Monthly Distribution and Catch Trends of Eulachon (Thaleichthys pacificus) in Chatham Sound, British Columbia, July 2018 to March 2019

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MONTHLY DISTRIBUTION AND CATCH TRENDS OF EULACHON (*Thaleichthys pacificus*) IN CHATHAM SOUND, BRITISH COLUMBIA, JULY 2018 TO MARCH 2019

by

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ABSTRACT

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Eulachon (*Thaleichthys pacificus*) is an anadromous species of smelt that spawns within rivers in British Columbia. Despite range wide population declines in recent decades there remain substantial knowledge gaps which limit the ability to develop focused conservation efforts. A monthly bottom trawl study was therefore conducted to address knowledge gaps relating to Eulachon biology, distribution, and the timing of migration into the Nass and Skeena rivers by observing Eulachon occurrence and biological condition in Chatham Sound.

Eulachon catch per unit effort, size distributions, and sexual maturity observations varied over time, as did stomach contents and presence of teeth. Highest catches of Eulachon in Chatham Sound occurred in July and November. Catches were lowest in February and March, corresponding with the expected spawning periods in the Nass and Skeena rivers. The presence of Eulachon with developing gonads in Chatham Sound increased in frequency from July to November. In February and March, Eulachon had relatively smaller bodies with less-developed gonads, likely also corresponding to the spawning period and migration of mature individuals towards estuaries and rivers. Females that appeared to have spawned and returned to the marine environment were collected frequently in July and September, possibly providing some evidence of iteroparity, which has not been previously described for Eulachon. However, further histological analysis is required to confirm this finding, as resolving the potential for repeat spawning would provide useful information for future stock assessments and is a key knowledge gap for the species.

The presence of stomach contents decreased in frequency in November and February, which could indicate seasonal prey availability or possible sampling bias in terms of time of day or location of sampling. Individuals with reduced dentition were sampled most frequently in February and March, and may have reabsorbed minerals in their teeth for gonadogenesis prior to spawning, similar to other anadromous species.

RÉSUMÉ

Dealy, L.V. and Hodes, V.R. 2021. Monthly distribution and catch trends of Eulachon (*Thaleichthys pacificus*) in Chatham Sound, British Columbia, July 2018 to March 2019. Can. Manuscr. Rep. Fish. Aquat. Sci. 3187: ix + 37 p.

L'eulakane (*Thaleichthys pacificus*) est une espèce anadrome d'éperlan qui fraye dans les rivières de la Colombie-Britannique. Malgré les déclins de population observés à l'échelle de l'aire de répartition au cours des dernières décennies, la capacité de déployer des efforts de conservation ciblés demeure limitée en raison de lacunes importantes dans les connaissances. Un relevé mensuel au chalut de fond a donc été réalisé pour combler les lacunes dans les connaissances sur la biologie, la distribution et la période de migration de l'eulakane dans les rivières Nass et Skeena, en observant la présence et la condition biologique de l'eulakane dans le passage Chatham.

Les prises d'eulakane par unité d'effort, la répartition des tailles et les observations liées à la maturité sexuelle ont varié au fil du temps, tout comme le contenu de l'estomac et la présence de dents. Les prises d'eulakane les plus importantes dans le passage Chatham ont été enregistrées en juillet et en novembre. Les prises les moins importantes ont été enregistrées en février et en mars, ce qui correspond aux périodes de frai prévues dans les rivières Nass et Skeena. La présence d'eulakanes avec des gonades en développement dans le passage Chatham a augmenté en fréquence de juillet à novembre. En février et mars, les individus présentaient des corps relativement plus petits, avec des gonades moins développées, ce qui correspond probablement à la période de frai et à la migration des eulakanes matures vers les estuaires et les rivières. Les femelles qui semblaient avoir frayé et être retournées dans le milieu marin ont été prélevées fréquemment en juillet et en septembre, fournissant possiblement une preuve d'itéroparité, ce qui n'avait pas été évoqué auparavant pour l'eulakane. Toutefois, une analyse histologique plus poussée est nécessaire pour confirmer cette observation. En effet, faire la lumière sur la capacité de reproduction répétée de l'eulakane, une lacune importante dans les connaissances sur l'espèce, fournirait des renseignements utiles pour les futures évaluations des stocks.

La présence de contenu dans l'estomac a diminué en fréquence en novembre et en février, ce qui pourrait refléter la disponibilité saisonnière des proies ou un biais d'échantillonnage possible en ce qui concerne le moment de la journée ou le lieu de l'échantillonnage. Les individus ayant une dentition réduite ont été échantillonnés le plus souvent en février et en mars, et peuvent avoir réabsorbé des minéraux dans leurs dents pour la formation des gonades avant le frai, comme d'autres espèces anadromes.

INTRODUCTION

Eulachon (*Thaleichthys pacificus*, Osmeridae) is an anadromous smelt that occurs only in the eastern north Pacific Ocean from California to the Bering Sea (Schweigert et al. 2012). Eulachon are lipid rich compared to other north-eastern Pacific forage fish (Payne et al. 1999). As such, they constitute a nutritious prey item for many fish, mammal, and avian predators (Schweigert et al. 2012).

In British Columbia (BC), Eulachon have historically been and continue to be extremely important to First Nations who harvest them for food, social, and ceremonial (FSC) purposes. Eulachon was termed the ‘salvation fish’ because it was the first fish to return to rivers after the winter and provided an invaluable source of nutrition in the spring (Moody 2008). Traditional rendering of Eulachon (or ‘ooligan’) grease is a longstanding cultural practice for certain communities on the North Coast of BC where in-river Eulachon fisheries for FSC usage continue to occur (Moody 2008; Schweigert et al. 2012).

Eulachon spawn in coastal rivers that typically have a distinct spring freshet (Hay and McCarter 2000). Spawn timing varies over the species range but is distinct within specific river drainages (Hay and McCarter 2000). Spawning begins as early as January and February in southern rivers such as the Columbia River and as late as June in northern Alaskan rivers (Beacham et al. 2005; Moody 2008). In the Nass and Skeena rivers, Eulachon spawn mainly in late February and early March (Hay and McCarter 2000; Beacham et al. 2005).

Eulachon have been reported to spawn in at least 40 rivers in BC (Levesque and Therriault 2011). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed three Eulachon designatable units: Fraser River as Endangered, Central Pacific Coast as Endangered (COSEWIC 2011), and Nass/Skeena as Special Concern (COSEWIC 2013).

While the Nass/Skeena Eulachon population is reportedly stable, at lower abundances since declines in the early 1900s, reasons for the declines in abundance for Eulachon populations across all designatable units remain unclear (COSEWIC 2013). Commercial harvesting of Eulachon is currently prohibited within BC due to conservation concerns; however, Eulachon is caught as bycatch in trawl fisheries targeting shrimp and groundfish species (Schweigert et al. 2012). Changes in climate resulting in lower marine survival, and marine predation are also considered potential threats to Eulachon in the marine environment (Schweigert et al. 2012). Reduced marine survival is also considered a key factor driving population declines of other anadromous species in the Pacific Ocean (Kendall et al. 2017; Dorner et al. 2018). Variation in oceanographic factors, compounded by climate change, include both large-scale ocean and atmospheric events as well as more regional and local processes which ultimately influence and shape the composition and quality of food webs and can have direct impacts on the abundance, growth and survival in the ocean (Beamish and Bouillon 1993).

Effective conservation efforts for the Nass/Skeena rivers population of Eulachon require a greater understanding of their biology and ecology, including life history parameters, population dynamics and the impact of threats and limiting factors to the population. This research addresses key knowledge gaps and provides insights into Eulachon distribution, ecology and timing of migration to the Nass and/or Skeena rivers by observing occurrence and biological condition in Chatham Sound, which was recently identified as a potentially important foraging and rearing area for Eulachon (MacConnachie et al. 2016).

METHODS

SURVEY DESIGN

The study area (Figure 1) was chosen based on its proximity to the Nass and Skeena rivers. Within the study area, Eulachon are caught as bycatch in the commercial shrimp trawl fishery and in Fisheries and Oceans Canada (DFO) shrimp trawl surveys (Levesque and Therriault 2011; MacConnachie et al. 2016).

The study area was overlain with a survey grid using Microsoft SQL Server to create 2x2 km blocks for fishing. The grid contained only blocks of the target depth range, 80–300 m, based on similar depths at which Eulachon have been caught on previous bottom trawl research surveys (Boutillier et al. 1999a; 1999b). In total 164 blocks were identified within the target depths (represented by blue squares in Figure 1). Sponge reefs and rockfish conservation areas were excluded from the survey grid.

Six bottom trawl surveys were conducted from July 2018 to March 2019. Surveys ranged from 3 to 6 fishing days in length. For each survey, prior to departure using Microsoft SQL Server, 80 blocks were randomly generated out of 164 blocks in the survey grid for selection of potential fishing locations. Each morning during a survey, from the 80 available blocks, a cluster of about 8–10 blocks was selected to be fished that day; these were chosen by the Lead Scientist and Fishing Master based on proximity of blocks (for fuel and time efficiency), where the vessel was tied up or anchored the previous night, and daily weather forecasts. Only one fishing set was conducted per block each day. A given block was never fished more than once during a survey; however, the same block could be fished repeatedly over the course of the study if it were randomly generated for multiple surveys.

An additional two sets were conducted outside of the study area, in Hecate Strait (southeast of Chatham Sound), during October when weather and time allowed for exploratory fishing. Data from these sets were excluded from the Results section of this manuscript but are included in APPENDIX 1. with all survey trawl data by set (Table 9) and sample data is summarized in Table 10.

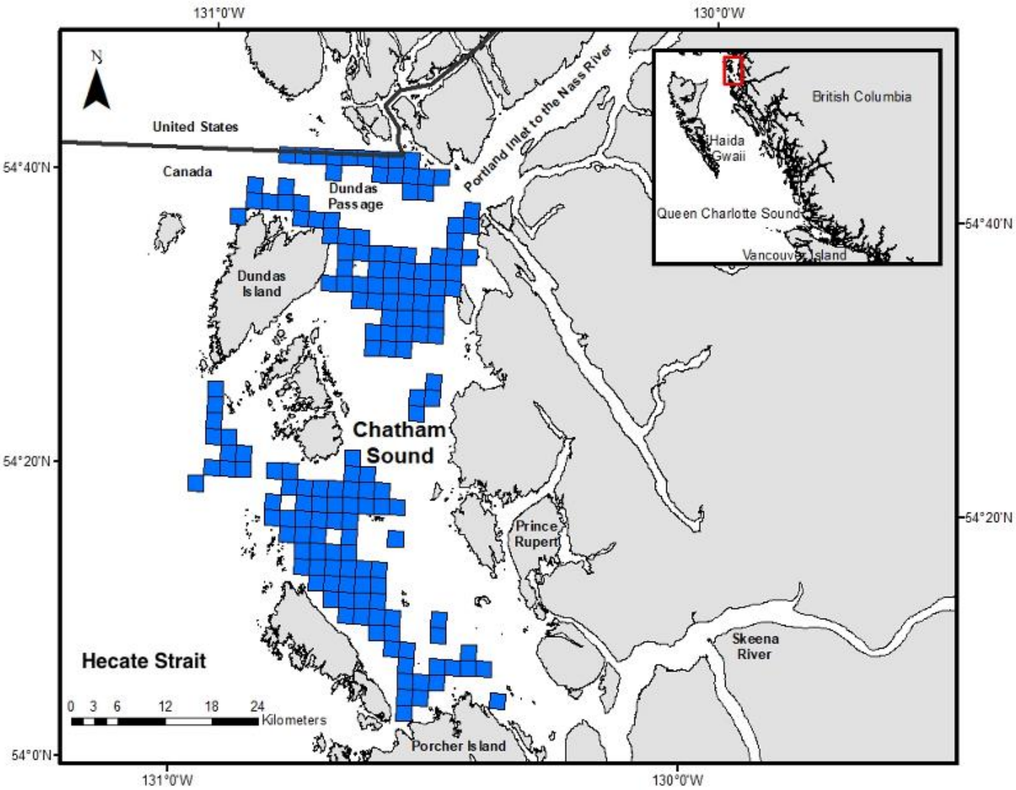

Figure 1. Chatham Sound, British Columbia – Eulachon bottom trawl study area, July 2018 to March 2019. Potential fishing blocks (2x2 km) are identified by a blue grid.

