Stock identification of eulachon (*Thaleichthys pacificus*), an anadromous smelt in the eastern Pacific

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Abstract

The anadromous eulachon (*Thaleichthys pacificus*) occurs from northern California to the Bering Sea but the number of populations is small (<100). Many populations declined suddenly in the 1990’s raising conservation concerns. In the last 70 years eulachon population structure has been examined by five approaches, from eight or more independent studies. Early meristic variation showed differences between populations in southern and northern populations, but no significant differences from adjacent populations. Comparison of life history traits (spawning time and larval distributions) and comparisons of elemental analyses in otoliths also reached similar conclusions. No approach provided a definitive answer to the basic problem of whether there was significant reproductive isolation among the populations: any or all of the observed differences could have been acquired. The first two genetic analyses (a mitochondrial DNA and another microsatellite DNA study that used only five loci) provided only limited resolution. A recent study, however, examined variation of 14 microsatellite loci from nine sites and found evidence of significant genetic differentiation and isolation by distance. This result does not contradict previous non-genetic studies. Rather it provides a biological basis for confirming that the observed meristic, life history and chemical differences were valid indicators of population differences. Similarly, these previous non-genetic studies provide a biological rationale for the observed genetic differences.
Introduction

In this paper we report and summarize results of stock identification activity as it has been applied to eulachon (*Thaleichthys pacificus*) for the last 70 years. We briefly discuss each of five different ‘approaches’ to eulachon stock identification (Table 1). We show that two or three of the first four approaches provided information that would support the hypothesis that there are different eulachon populations spawning among different rivers in the eastern Pacific. Mitochondrial DNA results, and the first microsatellite project, however, did not find strong corroborative evidence of fine-scale (River-specific) genetic variation, although the first genetic microsatellite study was based on a relatively few alleles. The general conclusion from these studies was that eulachon populations were not genetically isolated. In contrast, a more recent report on microsatellite DNA variation, using more alleles, provides much stronger evidence of stock-specific differences observed in the other, non-genetic approaches. In effect, the genetic work tends to corroborate results from other approaches.

We begin the paper with a brief review of the general biology, distribution and fisheries for eulachon. Then we discuss stock Identification (SID) activity on eulachons. We organized the various studies into five approaches (Table 1). The first approach on the list is not a dedicated SID activity per se, but rather represents accumulated information from other studies that are relevant to understanding SID in eulachons. We conclude with a discussion of the relevance of SID to management and conservation of eulachons.

Review: taxonomy, biology and fisheries

Eulachons (*Thaleichthys pacificus*) are a species of smelt (Osmeridae) that occur from northern California to the Southern Bering Sea (Hay and McCarter, 2000). Eulachons are small (<25cm), anadromous, and semelparous. There only are about 10-12 Osmerid species (McAllister 1963) but the exact number of species depends on the resolution of taxonomic interpretation within the genus *Hypomesus*. A representative drawing of an eulachon, and some other osmerid species is shown in Fig. 1. Eulachons are within the
Order Salmoniformes, and phenotypically resemble small Pacific salmon, with an adipose fin and long anal fin. Most osmerids are found in the North Pacific. Only two species occur in the Atlantic: both also occur in the North Pacific and the Arctic areas, so perhaps only the species that can tolerate sub-Arctic conditions were able to pass through the Arctic to Atlantic waters (McAllister, 1963). Within the Pacific, eulachons are found only on in the eastern Pacific, from northern California to the eastern Bering Sea (Fig. 2). Eulachons are not known in the western Pacific (Russian or Asian waters). 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.

