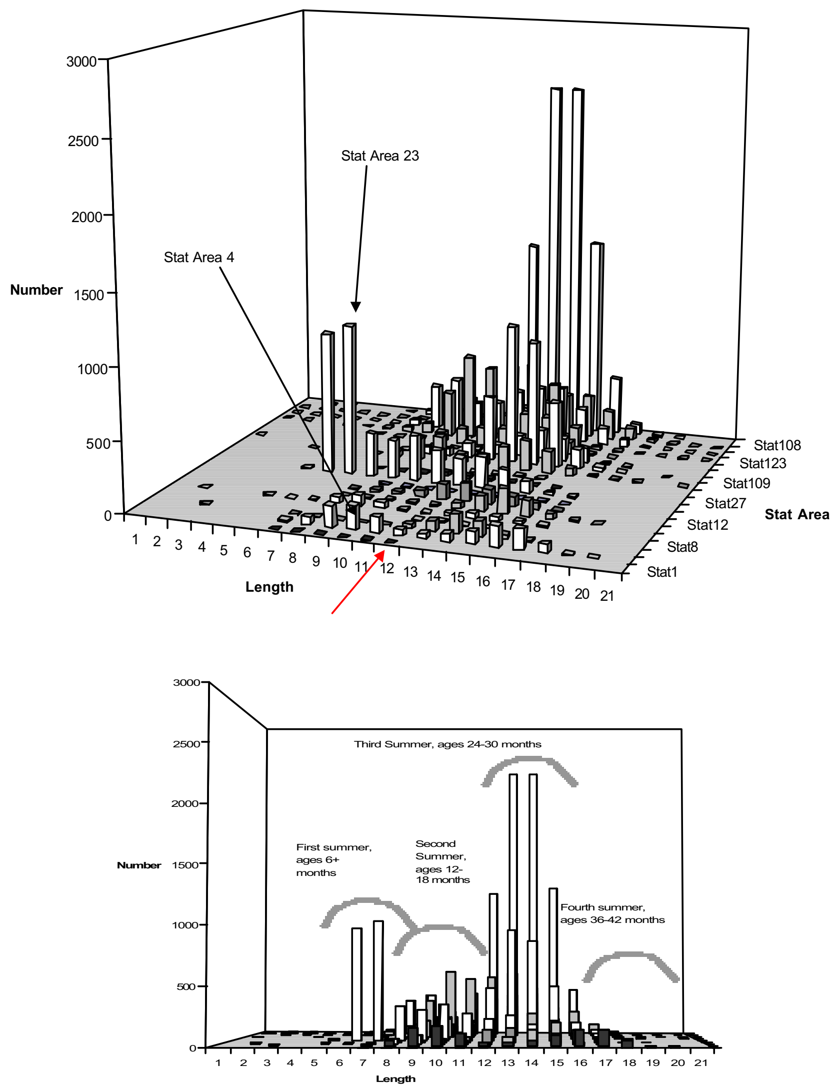


Fig. 8. (a) Three-dimensional histogram showing the numbers of fish at each cm size class for different statistical Areas of the BC coast, based on analyses of all data from offshore surveys, from samples collected by observers, mainly from 1997-1999. Note that for some areas, the samples may have been collected over a period of several months, so the distinction between the size modes is less than that seem in Fig. 7. Several area still show bimodality (see Statistical Area 4, indicated by an arrow), with an arrow (between 11 and 12 cm) indicating the approximate inter-mode length. Areas 23 shows a strong mode for very small classes (also seen in Fig. 6) corresponding to fish captured in their first summer of life. (b) The same figure, shown in 2 dimensions, with the approximate modes indicated according to each summer of life.

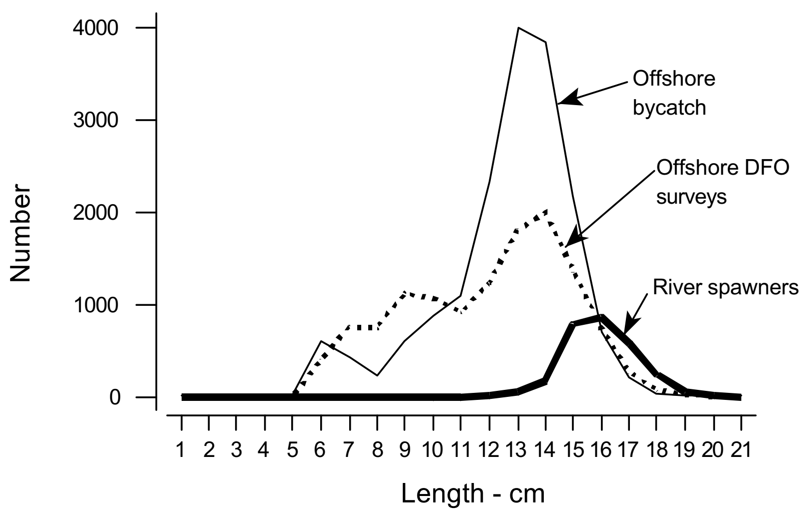


Fig. 9. The relationship between the lengths of eulachon in the sea and eulachons spawning in rivers. River pawning eulachons correspond to the larges size modes seen in the the sea.