FISHING AND ENVIRONMENTAL DATA

Fishing was conducted using the Nearshore Fishery Research Vessel CCGS *Neocaligus* to tow an American shrimp trawl net (Cantrawl Nets Ltd., Richmond, BC). The horizontal opening of the polypropylene net was estimated to be 34 to 37 ft (10 to 11 m), while the center of the opening had a vertical height of approximately 7 to 9 ft (2 to 3 m). A 0.4" (10 mm) liner was used in the codend. The net was configured with roller gear and 72" (1.8 m) Thyboron Type 2 trawl doors. The vessel was equipped with a Notus® trawl net mensuration system. These sensors were attached to the net to provide the Fishing Master with real-time net geometry including headline height and depth as well as door spread. To determine appropriate substrate and potential hazards, survey blocks were sounded by the Fishing Master prior to setting the net. When available, commercial shrimp trawl locations in the study area were helpful in determining soft bottom type and allowed for more efficient selection of set location within the block. When a block was rejected due to rocky substrate or hazardous objects, it was not fished and was removed from the sampling design on subsequent surveys. When a block was removed, the vessel would proceed to the next closest selected block in the survey.

Once deployed, the net was considered to be actively fishing (and the start time of the set was recorded) when the trawl doors reached the seafloor; this was determined by the Fishing Master using the net mensuration system and his expert opinion. Set duration approximated five minutes. Sets were initially intended to be 20 minutes, but set time was reduced after the first set to lessen Eulachon mortality. Set duration was shortened when necessary (e.g., the net hung up or the substrate changed) but was never less than two and a half minutes. Standard hours of fishing operations were 0800 H to 1700 H, but these times varied throughout the year depending on sunrise and sunset. Sets were made only during daylight hours.

Fishing event data was collected and stored in GFBioField, the Pacific Region's at-sea data acquisition system for DFO Groundfish Surveys (Olsen 2010). The net deployment and retrieval times and positions, as well as bottom depth, vessel speed and warp length were recorded for every set. Bottom sounder and GPS data were logged continuously for the duration of each survey. During sets, depth and water temperature were recorded every 10 seconds by a Star-Oddi® DST centi-TD temperature-depth logger mounted on the headline.

CATCH RECORDING AND EULACHON CPUE

For each set, catch was sorted into baskets to the lowest possible taxonomic classification and weighed to the nearest 0.01 kg on a 30 kg Marel® M1100 motion-compensated scale. Catch weights were entered into GFBioField using a Panasonic® Toughbook CF-31 computer. In the event of a large catch where a total sort and weigh was not possible, several baskets of mixed catch were randomly selected to be sorted by species and weighed; these species' weight proportions were later extrapolated to the unsorted catch weight. For most sets, the entire catch of Eulachon was sorted from the total catch even when the rest of the species were not completely sorted. Nonetheless, when it was not feasible to separate every Eulachon from the total catch, a sub-sample was sorted and extrapolated to the total catch.

To obtain a relative measure of Eulachon abundance, catch per unit effort (CPUE) was calculated using the weight of Eulachon caught per hour of bottom tow time. Unsuccessful sets, such as when the net hung up on the seafloor or caught a large log, were not included in calculations of CPUE.

BIOLOGICAL SAMPLING

After the total weight of Eulachon in a set was recorded, individual Eulachon were sampled. When the catch exceeded ~50 individuals, a random sample of approximately 50 Eulachon was taken. When less than ~50 Eulachon were caught, all were sampled.

For each of the following attributes, a maximum sample size was set due to time constraints. Attributes were recorded in GFBioField:

- standard length (mm) (maximum n=50)
- weight (g) (maximum n=50)
- sex (maximum n=30)

- maturity (maximum n=30)
- stomach contents – species, volume, and digestion state (maximum n=30)
- presence of teeth in three areas of the mouth (maximum n=30)
- tissue sample for DNA analysis (maximum n=10)
- presence of parasites

Length was measured to the nearest millimeter (mm) using an Ichthystick electronic measuring board connected to a Panasonic Toughbook CF-31 computer. Weight was measured to the nearest gram on a 3 kg Marel® M1100 motion-compensated scale (0.5–1 g accuracy).

The sex and maturity of specimens was assessed by macroscopic inspection of the gonads: using scissors, an incision was made on the ventral side of each specimen from the anus to the pectoral fins to reveal the gonads. To assign sex and stage of maturity consistently, a guide with photographs and descriptions was used for reference (Appendix 2). Gonads were staged as follows: (0) immature; (1) undeveloped; (2) starting; (3) developing; (4) maturing; (5) mature; (6) spent; (7) recovering. When gonads were not visible, the sex of the specimen was deemed 'undetermined' and a maturity stage was not assigned.

During each survey gonads from various maturity stages were opportunistically selected for future histological analyses (as described in Dealy and Hodes 2019), particularly to discern whether iteroparity is associated with stage 6 and 7 ovaries.

Stomach contents were determined by opening the posterior end of the stomach and pushing the contents out with the flat edge of the knife from the esophagus. A visual estimate of prey species, volume of content in cm^3, and digestion state on a scale of 1–5 with 5 being fully digested and 1 fresh was conducted. Teeth presence was determined by running a bare finger along the inside of the Eulachon's mouth. Presence or absence was noted at each of three locations: top, bottom, and along the tongue. Parasites were recorded when found attached to the gills or within the body cavity.

Eulachon samples and specimens were taken for other research not reported here including (i) operculum clips for DNA analysis, (ii) whole frozen fish for ageing, and (iii) organ samples (e.g., heart, gill, eye, tongue, liver, gonad) from each sex across a range of maturity stages for ongoing genome annotation efforts at the Pacific Biological Station.

RESULTS

EULACHON CATCH AND CPUE

Between July 2018 and March 2019, six surveys yielded 162 successful fishing sets. Eulachon were caught in 146 of the 162 sets. In total, 1,218 kg of Eulachon was caught in the study area, comprising 6% of the cumulative catch by weight. Eulachon was the sixth largest catch by weight after Spotted Ratfish, Walleye Pollock, Sidestripe Shrimp, Flathead Sole, and Arrowtooth Flounder (Appendix 3).

Total monthly catch of Eulachon was highest in July and November (>400 kg) and lowest in February and March (<70 kg) (Table 1). There was variability in Eulachon CPUE between months but mean catch rates were highest in July and November and lowest in February and March (Table 1). A monthly comparison of Eulachon CPUE at set locations in Chatham Sound was created in QGIS 3.6.0 (Figure 2).

Due to vessel availability constraints it was not possible to complete surveys in the months of August and December. A January survey was planned but cancelled due to poor weather.

Table 1. Summary of Eulachon bottom trawl survey set data from Chatham Sound, British Columbia, 2018–2019. CPUE= catch per unit effort; SE= standard error.

Survey month	Dates fished	Total sets	Sets with Eulachon	Total Eulachon Catch (kg)	CPUE (kg/hr)	
					Mean	SE
July	July 28–August 2, 2018	31	30	413.0	81.1	24.0
September	September 12–16, 2018	33	31	127.0	41.9	11.1
October	October 8–11, 2018	23	22	118.5	59.6	20.4
November	November 14–17, 2018	28	24	428.8	146.4	39.5
February	February 20–23, 2019	18	17	63.9	20.4	8.2
March	March 20–23, 2019	29	22	66.9	22.4	8.7

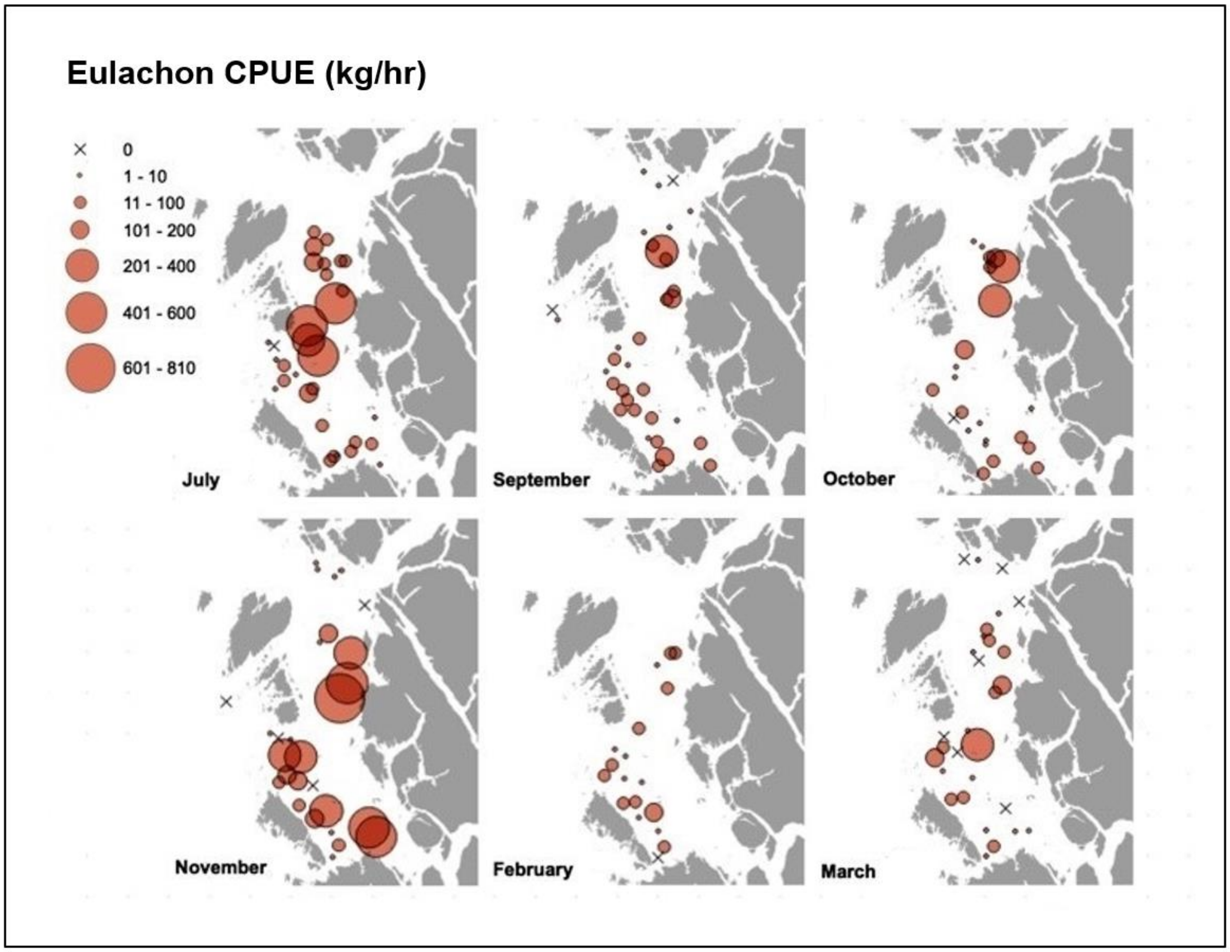

Figure 2. Proportional symbols representing Eulachon catch per unit effort (CPUE) at set locations for each of six surveys in Chatham Sound, British Columbia, between July 2018 and March 2019.