The Genus (*Thaleichthys*) is derived from Greek, meaning 'rich fish'. A recent comparative study found that eulachons have an oil content of about 20% (Payne et al. 1999). Eulachons have been fished by First Nation (FN) peoples who valued their exceptionally high lipid content. Dried eulachons can be burned like a candle, and this attribute has led to one of the common names of eulachons as ‘candle fish’. FN fisheries usually were small, and occurred during spawning runs. Freshly captured eulachons were placed in specially constructed boxes and allowed to decompose for several weeks or longer. Periodically as the oils rose to the surface they were skimmed off and stored. Later the non-lipid materials were carefully removed by elaborate and sophisticated processes. The end product was a clear, yellow oil that had the consistency of soft butter. This substance is known as ‘grease’ and is highly valued among FN communities. Grease was easily stored and used as an energy and food source throughout the winter. In many northern communities eulachon grease was produced as a trade commodity. It was transported throughout coastal areas and often to inland communities in the interior of the Province of BC and Alaska. The trails over which grease was delivered were known as ‘grease’ trails. These trails were used in 1793 by Alexander McKenzie, the first European to reach the Pacific through Canada by an overland route. This event, which was thoroughly documented by Mackenzie and widely read at the time in eastern North America and Europe, had a profound impact on the local and regional history of BC, and the eventual development of western North America.
With rare exceptions eulachons have never supported large commercial fisheries, except in the Fraser River (southern BC) and the Columbia River (Southern Washington State (Fig. 1). These commercial fisheries used eulachons for industrial purposes (meal or for animal feed). There also was an active recreational fishery in some rivers.

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. 3). Single eggs or clumps of eggs stick to grains of sand or other debris that appear to ‘anchor’ eggs to the bottom. 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. Larvae are small (6-8 mm), elongated with a distinct yolk sac and oil globule. They are pelagic 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. The 2-3 years 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 bottom in waters of moderate depth (20-150 m).

**Stock Identification**

**Approach 1: Life history, spawning distribution and timing**

Within British Columbia there are 33 spawning rivers (Fig. 4, Table 2) of which only 14 are classified as having regular spawning (Hay and McCarter 2000). The exact number and distribution of eulachon populations outside of BC is not well documented. In Alaska, 35 rivers are known to have either regular or intermittent eulachon spawning runs (unpublished data, Alaska Department of Fish and Game) but there could be a few more. There are few spawning rivers south of BC, probably less than 10, in Washington, Oregon and northern California. Eulachon runs probably were not large in California, but they appear to have disappeared during the last 20-30 years. The Columbia River eulachon run, however, like
the river, is the largest in the Pacific, and until the 1990’s supported both a commercial and recreational fishery of several thousand tonnes per year.

Eulachon usually spawn in rivers that drain into inlets (or fjords) (Fig. 4). Some inlets have only one river but other inlets may receive water from several rivers. In some areas separate rivers may drain into the inlets in the same approximate areas, separated by only a few kilometers although the headwaters and drainages of such rivets may be broadly separated (100’s of kms). Therefore if eulachons home to natal rivers, then they must have the capability of distinguishing between such adjacent rivers. Given their short duration in these rivers as eggs and larvae, the potential for such precise imprinting and homing is unlikely. Therefore stock differentiation between closely adjacent rivers is less likely than between widely separated rivers. For this reason Hay and McCarter (2000) proposed that the smallest stock unit for eulachons may be the estuary into which one or more rivers drain. This is shown in Table 2 as 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 which have classifications of ‘regular’ spawning - for a maximum of 9 potential stocks, classified according to estuarine waters.

Eulachons spawn in the lower reaches of rivers. The biological basis for selection of rivers is uncertain, but most spawning runs occur in rivers that contain glacial discharge and that have peak freshets in the spring. For instance, eulachons do not spawn in coastal rivers that drain islands, such as Vancouver Island, or the Queen Charlotte Island, and that do not have either glaciers or spring freshets. Although data on spawning times for all rivers is not complete, there are clear differences, with the Columbia being among the earliest (mainly in late January and February (Smith and Saalfeld 1955, DeLacy and Batts 1963), and the Fraser River as the latest, mainly in April and May (Ricker et al., 1955, Hay et al., 1997). 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.