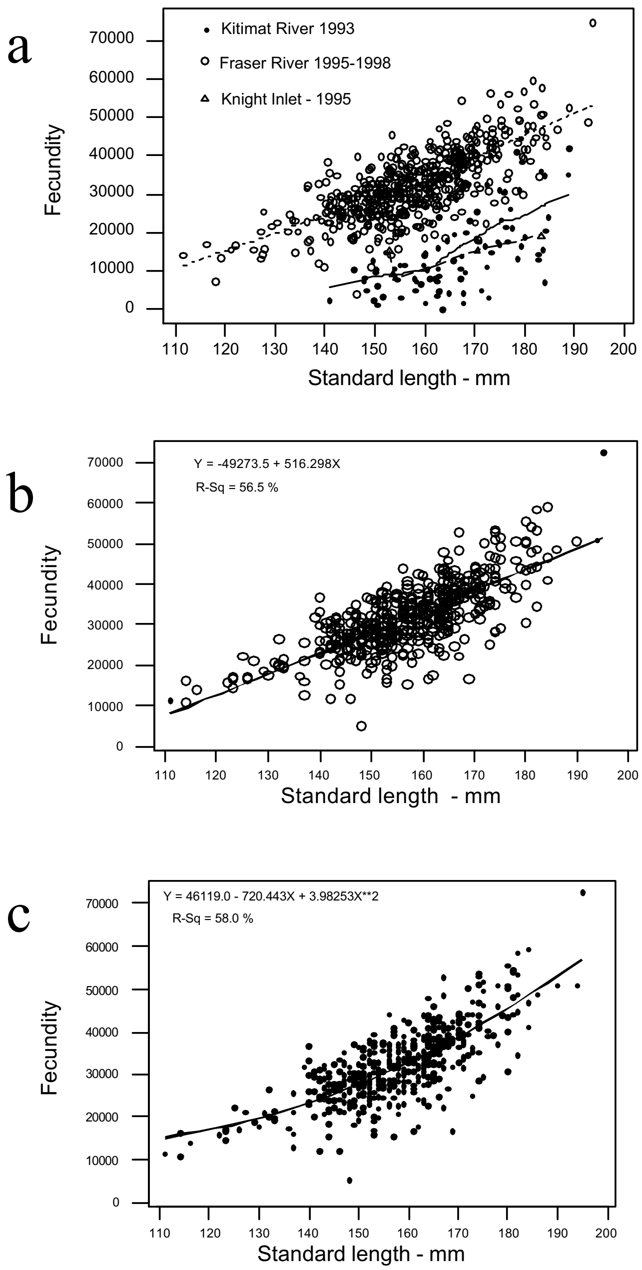


Fig. 10. Eulachon fecundity - relationships with length for the Fraser River (1995-1998), Kitimat River (1993) and Knight Inlet rivers (1995). (a) The length-specific fecundity of the Fraser River is higher, but this could be an artifact caused by loss of some eggs from from in the other rivers. (b-c) Based on analyses of only Fraser River fish, fecundity varies with a nearly linear relationship with length ($r^2 = 0.57$) and the correlation cofficient of the power function is only slightly better that the linear fit (r^2=0.58).