BIOLOGICAL SAMPLING

During the study period, 6,863 Eulachon were sampled from sets in Chatham Sound (Table 2). All 6,863 were measured for total length, 5,475 were weighed, and sex and maturity were determined for 4,915. Stomach contents of approximately one fifth of the sampled fish (1,421 of 6,863) were recorded and 3,560 were examined for the presence of teeth. DNA was collected from 1,397 individuals.

Table 2. Number of Eulachon sampled for biological attributes per month during bottom trawl surveys in Chatham Sound, British Columbia (July 2018–March 2019).

Month	Length	Weight	Sex	Maturity	Stomach	Teeth	DNA
July	1,603	1,480	746	746	335	778	291
September	1,439	1,398	1,172	1,172	324	793	312
October	1,088	841	803	803	203	535	231
November	1,036	743	829	829	212	529	213
February	787	456	626	626	151	425	152
March	910	557	739	739	196	500	198
Total	6,863	5,475	4,915	4,915	1,421	3,560	1,397

LENGTH AND WEIGHT

Standard length was recorded for 6,863 Eulachon, 5,475 of which were weighed (Table 2; Figure 3). The standard length ranged from 44 to 208 mm; weights ranged from 1 to 86 g.

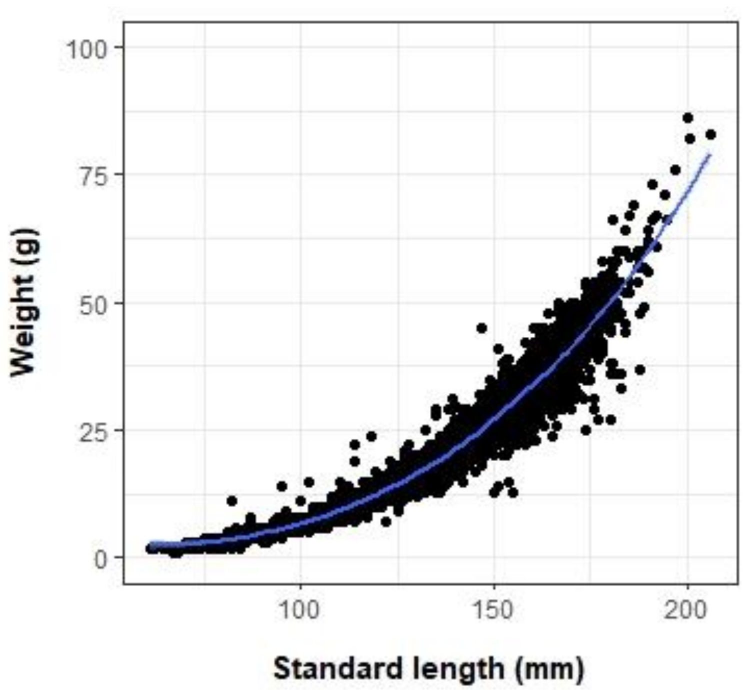

Figure 3. Cumulative length-weight relationship of Eulachon (n=5,475) sampled from July 2018 to March 2019 during trawl surveys in Chatham Sound, British Columbia. Locally Weighted Scatterplot Smoothing (LOWESS) is represented by a blue line.

The mean length of Eulachon generally increased from July to November (139–150 mm; SE 0.53–0.87), while those caught in February and March were smaller on average (130 and 125 mm respectively; SE= 0.77 and 0.76) (Figure 4; Table 3). Between the six survey months, mean lengths differed significantly at the $p<0.05$ level (one-way ANOVA, $F(5, 6857)$, $p = 0.000$) and post hoc comparisons indicated that mean lengths in February and March were significantly different from all other months. Results suggest that overall, Eulachon in Chatham Sound were smaller in February and March compared to other months in the study.

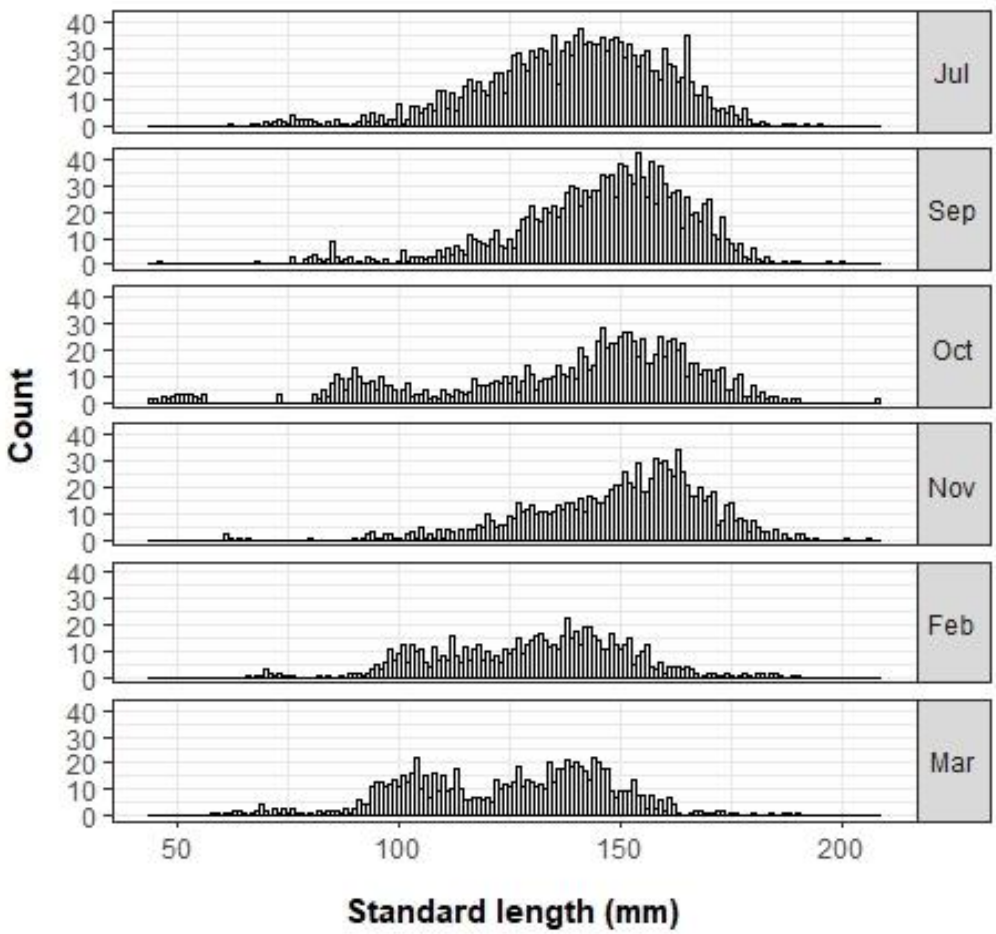

Figure 4. Monthly length distribution of Eulachon sampled from July 2018 to March 2019 during Eulachon bottom trawl surveys in Chatham Sound, British Columbia (n=6,863).

Table 3. Summary of length measurements of Eulachon sampled from July 2018 to March 2019 during Eulachon bottom trawl surveys in Chatham Sound, British Columbia. Min= minimum, Max= maximum, Q1= 25th percentile, Q3= 75th percentile, SE= standard error.

		Standard length (mm)						
Month	**Count**	**Min**	**Q1**	**Median**	**Mean**	**Q3**	**Max**	**SE**
July	1,603	62	127	141	139	154	195	0.53
September	1,440	46	135	148	146	159	200	0.53
October	1,088	44	125	147	139	159	208	0.87
November	1,036	61	138	153	150	163	206	0.61
February	787	66	115	133	130	145	190	0.77
March	910	58	106	127	125	142	190	0.76

Juvenile Eulachon (<70 mm) were sampled on all six surveys. ‘Air bubbles’ above the gut were observed in individuals ~60 mm in length, visible in Figure 5. Eulachon are reported to have no swim bladder (COSEWIC 2011) so this created uncertainty in species identification. Several individuals were frozen and brought back to the Pacific Biological Station where the authors confirmed the species identification through meristic counts and feedback from larval fish experts.

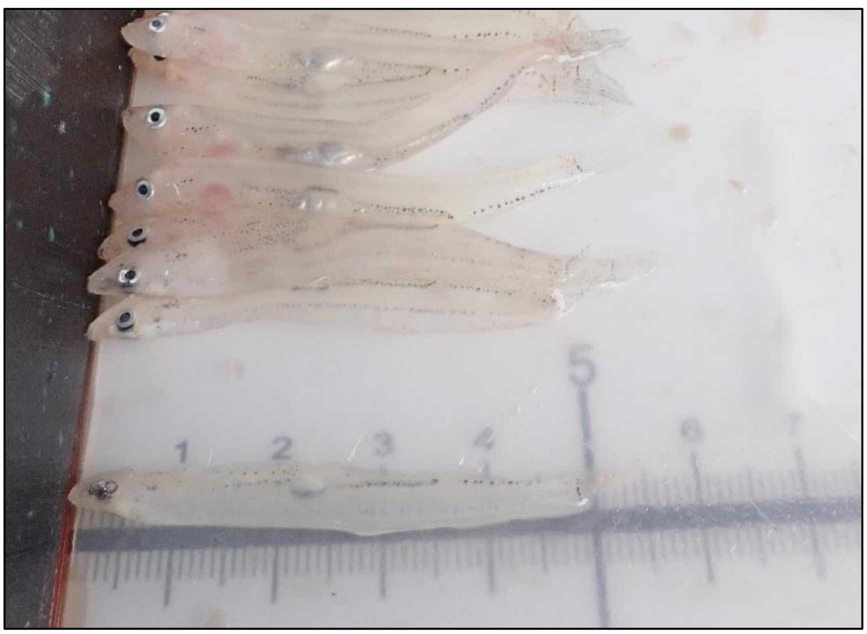

Figure 5. Juvenile Eulachon sampled in October 2018 in Chatham Sound, British Columbia during a monthly Eulachon bottom trawl survey.