**Approach 2: Meristic variation**
In one of the earliest scientific reports on eulachons, Hart and McHugh (1944) examined inter-population differences in eulachon vertebral number. They found significant differences between eulachon from northern and southern BC. Later, DeLacy and Batts (1963) looked for vertebral number differences for eulachon spawning within different tributaries within the Columbia river, but failed to find any difference. Later, Hay and McCarter (2000) pooled data from these separate studies, and found significant differences between northern and southern eulachon, but no differences between the two largest southern populations (the Fraser and Columbia River (Fig. 5). Vertebral numbers for the Columbia and Fraser rivers are lower than those from more northern areas (1) Rivers Inlet, (2) Kingcome-Knight Inlets and (3) the Nass River (Fig 2, 4). Compared both by parametric and non-parametric statistical analyses (Hay and McCarter, 2000, 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 River, but the differences among all rivers were highly significant, which was the original conclusion reached by Hart and McHugh (1944).

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 earlier spawning northern rivers, where spawning may sometimes occur under ice. The differences in meristic variation (Fig. 5) do not demonstrate that the populations are 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.

**Approach 3: Larval eulachon distribution in BC**

Hay & McCarter (1997) used surveys of Pacific herring larvae (*Clupea pallasi*) to comment on herring stock structure and also applied the same approach to eulachons McCarter and Hay, 1999). Those surveys also determined the distribution of larval eulachons and were
used to 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 locations nearest rivers that might serve as potential eulachon spawning areas. The *a priori* hypothesis was that if substantial mixing of larvae occurs among rivers, then maintenance of genetic isolation between individual spawning rivers 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. Fig. 4 shows detailed maps of larval eulachon densities represented by the size (areas) of each sampling station circle for representative areas. Most larval eulachon were found adjacent to known eulachon spawning rivers. Larvae collected at the heads of inlets, adjacent to known eulachon spawning rivers, were small and newly hatched. Mean eulachon larval size (mm) generally increased at each sampling station in a seaward direction away from eulachon spawning rivers. Larval eulachon collected at some sampling stations located mid-way within inlets showed a wide range of larval sizes indicating mixing of small newly hatched larvae from nearby rivers. The general conclusion from this work is that in inlets with several rivers, there is extensive larval mixing in the marine estuarine areas, but there is no indication of larval mixing between adjacent inlets.

The distribution of larval eulachons is consistent with oceanographic factors that may affect their distribution, particularly estuarine circulation. The distribution also has implications for stock structure. Based on a review of larval distributions, McCarter and Hay (1999) suggested that the minimum geographical feature area that could support a ‘unique’ eulachon stock was a marine estuary, and not necessarily a river, although this could depend on the proximity of nearest rivers. 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. The duration of larval residency in estuaries may be sufficient for geographic imprinting to occur. The close proximity of different potential spawning rivers casts doubt on the capability for adjacent rivers to maintain distinct biological stocks. For instance, based on a salmonid 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,
provisionally 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 would probably have to do it
rapidly, because in most instances they are immediately rapidly advected to estuarine or
marine waters, probably within hours, or a few days at most, even in the largest rivers. 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, it is unlikely that
eulachons imprint during their freshwater egg and larval stages. In contrast, 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
residence 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. Estuaries
may be important for stock configuration and that the numbers of different populations could
be determined 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.

**Approach 4. Chemical (elemental) analysis of otoliths**

Elemental Analysis with Laser Ablation Inductively Coupled Mass Spectrometry (LA-ICPMS)
can provide an elemental signature in otoliths by vaporizing the area of interest of the tissue
with a laser and then analyzing the elemental composition of the vapour with mass
spectrometry (Campana et al. 1994). We experimented with elemental analyses of otoliths to
determine if eulachons from different areas could be recognized. This assumes there were
distinctive elemental compositions of estuarine waters close to spawning areas that left a
unique chemical signature in the core of eulachon otoliths. A comparison of the LA-ICPMS
analysis of the core of otoliths of adult eulachon, corresponding to their larval period, collected
on different spawning grounds should thus indicate if eulachons returned to their natal spawning
area or emigrated from other areas. 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 mixing of fish originating from different spawning sites.