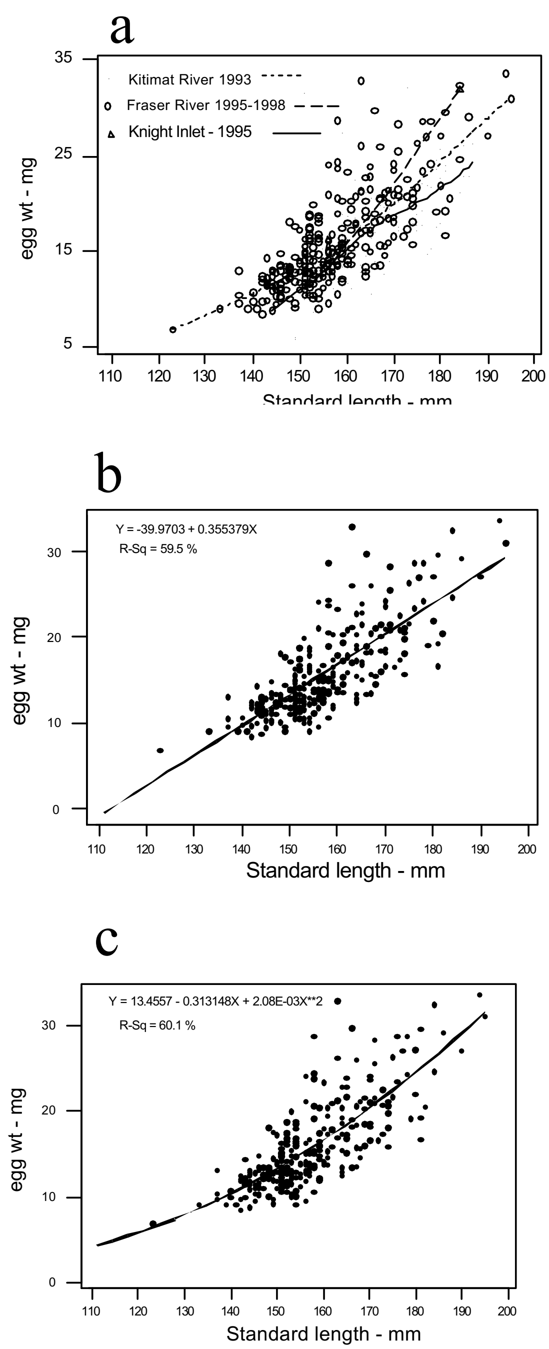


Fig. 11. Eulachon egg weight - relationship with size. The egg weights are approximately equal among all areas but very with size from about 10 mg in small 120 mm fish to nearly 30 mg in larger fish of 180-190 mm (standard length). (b-c) Based on analyses of only Fraser River fish, egg weight varies with a nearly linear relationship with length and the correlation cofficient of the power function (r^2=0.60)is only slightly better that the linear fit (r^2=0.59).

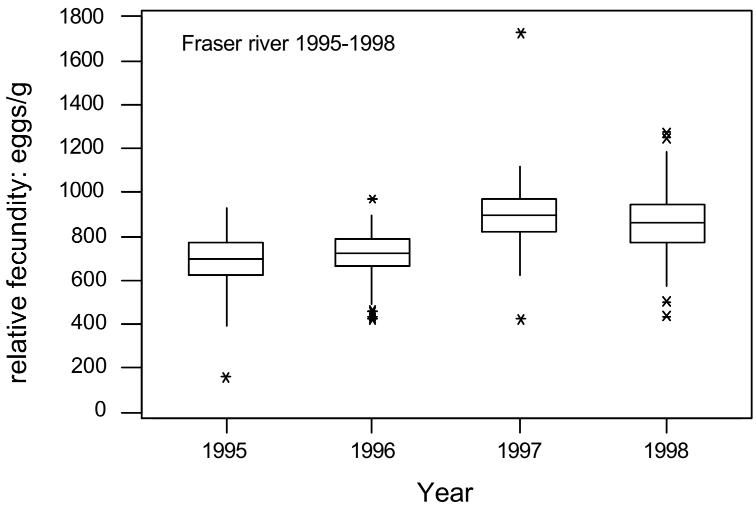


Fig. 12. Relative fecundity, indicated by boxplots, of eulachons in the Fraser River, 1995-1998. Relative fecundity varied slighly bamong years, with significantly higher estimates in 1997 and 1998.

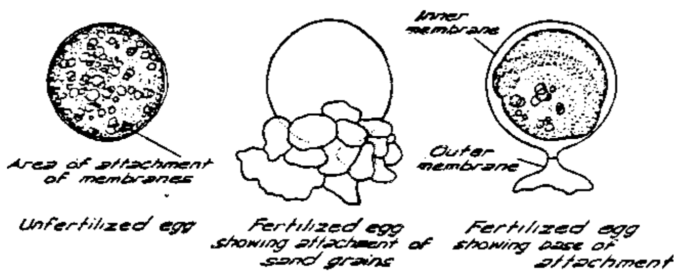


Fig. 13. (a) drawing of an eulachon egg showing the adhesive stock, from Hart and McHugh 1944).

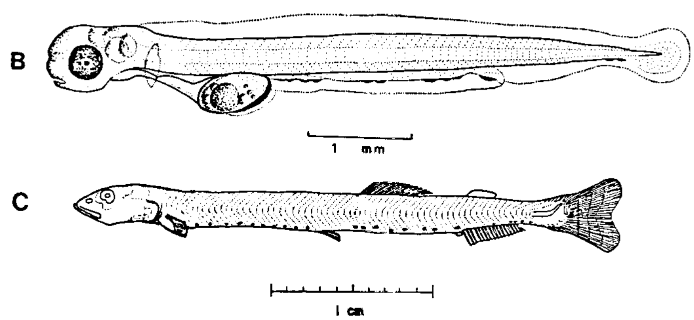


Fig. 13. (b) drawing of an eulachon larvae, showing yolk sac and oil globules, from Barraclough (1964).