SEX AND MATURITY

In total, 2,050 males and 2,400 females were examined (Table 4). Sex could not be determined macroscopically for an additional 465 individuals as the gonads were too small. Proportion of males and females by month is provided in Figure 6. The male-to-female sex ratio was approximately 1:1 in July, September, October, and November, and approximately 1:2 in February and March, with a greater proportion of fish (~25%) of undetermined sex in the latter two months. The uneven sex ratios observed in February and March could be a result of uncertainties associated with sexing immature male Eulachon.

Table 4. Sex determination of Eulachon sampled from July 2018 to March 2019 in Chatham Sound, British Columbia. Total males sampled: n=2,050; total females sampled: n=2,400; undetermined: n=465.

Month	% Male (n)	% Female (n)	% Undetermined (n)
July	51 (381)	47 (349)	2 (16)
September	51 (596)	45 (532)	4 (44)
October	46 (366)	54 (387)	6 (50)
November	45 (375)	54 (445)	1 (9)
February	21 (133)	50 (316)	28 (177)
March	27 (199)	50 (371)	23 (169)

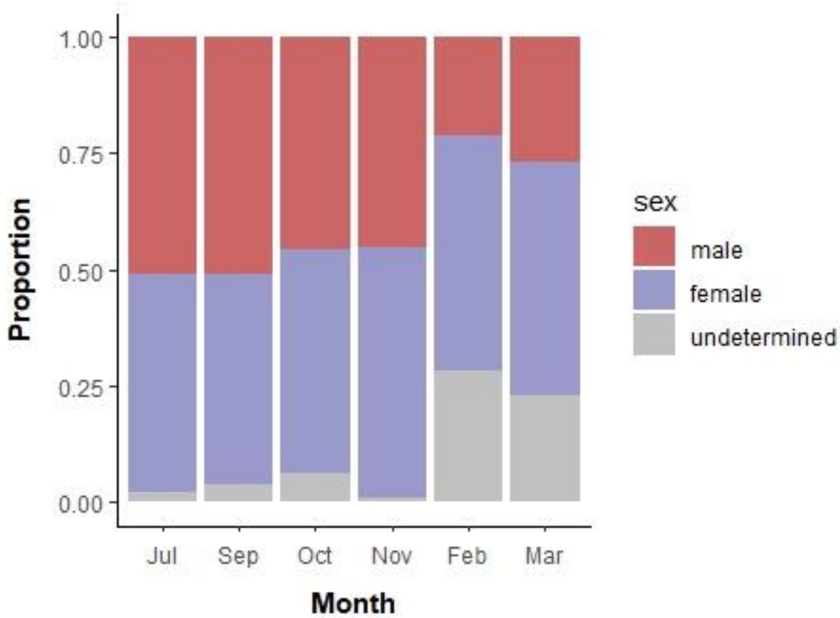

Figure 6. Proportion of male, female, and undetermined Eulachon sampled from July 2018 to March 2019 during Eulachon bottom trawl surveys in Chatham Sound, British Columbia (n=4,915).

The degree of sexual maturity of 4,915 Eulachon was assessed and observations by month are provided in Table 5 and Figure 7 (males, females, and undetermined sex combined). A summary of results by maturity stage is described below.

Immature and undeveloped (stage 0 and 1) fish were caught in every survey month. The proportions of stage 0 and 1 fish were highest in February and March, accounting for nearly half of the sampled fish during these two months. Starting and developing (stage 2 and 3) Eulachon dominated observations over all months combined, accounting for 64% of all fish sampled in this study. Stage 2 fish were more common in July and September but a transition to stage 3 was observed in October and November. Maturing (stage 4) fish first appeared in October and numbers peaked in February. Mature (stage 5) fish were only sampled in February and at very low frequency (1%). Spent fish (stage 6, all female) were most common in March samples but were also seen in February, July, and September. No spent, stage 6 fish (i.e., specimens appearing to have recently spawned, with residual eggs and flaccid ovaries) were caught in October or November. Recovering, stage 7 fish (i.e., specimens appearing to be in the process of recovering some time after a spawning event) were caught in July, September and October, and were absent in samples taken in November, February and March.

Histological sections are currently being examined for postovulatory follicles (POFs) and atretic oocytes to help resolved uncertainty regarding spent (stage 6) and recovering (stage 7) female Eulachon specimens. The POF consists of follicular layers which remain in the ovary after the release of the ovum during spawning (Saidapur 1982). Preliminary scans of histological sections from maturity stage 6 and 7 ovaries have detected POFs.

Table 5. Stages of maturity of Eulachon (male, female, and undetermined sex combined) sampled on bottom trawl surveys in Chatham Sound, British Columbia, between July 2018 and March 2019 (n=4,915).

	% Maturity stage (n)							
Month	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
July	2 (16)	7 (54)	75 (559)	0 (2)	0 (0)	0 (0)	2 (17)	13 (98)
September	4 (44)	9 (110)	45 (530)	12 (135)	0 (0)	0 (0)	0 (2)	30 (351)
October	6 (50)	16 (126)	29 (236)	48 (389)	0 (1)	0 (0)	0 (0)	0 (1)
November	1 (9)	17 (138)	9 (76)	72 (597)	1 (9)	0 (0)	0 (0)	0 (0)
February	28 (177)	12 (74)	40 (251)	5 (32)	12 (75)	1 (7)	2 (10)	0 (0)
March	23 (169)	23 (173)	46 (343)	2 (15)	1 (9)	0 (0)	4 (30)	0 (0)

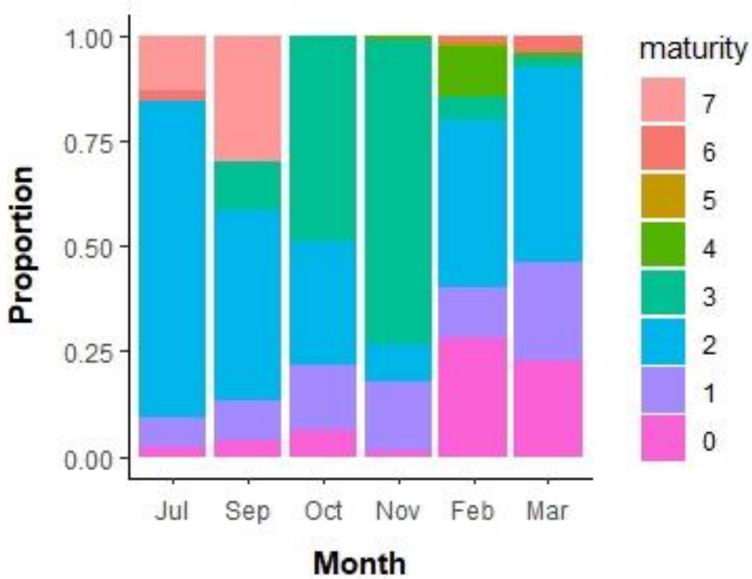

Figure 7. Proportion of maturity stages assigned to Eulachon sampled from July 2018 to March 2019 in Chatham Sound, British Columbia (n=4,915; males, females, and undetermined sex combined). Maturity stages: 0=immature, 1=undeveloped, 2=starting, 3=developing, 4=maturing, 5=mature, 6=spent, 7=recovering.

Mean body length increased with stage of maturation, and ranges in length between stages of maturation 2–7 overlapped greatly (Table 6; Figure 8). This finding is similar to Eulachon sampled in Juan de Fuca and the Strait of Georgia as reported in Dealy and Hodes 2019 where beyond stage 2, differences in mean lengths between stages were statistically undetectable as length ranges overlapped one another.

Table 6. Length measurements of Eulachon for each maturity stage assigned from July 2018 to March 2019 in Chatham Sound, British Columbia (n=4,915; males, females, and undetermined sex combined). Min= minimum, Max= maximum, Q1= 25th percentile, Q3= 75th percentile, SE= standard error. Maturity stages: 0=immature, 1=undeveloped, 2=starting, 3=developing, 4=maturing, 5=mature, 6=spent, 7=recovering.

	Standard length (mm) by maturity stage							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Min	59	69	82	102	134	134	119	114
Q1	93	114	130	151	151	154	150	141
Median	104	127	143	159	161	164	158	149
Mean	105	125	142	159	162	161	158	150
Q3	118	137	155	167	172	168	167	158
Max	153	175	195	208	201	185	188	183
SE	0.91	0.68	0.40	0.35	1.43	6.05	1.87	0.56
n	465	675	1,995	1,170	94	7	59	450

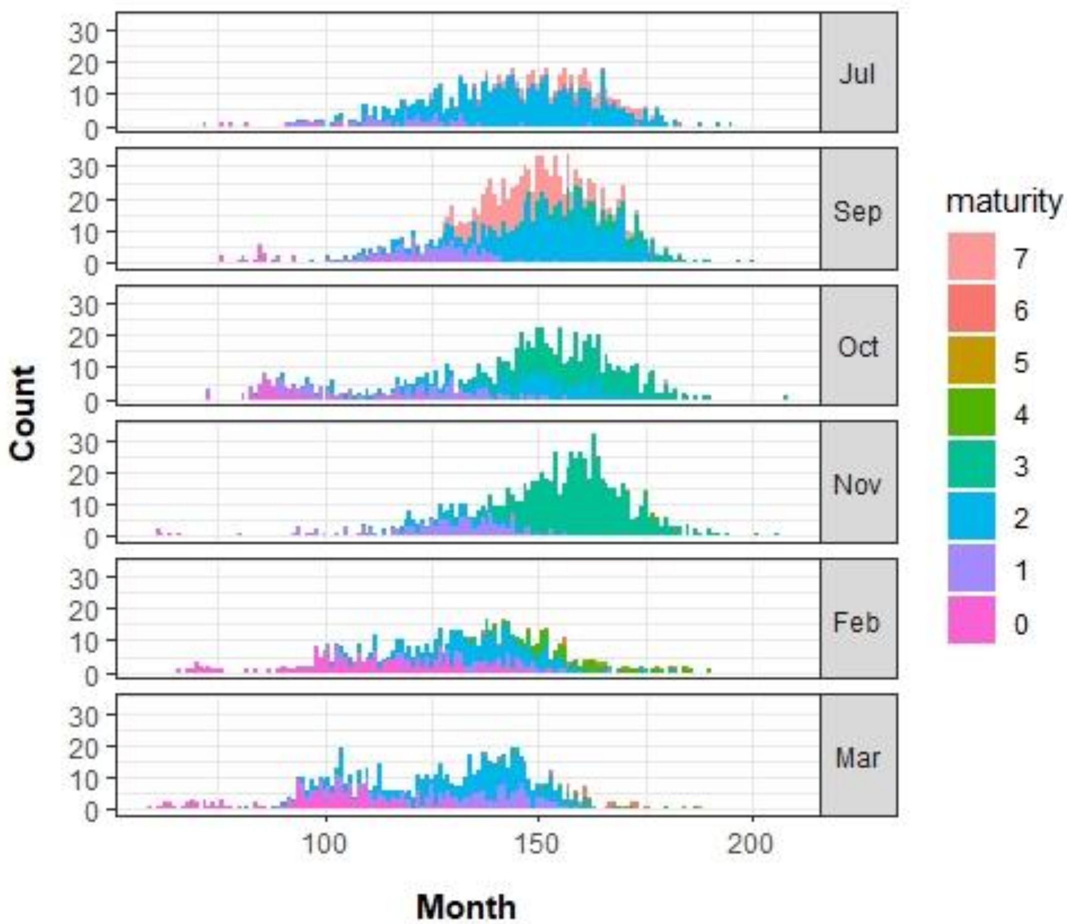

Figure 8. Monthly length distribution showing maturity stage of Eulachon sampled from July 2018 to March 2019 in Chatham Sound, British Columbia (n=4,915; males, females, and undetermined sex combined). Maturity stages: 0=immature, 1=undeveloped, 2=starting, 3=developing, 4=maturing, 5=mature, 6=spent, 7=recovering.