Eulachons were collected from different rivers in BC. All otoliths were analyzed with a single spot in the centre of the otolith core, presumed to represent the larval period. Subsequent analyses by a Scanning Electron Micrography showed that the laser ablation crater in the otolith was generally 80-120 µm in diameter. Based on an assumption of a daily growth increments of 2 µm, the ablation crater was taken from a period corresponding to the first 40-60 days of life. 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. Signals from 14 of the remaining elements/isotopes were too weak for analytical use. Three had unpredictable background variation.

The results indicated that there was significant variation associated with the LA-ICPMS session date, which was a potential source of experimental error. Also, we noted variation associated with the geographic origin of samples, which was the objective of the work. Also, for the Fraser River, we found evidence of significant inter-annual differences from samples taken form the Fraser River. Because correct classification into our hypothesized stock groupings was influenced by the date and sequence of submission of samples for LA-ICPMS analyses, there must have been (error) or ‘drift’ in the LA-ICPMS apparatus (or a qualitative change in the otolith material between analytical sessions, but this is unlikely). We could determine this because samples for LA-ICPMS analyses were prepared and submitted for analyses in 'blocks', with about 18 otoliths per block. Each block contained samples from all river systems. If we had submitted the samples of otoliths for LA-ICPMS according to location, the results from each analytical session would have corresponded exactly to a single location. In this case we would have had strong but potentially misleading results because we could not have distinguished between variation associated with the session date from sample location. Indeed, in subsequent analyses we found that both location and sample date provided a basis for grouping the samples. This is a problem for further analyses of these data because of the experimental error associated with the analyses. This
error, however, was not so large that it masked all real variation associated with geographic
differences (and inter-annual difference in one river). Still, there was considerable overlap in
the distinction of geographic differences which led us to the conclusion that elemental
analysis was not useful to distinguish between closely adjacent stocks – either the resolution
of the equipment was inadequate or there was considerable straying between rivers.
However, subsequent analysis of data pooled among adjacent areas, but compared over a
broad geographic range, indicates that there are indeed differences associated with
elemental analyses of eulachon otoliths. What is not resolved at the present time is the
extent to which this technique is useful as a SID approach, compared to other techniques.
There is no doubt however, that barring experimental error, LA-ICPMS analyses may
contribute substantially to life history studies.

**Approach 5: Genetic variation: Mitochondrial and Microsatellite DNA analysis**

Genetic evidence, based on mitochondrial DNA (McLean et al., 1999) indicated few
differences among widely separated rivers in BC and virtually none between geographically
adjacent rivers. There was, however, a clear demonstration of a degree of 'isolation by
distance' among the most geographically separated stocks (Oregon-Alaska). The lack of
apparent genetic variation among different spawning populations led to the tentative
conclusion that eulachons consists mainly of one large genetic unit and that the probability of
finding future genetic variation among eulachon populations is low. Further genetic
evidence, based on the first microsatellite DNA study (McLean and Taylor, 2001), confirmed
the previous report (McLean et al 1999) that there was little apparent genetic variation among
eulachon populations. This report was limited to using only 5 microsatellite loci.

A recent report (Beacham et al., 2005) however, examined variation of 14 microsatellite loci
from about 1900 eulachons from 9 sites distributed in BC, Alaska and Washington State.
Significant genetic differentiation occurred among the populations. There was a significant
correlation between population genetic differentiation ($F_{ST}$) and geographic distance.
Although only about half of the potential BC rivers were included in these analyses, it is clear
the evidence supports the hypotheses of reproductive isolation, especially between
eulachons from widely separated populations. The greatest differentiation was observed
between the Columbia River drainage populations and those populations north of the Fraser River.