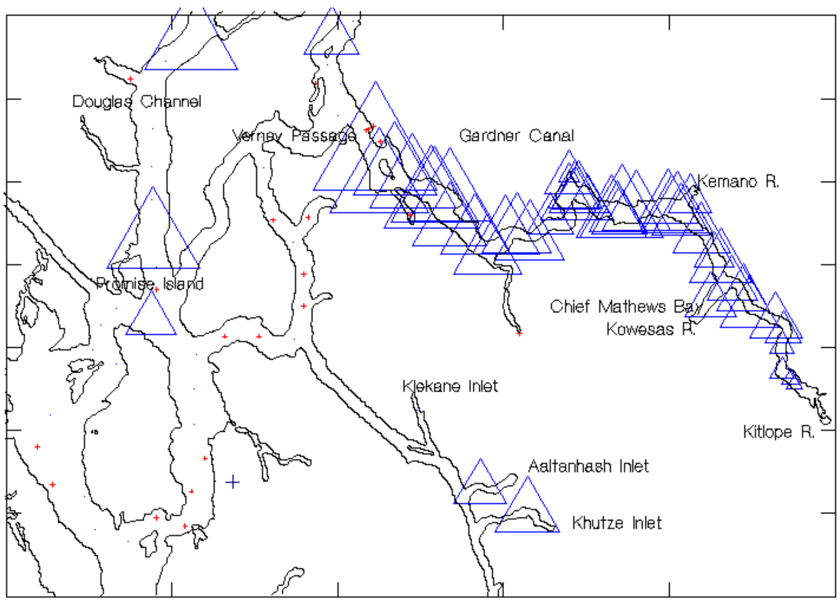
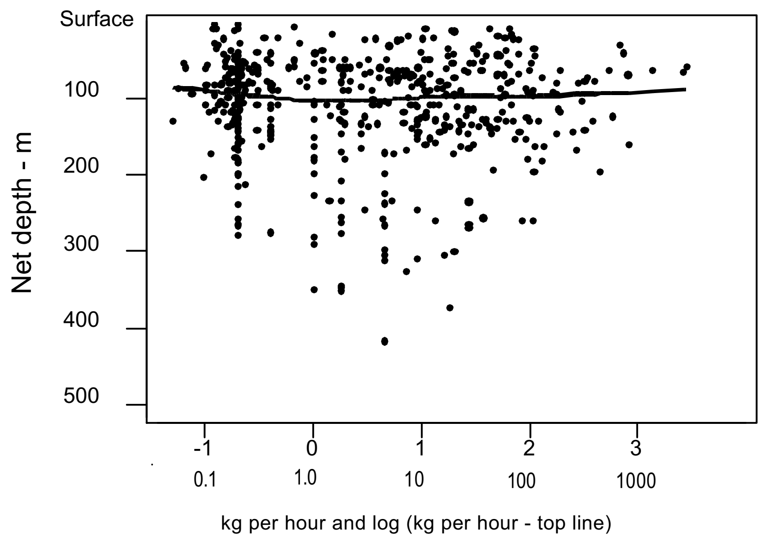


Fig. 14. Larval eulachon mean lengths (N=20) are represented by the size of a triangle at each sampling station along Gardner Canal (May 27 – June 7, 1996). Mean lengths ranged from 5.2 mm at the head of Gardner Canal near the Kitlope River estuary to 12.1 mm where Gardner Canal joins Douglas Channel. A small dot or cross indicates a station where less than 20 eulachon larvae were captured.



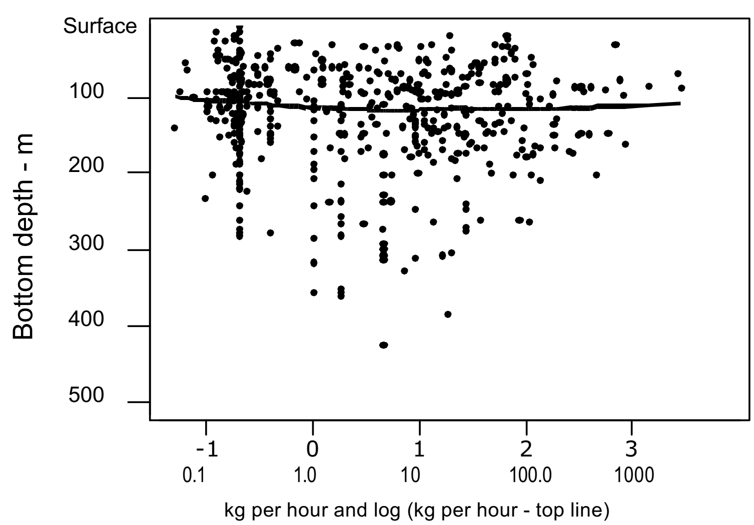


Fig. 15. The depth of the net and the depth of bottom and the versus the mean capture rate of eulachons (kg/hour) determined form analyses of data from incidental capture in offshore surveys.

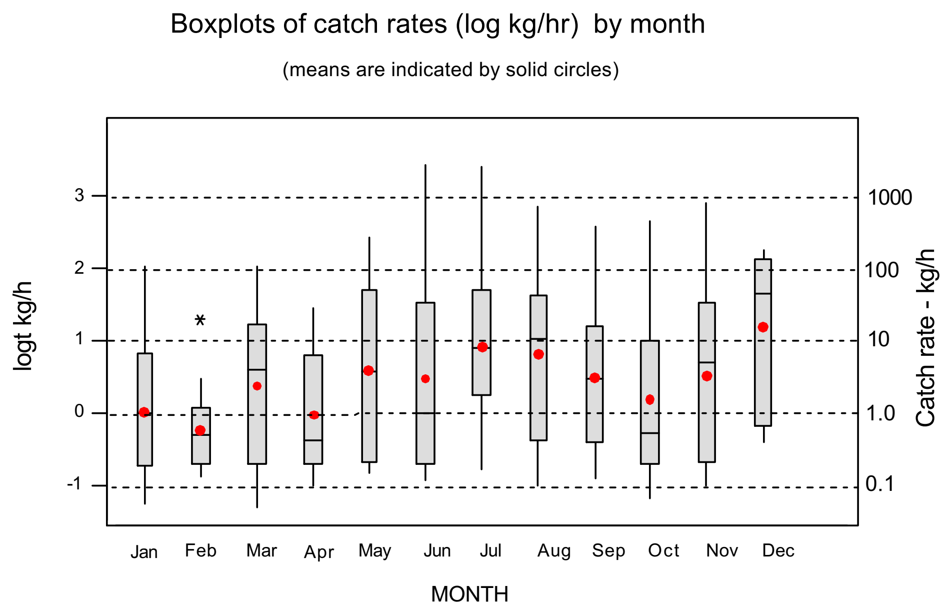


Fig. 16. Monthly variation in catch rates (kg/h) in offshore waters determined form analyses of data from incidental captured in offshore surveys. The differences, analysed by ANOVA are significant (P<0.01). The highest catch rates were in the summer months, although this does not account for possible differences in size composition during the season.