STOMACH CONTENTS

Approximately half (54%) of all Eulachon stomachs examined were empty (Table 7). Eulachon stomachs that were sampled never contained more than one identifiable taxonomic group. The presence of stomach contents varied by month with the greatest percentage of empty stomachs occuring in November and February (76 and 80% respectively) (Figure 9). The most common item was Euphausiid (Order Euphausiacea, Figure 10), occurring in about half (42–65%) of stomachs sampled in all months except November (22%) and February (14%). Other stomach contents (i.e., unidentified remains, unidentified fishes, shrimp, and Eulachon) comprised less than 3% of total contents.

Table 7. Frequency of occurrence of prey items in Eulachon stomachs from July 2018 to March 2019 in Chatham Sound, British Columbia (n=1,421). Each stomach contained only one type of content.

	Month							
Stomach contents	**Jul**	**Sep**	**Oct**	**Nov**	**Feb**	**Mar**	**Total**	**Relative freq. (%)**
Empty	164	155	69	161	121	104	774	54
Euphausiids (Order Euphausiacea)	157	164	132	46	21	87	607	43
Unidentified remains	13	5	2	2	9	4	35	2
Unidentified fishes	0	0	0	1	0	0	1	0
Shrimp (Suborder Natantia)	1	0	0	1	0	1	3	0
Eulachon	0	0	0	1	0	0	1	0

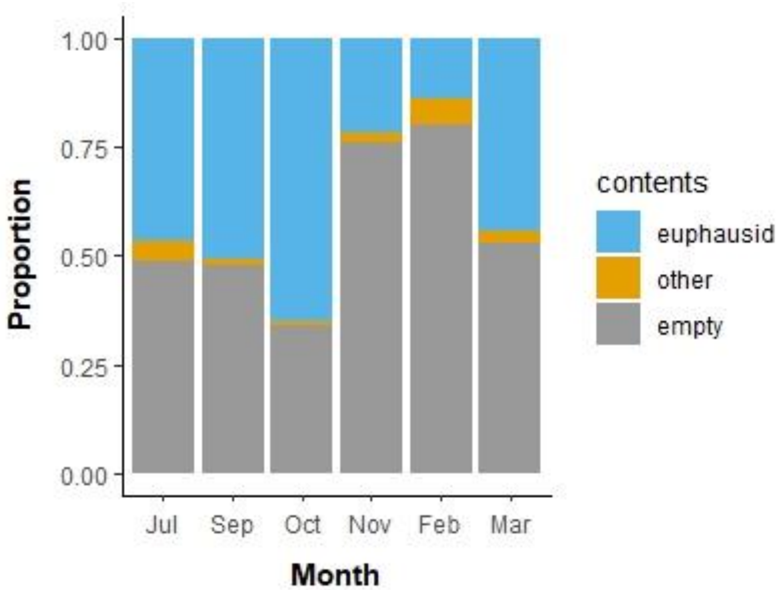

Figure 9. Summary of proportions of stomach content categories observed in Eulachon stomachs sampled from July 2018 to March 2019 in Chatham Sound, British Columbia (n=1,421). Category "other" includes unidentified remains, unidentified fishes, shrimp, and Eulachon.

Figure 10. Stomach contents (Euphausiids) from the stomach of an Eulachon specimen sampled on a 2018–19 Eulachon bottom trawl survey in Chatham Sound, British Columbia.

A juvenile Eulachon was found in the stomach of a 165 mm long female Eulachon specimen sampled in November (Figure 11). Its partially digested state indicated that it had been consumed prior to capture as opposed to being forced into the larger Eulachon's mouth during net retrieval.

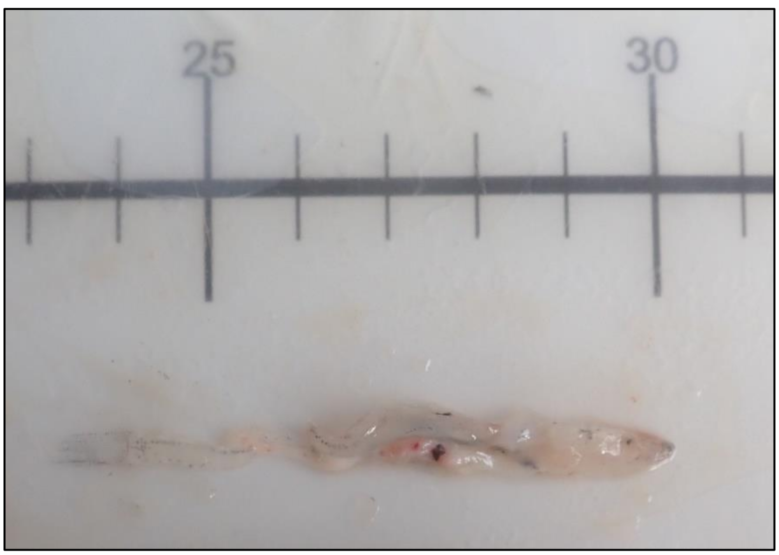

Figure 11. A partially digested Eulachon (~60 mm long) found inside the stomach of a 165 mm long female Eulachon specimen sampled in November 2018 on an Eulachon bottom trawl survey in Chatham Sound, British Columbia.

TEETH

The presence of teeth was recorded on every survey from July 2018 to March 2019 (Table 8). Overall, relatively few fish had reduced or no teeth (<3% of specimens) and these occurred most frequently in February and March. Eulachon with no teeth were only caught in February (n=10). Nine of the fish with no teeth were male and one sex was undetermined; all ten ranged from 148–190 mm in length. The sexual maturation of the nine fish ranged between stage 3 and 5. The proportions of teeth categories observed each month are provided in Figure 12.

Table 8. Counts of Eulachon sampled for presence of teeth from July 2018 to March 2019 in Chatham Sound, British Columbia (n=3,560). Categories: All teeth=teeth present on the top, tongue, and bottom of the mouth; Reduced teeth: TM=teeth on top and tongue only; TB=teeth on top and bottom only; MB= teeth on tongue and bottom only; M=teeth on tongue only; and T=teeth on top only; No teeth=teeth entirely absent from mouth.

Month	All teeth	Reduced teeth					No teeth
		TM	TB	MB	M	T	
July	774	0	0	2	2	0	0
September	786	1	0	6	0	0	0
October	535	1	0	6	0	0	0
November	523	0	0	6	0	0	0
February	379	5	0	8	23	0	10
March	473	8	0	6	13	0	0
Total	3,463	15	0	34	38	0	10

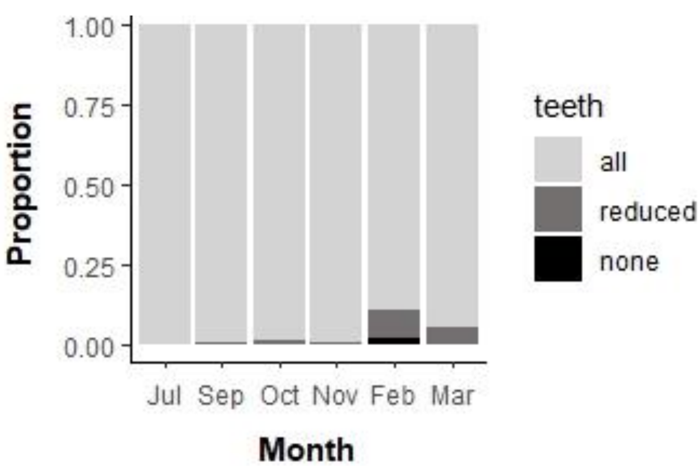

Figure 12. Summary of proportions of teeth categories (all, reduced, none) observed from July 2018 to March 2019 in Chatham Sound, British Columbia (n=3,560). Categories: all=teeth present on top, tongue, and bottom of mouth; reduced=teeth found on top only, on top and tongue only, on tongue and bottom only, on top and bottom only, or on tongue only; none=no teeth in mouth.

DNA

Operculum tissue samples were collected from 1,397 Eulachon in Chatham Sound from July 2018 to March 2019. Results of the genetic analyses will be reported in a future publication.

PARASITES

Gill parasites were observed on Eulachon specimens caught in February (7 fish in 3 sets) and March (17 fish in 9 sets). The set locations of the infected fish were located throughout Chatham Sound (Figure 13). Gill parasites were identified as *Haemobaphes disphaerocephalus*, a copepod known to exist in gill cavities of Eulachon (Grabda 1976; Kabata 1988) (Figure 14). Infected fish ranged from 104 to 162 mm in length and were mostly female (19 females; 3 males; 2 undetermined) with sexual maturities ranging from 0 to 3.

Internal parasites (nematodes, *Anisakis* spp.) were at times observed within the body cavity of Eulachon specimens. These small, translucent worms were less visible compared to *H. disphaerocephalus*.

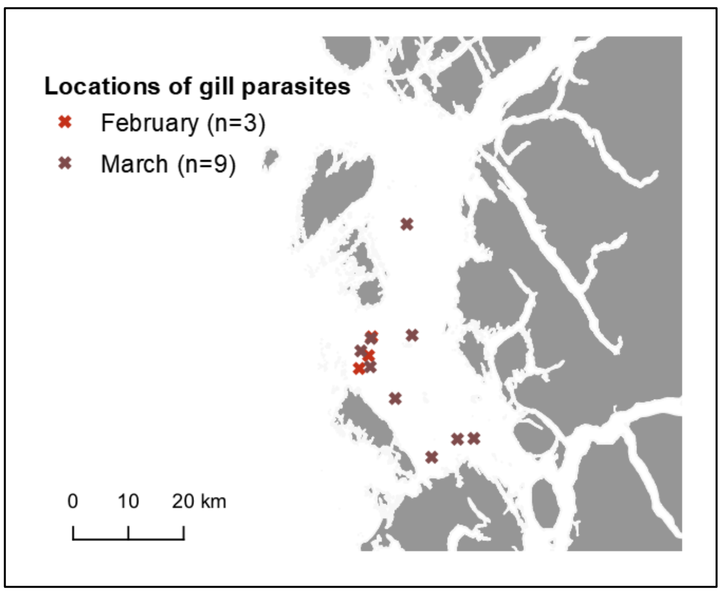

Figure 13. Set locations (n=12) of gill parasites (*Haemobaphes disphaerocephalus*) observed on Eulachon specimens sampled between July 2018 and March 2019 during Eulachon bottom trawl surveys in Chatham Sound, British Columbia.