Discussion

During the 70 years that eulachon stock structure has been examined, the conclusions have varied. From the perspective of a simple understanding of life history, distribution and spawning times (approach 1) there would be little question that most eulachon runs were distinct. The life history model seems to follow that of Pacific salmon, also an anadromous semelparous fish. Clearly there was ample evidence of the proclivity for salmon to diversity into separate stocks (Slaney et al 1996). On the other hand, the life history of eulachons was also typical of marine fish with pelagic larvae, like herring, sardine and anchovy. In these species, the evidence of stock structure varies, from very large stocks, such as anchovy stretching thousands of kilometers (Richardson 1981) to very small herring stocks in northern Hokkaido, occupying relatively tiny areas such as local lagoons (Kobayashi 1983). Of all the characteristics, the striking differences in spawning time might have been the most revealing, with the very late Fraser River run (April and May) and the very early run in the adjacent Columbia River run (January-February). There is no obvious physical explanation (i.e. water temperature) that would explain such a difference. Spawning time differences were less evident among most of the northern runs in BC and Alaska. Most occurred during March and April.

The earliest dedicated SID approach, examining differences in vertebral number, concluded that there were significant differences, but only on a broad geographic scale – separating the Columbia and Fraser River (Hart and McHugh 1944). After the 1940’s there was no further work done on eulachon SID, except for a 1963 study that compared eulachons from two different areas in the Columbia River. The work found no significant differences.

The analyses of larval eulachon distributions (McCarter and Hay, 1999, Hay and McCarter 2000) found evidence of geographic overlap – or mixing – during the larval stages within some estuaries, but there was no evidence of mixing between estuaries. The work
concluded that the estuary probably was the smallest potential location that could support a unique stock. In most instance, major estuaries supporting eulachons are separated by hundreds of kms, so it is not a major assumption to assume that there might be little inter-estuarine mixing at the early life stages.

The work on otolith microchemistry was not conclusive, mainly because of probable error (drift) with the instrumentation. Nevertheless the results did show evidence of geographic variation when comparisons were made over broad distances. This work, however, pointed out the risk of using potentially flawed experimental apparatus that provided slightly different results according to the date that samples were submitted for analysis. Such error would serve to erroneously support a conclusion that real differences existed when they did not. Clearly, such analyses should best proceed when the samples from different locations are mixed. After accounting for this error, however, there is evidence of difference in otolith chemical composition among areas, but it is unclear if further work could provide finer resolution of potential geographic differences.

The earliest genetic analyses, on mitochondrial DNA revealed little genetic differentiation. There was an inclination of the authors to conclude that there was little genetic variation among putative eulachon stocks. The same conclusion was reached in the first microsatellite study that examined only 5 loci with relatively small sample sizes. Both genetic studies concluded there was little evidence of isolation-by-distance except over broad areas of the North Pacific. Eulachon stock structure was considered to be more typical of marine fish, such as herring.

The observation of significant genetic variation and significant isolation-by-distance was observed in the most recent genetic study (Beacham et al. 2005), that examined 14 loci and greater sample size then the previous work. Although this recent study reports only on eight putative populations, the significant genetic differences would support a conclusion that most eulachon stocks should be considered as genetically isolated, pending further information. This important result is generally consistent with almost all of the previous SID approaches. Specifically, it is not surprising that an anadromous fish, migrating between feeding areas on the continental shelf to a relatively few number of spawning sites (13 main rivers in BC),
would develop some significant stock structure, especially when there are differences in spawning times among rivers.

More SID activity is essential for eulachons, not only for BC waters, but also in other parts of their range. Presently the abundance of eulachons in many rivers is at historical lows, including the Fraser and Columbia River. Eulachons runs have not appeared in California for years, and they are extremely low in some important rivers in BC. For instance, the Bella Coola River is the site where Alexander McKenzie first reached the Pacific coast of North America in 1793, by following eulachon ‘grease’ trails through the difficult passage through the coastal mountains. Now, over 200 years later, the eulachon runs have stopped, much to the consternation of local residents in the area. The cause of the problem is uncertain, but some partial solutions are straightforward: preserve the spawning habitat and reduce catches. Presently some eulachons are taken as bycatch in the commercial shrimp fishery in BC, and elsewhere along the Pacific coast. Probably in most areas, this level of bycatch is small, and would not have led to the widespread decline in eulachons, but continued bycatch is a concern and is controversial. Certainly it is part of the problem and not part of the solution. Some representatives of the commercial fisheries, and some fisheries managers, claim that some bycatch of eulachons in the vicinity of small runs is not a concern, because without firm evidence of genetic differences, eulachons must readily mix among rivers. Therefore, they claim, there is no risk of a loss of biologically or genetically unique populations. The most recent SID study (on microsatellite DNA) shows this claim to be incorrect. Continued bycatch, especially in the areas where eulachon runs are virtually extirpated, is most unwise for the conservation of this species.