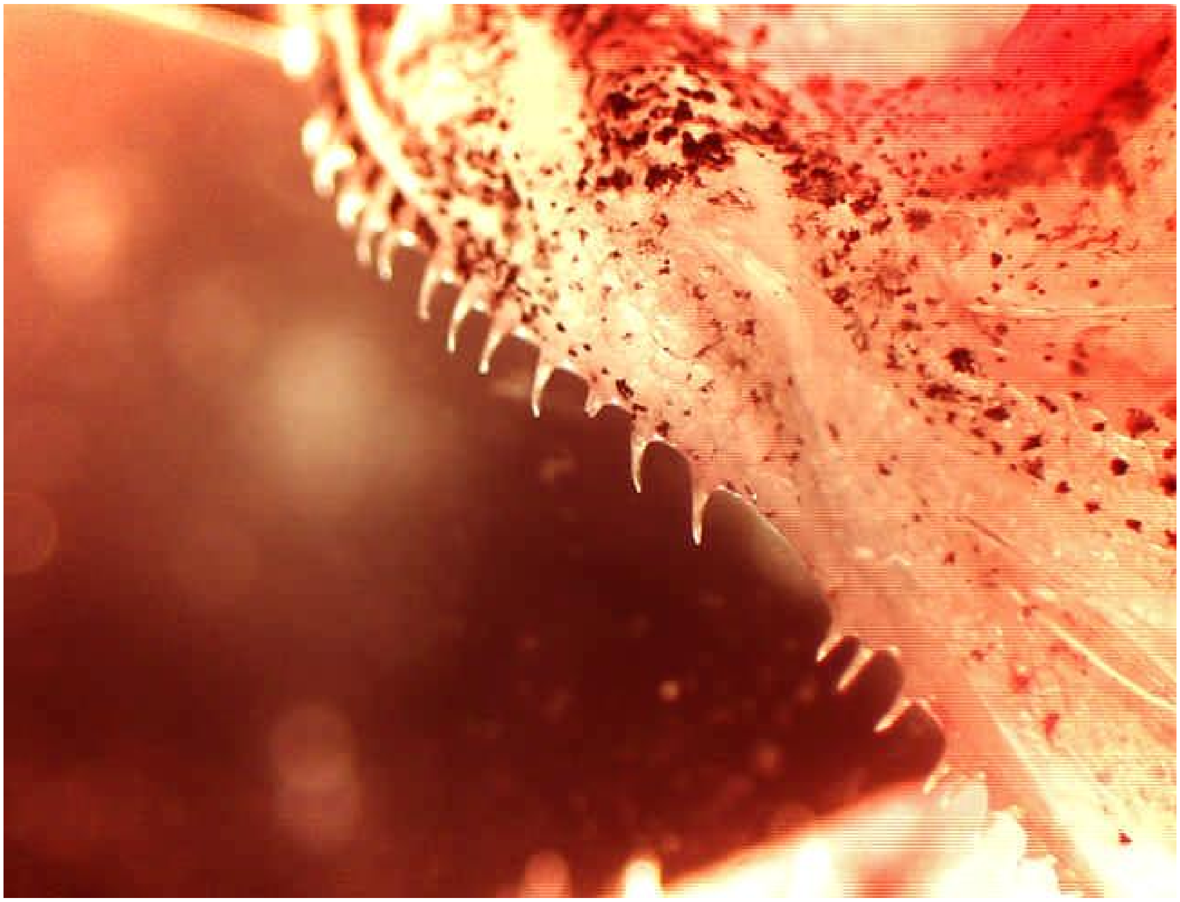


Fig. 17. An eulachon mouth showing dentition seen if fish from offshore waters. These teeth are missing or reduced in spawning fish.

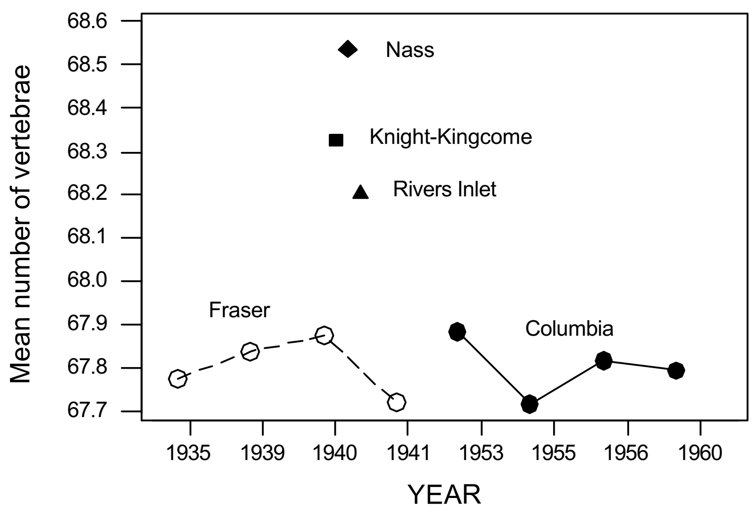


Fig. 18. Mean eualchon vertebral number - comparison among regions. Data collected separatly for the Columbia River by DeLacy and Batts (1963) and Hart and McHugh (1944) for the Fraser and northern BC rivers, were assembled and compared for this paper. The vertebral counts of the Fraser and Columbia are not significantly different, tut the differencves between these, and the remaining rivers, are different (See Table 9 for tests of significance).