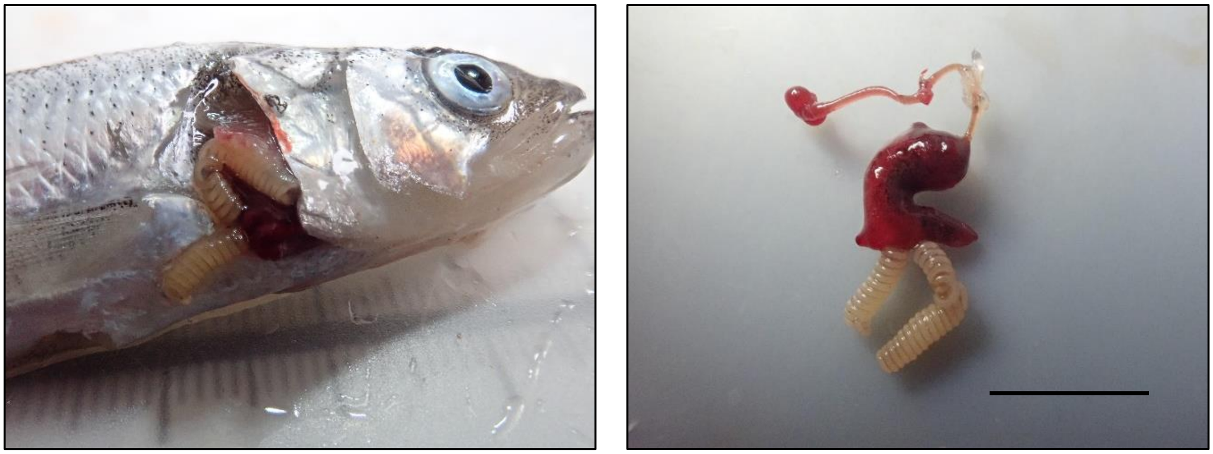

Figure 14. Left: parasite in the gill cavity of an Eulachon sampled on a 2018–19 Eulachon bottom trawl survey in Chatham Sound, British Columbia. Right: parasite (*Haemobaphes disphaerocephalus*) including two egg sacs in the form of tightly coiled spirals hanging from the genital segment (Grabda 1976). Scale bar represents 10 mm.

ENVIRONMENTAL OBSERVATIONS

For each set, time of day (i.e. time of net retrieval), mean depth of set, and mean temperature at depth is provided in APPENDIX 1. All fishing events occurred between 0745 to 1745 H and sets containing Eulachon occurred throughout this time period. Highest CPUE (>100 kg/hr) occurred between the hours of 0830 and 1630 H.

Fishing sets were made at depths from 55 to 261 m and Eulachon were caught throughout this depth range. Highest CPUE (>100 kg/hr) occurred at bottom depths between 87 and 186 m. Water temperatures at fishing depths varied from 6.3 to 10.0 ^{o}C in sets where Eulachon were present. There appeared to be a seasonal trend in water temperature (Figure 15); preliminary analysis showed that temperatures in the southern portion of Chatham Sound were warmest in the fall (September through November) (Figure 16).

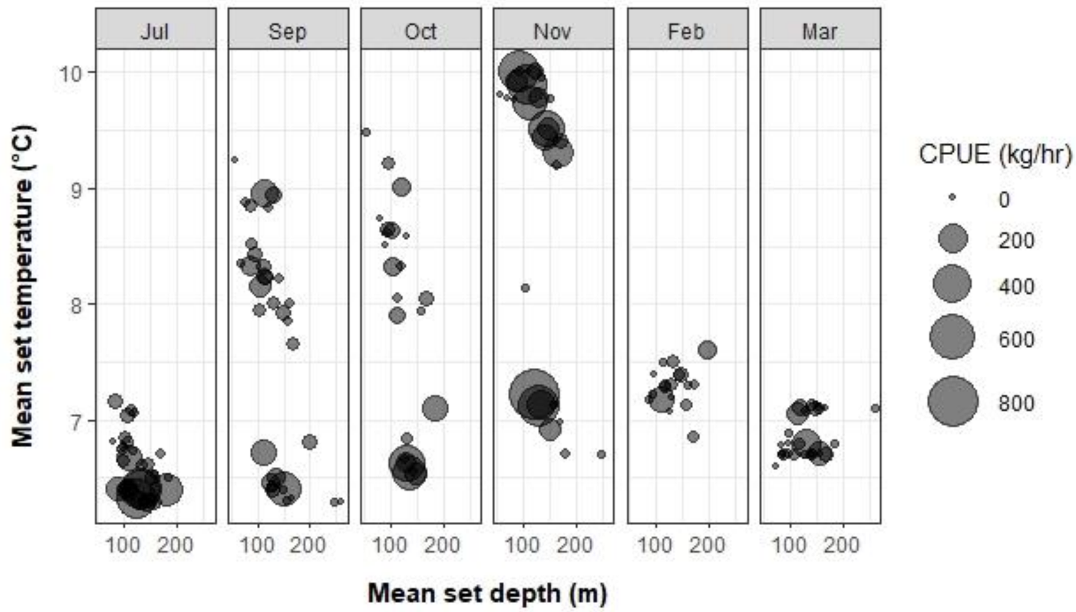

Figure 15. Eulachon CPUE (kg/hr) of each fishing set in relation to mean set temperature and depth from July 2018 to March 2019 in Chatham Sound, British Columbia.

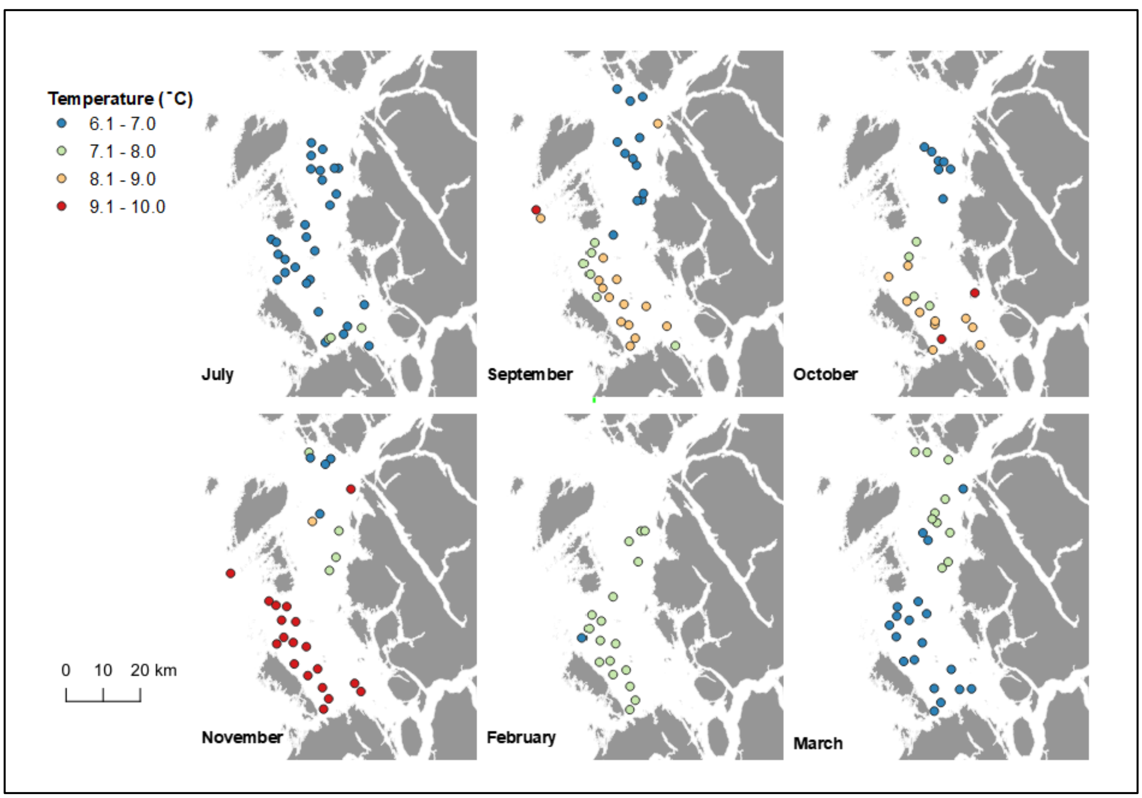

Figure 16. Bottom water temperature for each set (n=162) in Chatham Sound, British Columbia, between July 2018 and March 2019.

DISCUSSION

This study successfully characterized aspects of Eulachon ecology in the marine environment of Chatham Sound by applying methods previously developed for Eulachon in southern BC (Dealy and Hodes 2019). Though not all results from this study have been tested for statistical significance, we have observed general trends which are interpreted below. Here, we discuss key findings and suggestions for future investigations into Eulachon biology and migration to the Nass and Skeena rivers.

Key findings

The highest Eulachon catch rates (>100 kg/hr) occurred at bottom depths between 87 and 186 m, though Eulachon were caught throughout the bottom depth range of all fishing sets (55 to 261 m). There was variability in Eulachon catch rates in Chatham Sound among survey months. Catch per unit effort (CPUE) was highest in July and November with sets averaging 81 and 146 kg/hr respectively, and lowest in February (20 kg/hr) and March (22 kg/hr) corresponding with the reported spawning period in the Nass and Skeena rivers where Eulachon spawn mainly in late February and early March (Hay and McCarter 2000; Beacham et al. 2005). Eulachon sampled in February and March were on average shorter in length (130 and 125 mm respectively) and had less-developed gonads (mostly stages 0–2) compared with those caught in other survey months (averaging 139–150 mm in length, mostly stages 2–3) suggesting that the majority of larger, maturing Eulachon had left Chatham Sound and migrated toward estuaries or spawning rivers before the February survey.

The proportions of sexual maturity stages varied over surveys months. Fish with stage 2 ‘starting’ gonads were relatively more common in July and September, accounting for 45% and 75% of specimens respectively, compared to October (29%) and November (9%) when stage 3 ‘developing’ gonads represented 48% and 72% of specimens. Stage 4 ‘maturing’ gonads first appeared in October and peaked in February at 12%. Stage 5 ‘mature’ Eulachon were present only in February, comprising 1% of specimens sampled. Stage 6 ‘spent’ females were sampled in low proportions (2–4%) on surveys in February, March, July, and September. Proportions of stage 7 ‘recovering’ females were highest in July (13%) and September (30%). No male Eulachon specimens showed indications of having previously spawned.

Eulachon with maturity stage 7 gonads were not sampled on Eulachon surveys in southern BC (Dealy and Hodes 2019). This inconsistency is likely related to the timing of the study; no surveys occurred in the months following the peak spawning run in the Fraser River (i.e. July to September) so this stage of sexual maturity could have been missed.