REFERENCES


Table 1. List of stock-identification approach for eulachon: 1930’s-present.

<table>
<thead>
<tr>
<th>Stock Identification Approach</th>
<th>Time</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Life history (distribution, spawning times, etc)</td>
<td>1930’s-</td>
<td>- Several studies, summarized in Hay and McCarter, 2000</td>
</tr>
<tr>
<td></td>
<td>present</td>
<td></td>
</tr>
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</table>
Table 2. (Adapted from Hay and McCarter 2000). List and classification of known and probable eulachon spawning areas, and adjacent marine areas, estimated from larval surveys (McCarter and Hay, 1999) and other information. The numbers in the first column correspond to the rivers shown in Figure 4. The column headed by 'R/I' indicates rivers where spawning is mainly regular, 'R' (occurring most years), 'I' (irregular) or '?' (unknown). 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), or some combination. The column 'estuary' shows common estuarine waters for different rivers.

<table>
<thead>
<tr>
<th>Number</th>
<th>Eulachon Spawning Areas</th>
<th>R/I</th>
<th>Size</th>
<th>Estuary</th>
<th>Marine areas</th>
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<tbody>
<tr>
<td>1</td>
<td>Nass</td>
<td>R</td>
<td>M-L</td>
<td>Pl - 1</td>
<td>Portland Inlet</td>
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<tr>
<td>2</td>
<td>Skeena</td>
<td>R</td>
<td>L-S</td>
<td>CS - 2</td>
<td>Chatham Sound</td>
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<tr>
<td>3</td>
<td>Kitimait River</td>
<td>R</td>
<td>S-M</td>
<td>DC - 3</td>
<td>Douglas Ch - Kitimat Arm</td>
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<tr>
<td>4</td>
<td>Kildala River</td>
<td>R</td>
<td>S-S</td>
<td>DC - 3</td>
<td>Douglas Ch - Kitimat Arm</td>
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<tr>
<td>5</td>
<td>Giltoyses Inlet</td>
<td>I</td>
<td>V-V</td>
<td>DC - 3</td>
<td>Douglas Ch.</td>
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<tr>
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<td>Foch Lagoon</td>
<td>I</td>
<td>V-V</td>
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<td>M-M</td>
<td>GC - 4</td>
<td>Gardner Canal - head</td>
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<td>R</td>
<td>S-S</td>
<td>GC - 4</td>
<td>Gardner Canal - Chief Matthew's Bay</td>
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<td>Kemano/Wahoo River</td>
<td>R</td>
<td>M-M</td>
<td>GC - 4</td>
<td>Gardner Canal - Kemano Bay</td>
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<td>Khutzete River</td>
<td>?</td>
<td>V-V</td>
<td>NC -</td>
<td>Princess Royal Ch. - Khutzete Inlet</td>
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<td>Aaltanhash River</td>
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<td>V-V</td>
<td>NC -</td>
<td>Princess Royal Ch. - Aaltanhash Inlet</td>
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<td>Kainet or Lard Creek</td>
<td>?</td>
<td>V-V</td>
<td>NC -</td>
<td>Kynoch Inlet - Mathiesen Ch.</td>
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<td>Bella Coola River</td>
<td>R</td>
<td>M-M</td>
<td>DC - 5</td>
<td>Dean Ch. North Bentick Arm</td>
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<td>M-M</td>
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<td>Dean Ch.</td>
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<td>S-S</td>
<td>DC - 5</td>
<td>South Bentick Arm</td>
</tr>
<tr>
<td>17</td>
<td>Skowquitz River</td>
<td>?</td>
<td>S-S</td>
<td>DC - 5</td>
<td>Dean Ch. - west side</td>
</tr>
<tr>
<td>18</td>