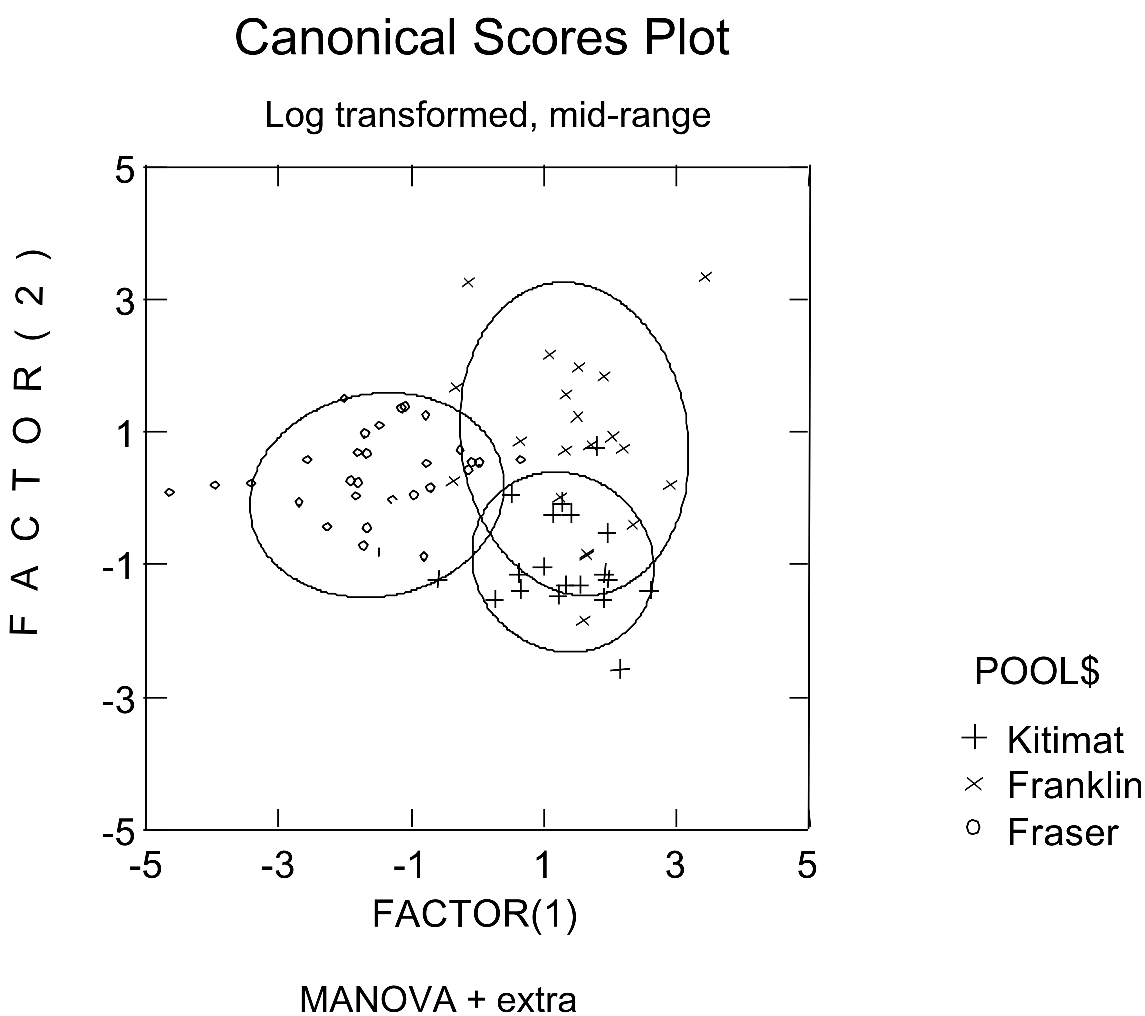


Fig. 19. Preliminary analyses of factors separating 3 eualchons samples (from the Fraser River, Franklin River, Knight Inlet and Kitimat River) stocks based on elemental analyses of the cores of otoliths (from Carolsfeld and Hay, 1988). These results may be subject to revision, as we are concerned that some of the apparent differences may be associated with laboratory artefacts related to the date of analysis.