The highest proportions of empty stomachs in Chatham Sound occurred in November (76%) and in February (80%). It is unclear whether this observation was related to seasonal prey availability or sampling bias (e.g., time of day or location). A reduction or absence of teeth was sampled most frequently in February (11%) and in March (5%). Individuals with reduced dentition might have been preparing to spawn. As Eulachon approach rivers, they reportedly stop feeding and resorb minerals in their teeth to use for gonadogenesis (Hart and McHugh 1944; Hay and McCarter 2000). Similarly, Dealy and Hodes (2019) found that Eulachon with reduced dentition were found more frequently with increased proximity to the Fraser River.

In a small number of Eulachon specimens (<80 individuals), parasites were observed protruding from the operculum (the copepod *H. disphaerocephalus*) or found inside the body cavity (the nematode *Anisakis* spp.). While seeming to occur at a low frequency, parasites could have easily gone unnoticed, thus infection rates were likely higher than reported. Eulachon specimens were not thoroughly examined for parasites. Nematodes in particular are often difficult to spot in a body cavity filled with maturing gonads as they are small and translucent. Smaller, less-developed parasites would have been impossible to see macroscopically. Although possibly not a threat to Eulachon populations, *Anisakis* spp. is becoming more abundant globally and has been reported to cause adverse effects to other fish and mammal species (Florenza et al. 2020).

Juvenile Eulachon were sampled in all six survey months. Overall, 137 individuals <100 mm in length (some as small as 44 mm) were sampled in 2018–19. The distribution of juvenile Eulachon in BC is not well understood, but it has been suggested that fish disperse to open marine waters within their first year of life and possibly within the first few months (COSEWIC 2011). McCarter and Hay (1999) describe finding 100+ Eulachon larvae, 12–34 mm in size, in late July and early August in the center of Chatham Sound and west of Porcher Island using bongo net gear and techniques. Chatham Sound was recently identified as a potentially important foraging and rearing location for young of the year and 1+ Eulachon (MacConnachie et al. 2016).

Our study demonstrated that bodies of juvenile Eulachon <70 mm in length contained an ‘air bubble’ contrary to reporting in COSEWIC 2011 that Eulachon lack swim bladders. This small air sac could affect the fish’s ability to navigate the water column; thus, the vertical distribution of juveniles may differ from that of adults.

Ongoing investigations

Work is underway to analyze genetic material from tissue samples collected during this study. There is uncertainty as to which natal river(s) and/or spawning river(s) the sampled Eulachon were associated with, as stocks from different natal river can mix in their marine distribution. For example, Beacham et al. (2005) estimated that the mixed stock origin of an Eulachon sample collected by shrimp trawl in Chatham Sound was dominated by fish from the Nass and Skeena rivers as well as from the Kemano and Bella Coola rivers of the Central Coast of BC.

Histological analyses of Eulachon ovaries are ongoing to investigate maturity stage 6 and 7 observations. Discerning if iteroparity is associated with these ovaries will be highly informative. There has been a general understanding that Eulachon die after spawning (Hay and McCarter 2000). Spent Eulachon have, however, been captured in marine waters in BC (Barraclough 1964; Dealy and Hodes 2019) although histological evidence for repeat spawning was previously lacking.

Potential relationships between environmental variables and Eulachon catch collected during this study are also being explored.

Future studies

This nine-month study provides a snapshot of Eulachon distribution and biological condition. We recommend additional surveys in Chatham Sound to collect CPUE and biological data, particularly to fill data gaps in December to January to gain further insight into the timing of sexual maturation and migration into rivers, and in April through June to help inform whether post-spawn individuals are present in Chatham Sound at this time.

Marine habitat use and requirements of Nass/Skeena Eulachon requires further examination. As Eulachon have been caught during both day and night surface and midwater research trawls on the west coast of Vancouver Island (L. Flostrand 2019, pers. comm.), we recommend expanding the depth range of these surveys to include surface and midwater sets at varying times and expanding the study area to include areas closer to the river mouths. Adding bongo and Neuston net survey methodology and CTD casts could provide further insight into the relationships between envionmental variables and juvenile Eulachon distribution.

Eulachon otoliths collected in this study could be used for age validation studies as age determination of the species remains a challenge. Age estimates currently generated across agencies are not validated; however, new methodologies are being developed, including the use of otolith microchemistry as a tool to help interpret otolith growth zone counts (Benson et al. 2019).

Existing knowledge gaps in Eulachon life history and general biology must be addressed to best conserve this species which has undergone a nearly coast-wide decline for unknown reasons. Resolving age-at-maturity and the potential for repeat spawning would provide useful information for future stock assessments. Although no evidence exists to suggest that parasites currently pose a threat to the Nass/Skeena Eulachon population, parasitic nematodes and copepods should be monitored.

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APPENDIX 1. SURVEY DATA BY SET

Table 9. Details from all Eulachon trawl survey sets (n=164) completed between July 2018 and March 2019 on the North Coast of British Columbia including set duration, mean fishing depths, and water temperature. Two exploratory sets that were conducted outside of Chatham Sound are highlighted in blue.

Survey start date	Set	Time at retrieval	Duration (min)	Mean temp (°C)	Mean depth (m)	Eulachon catch (kg)	CPUE (kg/hr)
7/28/2018	1	4:05:21 PM	20.4	6.3	123.4	152.4	448.3
7/28/2018	2	4:42:54 PM	10.5	6.3	129.4	10	57.3
7/28/2018	3	5:38:00 PM	13.8	6.3	138.7	2.7	11.7
7/28/2018	4	8:22:21 AM	10.4	6.3	143.3	10.2	58.4
7/28/2018	5	9:09:08 AM	10.9	6.4	110.7	9	49.9
7/28/2018	6	9:55:02 AM	10.6	6.4	105.3	8.8	49.6
7/28/2018	7	10:39:42 AM	13	6.4	90.2	27.4	126.8
7/28/2018	8	12:55:53 PM	10.6	6.3	142.7	2.1	11.8
7/28/2018	9	1:52:07 PM	9.7	6.3	154.4	4.9	30.6
7/28/2018	10	2:45:09 PM	11	6.4	104.1	19.9	108.1
7/28/2018	11	1:07:46 PM	8.6	6.4	132.5	68.3	478.4
7/28/2018	12	1:46:08 PM	5.2	6.4	177.9	24.3	280.4
7/28/2018	13	2:26:47 PM	5.6	6.4	131.8	37.5	401
7/28/2018	14	4:02:12 PM	3.2	6.7	94.6	0.5	9.3
7/28/2018	15	9:44:27 AM	5.2	6.7	115.7	0.2	2
7/28/2018	16	10:19:07 AM	5.1	6.6	144.5	1.6	18.4
7/28/2018	17	11:30:54 AM	5.1	6.5	153.7	2.5	29.8
7/28/2018	18	12:33:44 PM	7.3	6.5	181	0.2	2
7/28/2018	19	1:59:40 PM	3.5	6.5	156.7	0.1	0.9
7/28/2018	20	3:08:59 PM	5.6	6.8	80.6	0	0
7/28/2018	21	8:55:36 AM	4.2	6.8	100.6	0.5	7.5
7/28/2018	22	9:35:35 AM	3.8	7.2	83	2.1	33
7/28/2018	23	10:30:41 AM	5.4	6.8	101.8	2.4	26
7/28/2018	24	11:20:10 AM	5.4	6.8	106.8	1.4	15.9
7/28/2018	25	12:27:37 PM	5.6	7	107.1	3.6	38.1
7/28/2018	26	1:08:57 PM	6.1	7.1	111.3	1.3	12.3
7/28/2018	27	1:43:56 PM	3.6	7.1	117.8	0.5	8
7/28/2018	28	2:35:51 PM	5.1	6.6	133.3	1.2	13.9
7/28/2018	29	3:37:37 PM	5.6	6.6	97.8	2	21.2
7/28/2018	30	7:50:55 AM	7.6	6.7	170.7	1	7.9
7/28/2018	31	9:02:14 AM	5.6	6.7	107.5	14.4	154.1
9/8/2018	1	9:34:38 AM	5.1	6.7	111.6	12.3	144.2
9/8/2018	2	10:16:45 AM	6.1	6.5	124.5	5.9	57.4
9/8/2018	3	10:52:11 AM	5.6	6.4	127.2	1.3	14
9/8/2018	4	12:11:16 PM	6.1	6.5	135	7.1	69.5
9/8/2018	5	12:52:56 PM	6.2	6.4	127.1	3.5	33.5

Survey start date	Set	Time at retrieval	Duration (min)	Mean temp (°C)	Mean depth (m)	Eulachon catch (kg)	CPUE (kg/hr)
9/8/2018	6	1:30:39 PM	5.9	6.4	148.1	0.3	3.2
9/8/2018	7	9:10:55 AM	5.6	6.3	155.9	0.2	2.2
9/8/2018	8	10:48:16 AM	11.5	6.3	164.3	0	0
9/8/2018	9	12:19:23 PM	11.2	6.3	243.7	0.3	1.7
9/8/2018	10	2:11:30 PM	10.7	8.4	69.3	0.4	2
9/8/2018	11	3:19:08 PM	10.6	6.3	260	0	0.2
9/8/2018	12	4:20:02 PM	4.8	6.4	151.8	25.2	313.3
9/8/2018	13	8:06:41 AM	6.6	9.2	57.2	0	0
9/8/2018	14	9:08:56 AM	5.2	8.8	121.8	0.5	5.4
9/8/2018	15	11:18:59 AM	6	8	162.2	0.6	6.1
9/8/2018	16	12:39:52 PM	10.6	7.7	168	4.1	23.3
9/8/2018	17	1:57:32 PM	5.8	7.8	158.1	0.7	6.8
9/8/2018	18	3:10:16 PM	6.3	7.9	147.3	3.5	33.9
9/8/2018	19	3:48:14 PM	5.3	8.3	110.8	3.5	39.7
9/8/2018	20	9:23:08 AM	5.9	8.2	140	0.4	3.9
9/8/2018	21	10:25:12 AM	3.3	8.2	116.3	1.7	30.9
9/8/2018	22	11:06:15 AM	5.4	8	130	2	21.8
9/8/2018	23	12:18:26 PM	5.8	8.2	114.3	4.3	44.7
9/8/2018	24	1:20:28 PM	5.8	8.4	95.5	2.8	29.2
9/8/2018	25	2:17:40 PM	5.7	8.2	104.8	9.2	96.4
9/8/2018	26	3:15:48 PM	5.5	8.5	88.4	0.8	9.1
9/8/2018	27	8:57:14 AM	5.6	7.9	104.4	2.2	23.1
9/8/2018	28	9:38:42 AM	6.1	8.3	89.1	7.5	73.9
9/8/2018	29	11:08:07 AM	5.6	8.9	130.2	4.6	49.1
9/8/2018	30	12:34:51 PM	5.5	8.9	116.5	16.7	180.9
9/8/2018	31	1:17:00 PM	5.2	8.8	89.2	1.8	21.1
9/8/2018	32	1:48:37 PM	5.6	8.9	77.1	0.5	5.4
9/8/2018	33	3:37:24 PM	5.5	6.8	197.1	3.4	36.8
10/8/2018	1	9:46:32 AM	6.5	9	121.3	6.8	62.1
10/8/2018	2	10:40:39 AM	5.1	9.2	96.8	1.5	17.4
10/8/2018	3	11:30:06 AM	6.1	8.6	92.5	0.4	3.8
10/8/2018	4	12:51:39 PM	2.5	8.7	81.6	0	0.2
10/8/2018	5	1:43:32 PM	6.1	8.5	89.6	0	0.4
10/8/2018	6	2:38:29 PM	5.6	8.6	129.4	0	0
10/8/2018	7	3:24:26 PM	5.9	7.9	113.4	4.4	45.2
10/8/2018	8	4:01:11 PM	6.4	8	112.4	0.5	4.3
10/8/2018	9	10:58:15 AM	5.5	6.5	143.3	0.4	3.8
10/8/2018	10	11:32:12 AM	5.6	6.7	127.6	0.5	5.5
10/8/2018	11	12:45:22 PM	5.6	6.6	129.8	7.6	80.9
10/8/2018	12	1:19:10 PM	5.9	6.5	148.9	10.2	104.1
10/8/2018	13	1:55:44 PM	4.7	6.5	137.8	26.1	329.1
10/8/2018	14	2:46:58 PM	5.7	6.9	131.7	1.1	11.3