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<td>?</td>
<td>V-V</td>
<td>DC - 5</td>
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</tr>
<tr>
<td>19</td>
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<td>?</td>
<td>S-S</td>
<td>DC - 5</td>
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</tr>
<tr>
<td>20</td>
<td>Chuckwalla/Kibbella</td>
<td>R</td>
<td>M-M</td>
<td>RI - 6</td>
<td>Rivers Inlet - Queen Charlotte Strait</td>
</tr>
<tr>
<td>21</td>
<td>Wannock</td>
<td>R</td>
<td>M-M</td>
<td>RI - 6</td>
<td>Rivers Inlet - Queen Charlotte Strait</td>
</tr>
<tr>
<td>22</td>
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<td>?</td>
<td>S-S</td>
<td>RI - 6</td>
<td>Rivers Inlet-Moses Inlet</td>
</tr>
<tr>
<td>23</td>
<td>Hardy Inlet(?)</td>
<td>?</td>
<td>S-S</td>
<td>RI - 6</td>
<td>Rivers Inlet</td>
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<td>24</td>
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<td>S-S</td>
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<tr>
<td>25</td>
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<td>R</td>
<td>M-M</td>
<td>KI - 7</td>
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<td>26</td>
<td>Kakweiken River</td>
<td>?</td>
<td>S-S</td>
<td>JS -</td>
<td>Thompson Sound - Johnstone Strait</td>
</tr>
<tr>
<td>27</td>
<td>Klinaklini River</td>
<td>R</td>
<td>L-M</td>
<td>KI - 8</td>
<td>Knight Inlet</td>
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<tr>
<td>28</td>
<td>Franklin River</td>
<td>?</td>
<td>S-S</td>
<td>KI - 8</td>
<td>Knight Inlet</td>
</tr>
<tr>
<td>29</td>
<td>Port Neville</td>
<td>?</td>
<td>V-V</td>
<td>JS -</td>
<td>Johnstone Strait</td>
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<tr>
<td>30</td>
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<td>?</td>
<td>V-V</td>
<td>LI -</td>
<td>Loughborough Inlet</td>
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<td>I</td>
<td>M-S</td>
<td>BI -</td>
<td>Bute Inlet - Johnstone Strait</td>
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<td>M-S</td>
<td>GS -</td>
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Fig. 1. Distribution of smelts (Osmeridae) and eulachons, 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.
Fig. 2. Distribution in eulachon spawning rivers in Alaska, British Columbia, Washington, Oregon and California, showing the southern and northern limits of the range (adapted from Hay and McCarter, 2000).
Fig. 3. Top: drawing of an eulachon egg showing the base of attachment. Lower: drawing of an eulachon larva. (From Hart and McHugh, 1944).
Fig. 4. Eulachon spawning rivers in BC (Adapted from Hay and McCarter 2000). The small circles represent every known spawning river indicated in Table 2. 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. 5. Mean eulachon vertebral number - compared among regions (from Hay and McCarter 2000). Data collected separately for the Columbia river by Lacey and Batts (1963) and Hart and McHugh (1944) for the Fraser and northern BC rivers, were assembled and compared. The vertebral counts of the Fraser and Columbia are not significantly different, but the differences between these, and the northern rivers, were significant.
Fig. 6. Larval eulachon density map (adapted from McCarter and Hay, 1999). (a) Douglas Channel Region, northern BC, (b) Dean Channel Area (Bella Coola River (Central BC) (c) Rivers Inlet south Central BC, (d) Johnstone Strait Region. Circle sizes show larval eulachon density (maximum density = 21.3 larvae/m³). In all figures, a red cross indicates a location where no eulachon larvae were captured.