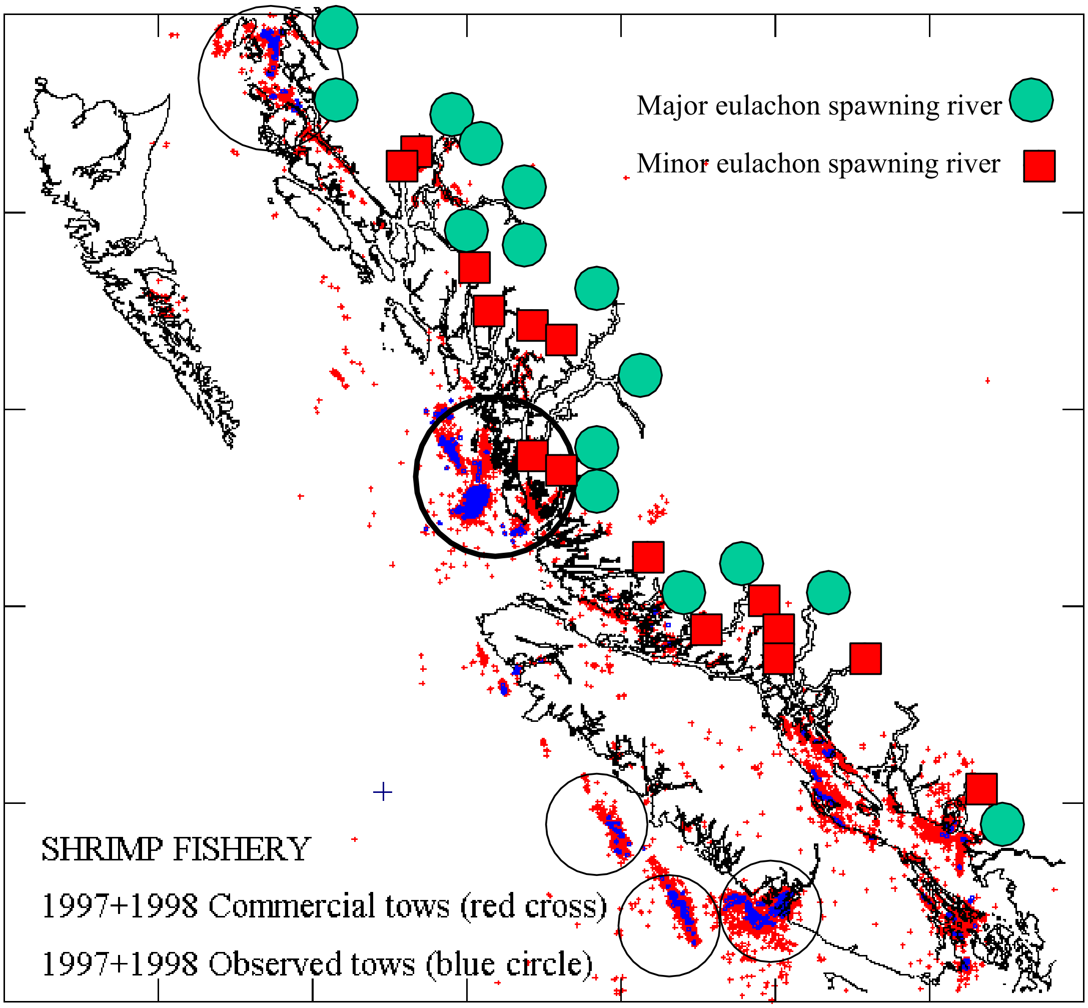


Fig. 21. The relative locations of the 1997 and 1998 shrimp fisheries to all major and (most) minor eulachon spawning rivers. Each cross represents a single tow. Note that some tows are shown as occuring on land, and these represent errors in the raw data as recorded in the logbooks submitted to DFO, although most posiitons are reasonable and many overlap. The general areas of concentrated shrimp fisheries are indicated with large dark circles, with 3 concentrated areas occurring off the West Coast of Vancouver Island and another in Chatham Sound. There are several distinct areas of fishing concentration in the Queen Charlotte Sound fishery which are grouped into a single large dark circle. The eulachon spawning areas are distinguished as regular (shaded circles) and irregular (squares) as defined in Fig. 3.

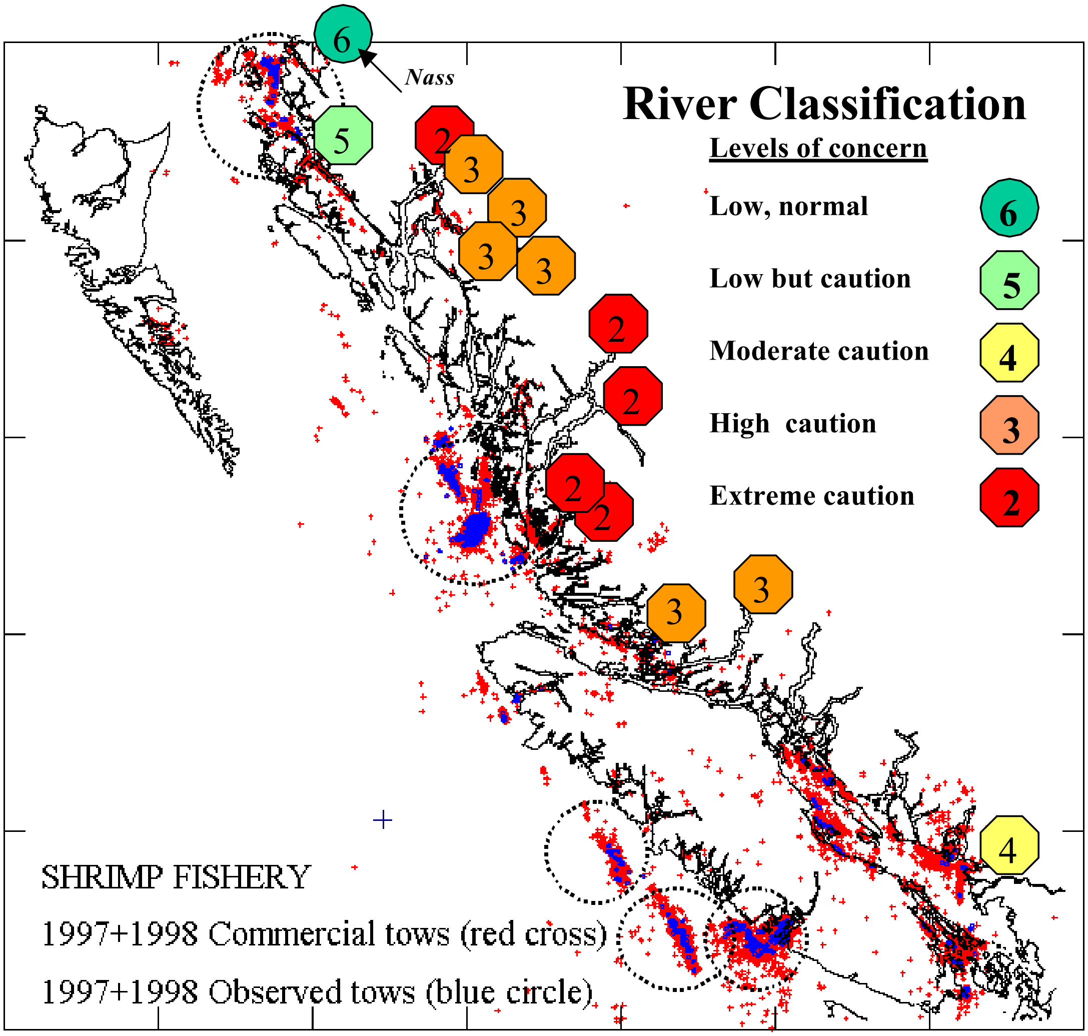


Fig. 22. Classification of 14 key eulachon rivers according to levels of recommended caution (defined in Table 10). The dark octagons (category 2) are rivers that have not had spawning runs for 2 years and the level of concern is extreme. The other octagons indicate lower degrees of concern (categories 3-4) or little or no concern (circle). The locations of the shrimp fisheries are indicated with large dark dashed circles.

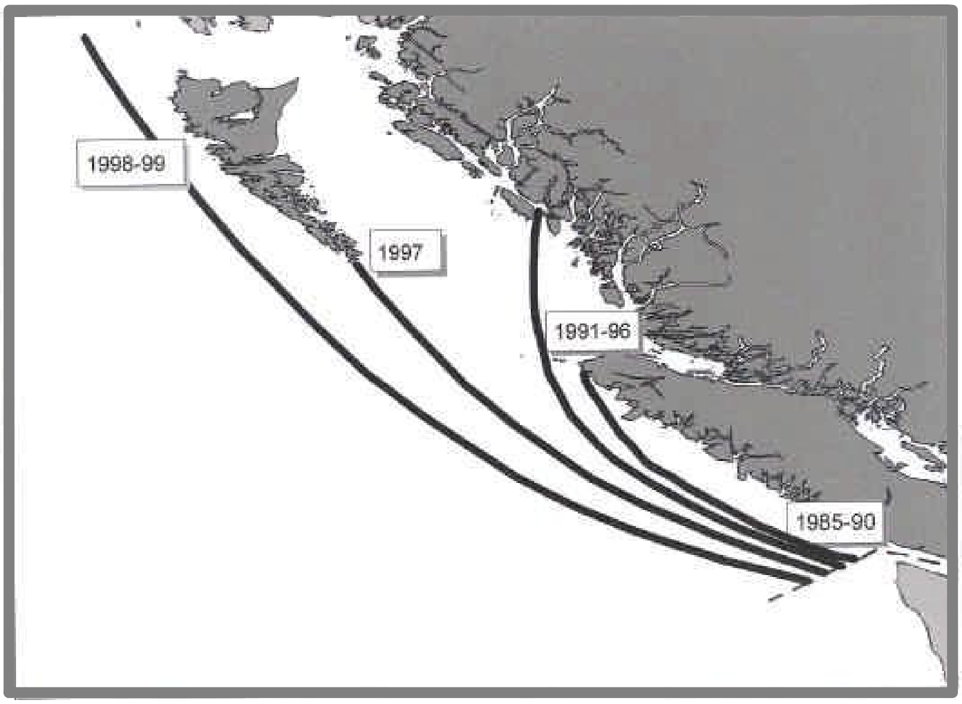


Fig. 23 Changes in the distribution of Pacific hake from 1989-99 off the west coast of Canada (from McFarlane et al. 2000). The lines indicate the northward shift of hake from the mid-1980's to1999.