Survey start date	Set	Time at retrieval	Duration (min)	Mean temp (°C)	Mean depth (m)	Eulachon catch (kg)	CPUE (kg/hr)
10/8/2018	15	3:35:57 PM	5	6.6	129.1	30.2	360.1
10/8/2018	16	9:07:29 AM	4.2	7.1	185.6	10.3	148.2
10/8/2018	17	10:00:17 AM	5.6	7.9	157.5	0.3	3.4
10/8/2018	18	10:42:27 AM	5.7	8.3	119.8	0.6	6
10/8/2018	20	2:10:41 PM	5.6	8.2	114.7	0.5	4.8
10/8/2018	21	3:18:33 PM	5.5	8.1	100.3	33.3	360.2
10/8/2018	22	5:06:11 PM	5.6	8.1	166.4	3.4	36.5
10/8/2018	23	9:01:12 AM	5.1	8.6	92.6	2.7	31
10/8/2018	24	10:25:23 AM	7	8.6	102.5	5.1	44
10/8/2018	25	11:16:49 AM	5.3	8.3	104.3	6.4	72.1
10/8/2018	26	1:05:13 PM	5.5	9.5	54.8	0.2	2.2
11/9/2018	1	10:38:54 AM	6.3	7.2	120.7	84.3	804.6
11/9/2018	2	11:14:40 AM	6	7.1	128.5	51.9	516.4
11/9/2018	3	12:45:09 PM	7	7.1	133.4	26.2	224.4
11/9/2018	4	1:49:37 PM	6.2	6.9	150.8	10.9	104.4
11/9/2018	5	9:37:43 AM	6.1	7.1	157.1	0.2	2
11/9/2018	6	10:34:04 AM	5.1	6.7	181.4	0.3	3.8
11/9/2018	7	12:32:30 PM	5.6	7	169.4	0	0.3
11/9/2018	8	1:29:44 PM	5.5	6.7	245	0.1	1.5
11/9/2018	9	2:58:41 PM	6	9.8	71	0	0
11/9/2018	10	4:05:35 PM	5.3	8.1	102.8	0.3	3.3
11/9/2018	11	8:13:23 AM	5.1	9.8	57.6	0	0
11/9/2018	12	9:45:11 AM	6	9.8	148.6	0.2	2.1
11/9/2018	13	10:30:30 AM	6	9.8	82.1	0	0
11/9/2018	14	11:15:14 AM	4.9	9.2	164.2	0.5	6
11/9/2018	15	12:42:10 PM	6.4	9.3	167.3	24.5	230.9
11/9/2018	16	1:34:16 PM	6.2	9.5	141.6	37.8	368.2
11/9/2018	17	2:38:08 PM	6.4	9.5	145.8	11.9	111
11/9/2018	18	3:15:52 PM	6.2	9.4	171.5	4.1	39.3
11/9/2018	19	4:00:55 PM	4.3	9.4	140.3	10.9	152.6
11/9/2018	20	4:48:12 PM	5.8	10	109.5	0	0
11/9/2018	21	8:22:27 AM	5.8	10	131.8	0.1	0.8
11/9/2018	22	8:56:57 AM	6.9	10	123.9	4.9	42.4
11/9/2018	23	9:33:16 AM	6	10	92.6	0.5	5
11/9/2018	24	10:08:08 AM	7	9.9	87.1	12.9	110.3
11/9/2018	25	10:45:15 AM	5.8	9.8	130.7	8.4	86.6
11/9/2018	26	11:30:22 AM	5.9	9.7	111.7	33.4	342.3
11/9/2018	27	12:53:45 PM	5.4	9.9	105.6	41.9	462.5
11/9/2018	28	1:28:32 PM	7.9	10	92.4	62.6	477.2
2/15/2019	1	10:20:02 AM	6.5	7.5	110.8	0.1	1.3
2/15/2019	2	11:10:45 AM	9.9	7.4	144.2	6	35.9
2/15/2019	3	12:37:05 PM	10.4	7.4	141.5	2.3	13.1

Survey start date	Set	Time at retrieval	Duration (min)	Mean temp (°C)	Mean depth (m)	Eulachon catch (kg)	CPUE (kg/hr)
2/15/2019	4	1:53:31 PM	10.9	7.5	131	4.2	22.8
2/15/2019	5	3:14:23 PM	9.3	7.6	195.4	8.6	55.8
2/15/2019	6	4:14:25 PM	9.8	7.3	160.1	0.3	1.5
2/15/2019	7	5:26:31 PM	9.9	7.4	97.1	0.1	0.5
2/15/2019	8	8:00:20 AM	10.5	7.1	125	0	0
2/15/2019	9	8:41:19 AM	10.5	7.3	115.5	2.3	13.1
2/15/2019	10	9:27:34 AM	11.2	7.2	90.7	0.6	2.9
2/15/2019	11	10:13:05 AM	11	7.2	86.9	0.5	2.6
2/15/2019	12	10:52:33 AM	10.5	7.3	128.1	4.3	24.8
2/15/2019	13	11:32:30 AM	10.4	7.3	115.6	2.6	14.9
2/15/2019	14	9:25:02 AM	10.5	7.1	154.3	2	11.6
2/15/2019	15	10:13:27 AM	10.2	7.3	171.8	0.8	4.6
2/15/2019	16	11:34:11 AM	10.1	6.9	169.2	2.4	14.5
2/15/2019	17	12:46:30 PM	11.2	7.2	129.7	0	0.2
2/15/2019	18	1:52:19 PM	11	7.2	110.2	27	147.6
3/20/2019	1	9:43:01 AM	11.5	7.1	122.4	9.9	51.9
3/20/2019	2	10:15:20 AM	6.1	7.1	113.5	10.9	106.8
3/20/2019	3	11:21:23 AM	5.9	7.1	142.8	1.2	12.3
3/20/2019	4	12:32:14 PM	5.8	7.1	146.5	2.6	27.5
3/20/2019	5	8:41:44 AM	10.4	7.1	150.7	0	0
3/20/2019	6	9:22:55 AM	11.2	7.1	153.3	0.1	0.4
3/20/2019	7	10:12:15 AM	10.4	7.1	168.1	0	0
3/20/2019	8	11:18:03 AM	10.8	6.6	74.9	0	0
3/20/2019	9	12:45:48 PM	7.6	7.1	261.1	0.3	2.1
3/20/2019	10	1:38:02 PM	7.3	7.1	155.9	1.9	15.9
3/20/2019	11	2:10:19 PM	5.2	7.1	130.6	0.5	5.7
3/20/2019	12	2:47:46 PM	5.9	6.9	97.4	0.3	3.4
3/20/2019	13	3:23:03 PM	5.3	6.8	84.4	0	0
3/20/2019	14	8:09:42 AM	5.6	6.7	144.3	0.3	3.6
3/20/2019	15	8:48:40 AM	5.8	6.7	158.8	11.3	117.5
3/20/2019	16	9:26:17 AM	5.8	6.7	169.1	3	31.1
3/20/2019	17	10:19:21 AM	5.6	6.7	159.2	0	0
3/20/2019	18	11:12:22 AM	5.4	6.8	185.5	0.1	1.2
3/20/2019	19	12:35:19 PM	5.5	6.8	131.9	19.3	212.6
3/20/2019	20	1:19:23 PM	6.3	6.7	142.8	0	0
3/20/2019	21	2:08:43 PM	5.5	6.8	98.6	0.1	0.5
3/20/2019	22	2:56:38 PM	5.2	6.7	140.7	1.4	16
3/20/2019	23	3:46:51 PM	5.7	6.8	117.2	1.3	13.5
3/20/2019	24	8:04:22 AM	5.2	6.7	127	0.1	0.9
3/20/2019	25	8:39:08 AM	4.9	6.7	108.2	0.9	11.5
3/20/2019	26	9:29:44 AM	6.1	6.7	86.2	0.1	1
3/20/2019	27	10:19:46 AM	6.1	6.7	99	0.4	3.7

Survey start date	Set	Time at retrieval	Duration (min)	Mean temp (°C)	Mean depth (m)	Eulachon catch (kg)	CPUE (kg/hr)
3/20/2019	28	10:58:35 AM	5.9	6.7	89.5	0.9	9.1
3/20/2019	29	12:17:28 PM	5.7	6.7	86.4	0	0

Table 10. Set locations and Eulachon specimen lengths sampled during two exploratory sets in October 2018 in Hecate Strait. n= number of Eulachon sampled for length; SE= standard error.

Survey start date	Set	Location (lat, lon)	n	Standard length (mm)			SE
				Minimum	Maximum	Mean	
10/8/2018	20	54.2884, -131.0707	18	114	173	146	3.48
10/8/2018	21	54.1822, -131.0632	129	80	150	97	1.16

APPENDIX 2. EULACHON SEX AND MATURITY GUIDE

The following is a practical guide for assessing the sex and sexual maturity of Eulachon at sea in British Columbia.

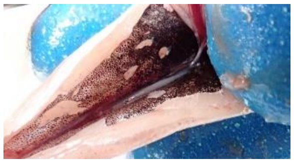
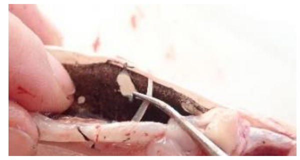
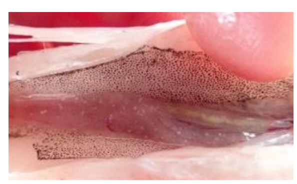
Background

Fisheries and Oceans Canada conducted a series of Eulachon trawl surveys in coastal waters of British Columbia from 2017 to 2019 (Dealy and Hodes 2019; Dealy and Hodes 2021). This resulting guide was produced to standardize the assignment of sex and maturity stage for Eulachon sampled in the field. Determination is challenging in the marine environment as Eulachon do not express external sexual dimorphism before they prepare to spawn. The ability to determine and to consistently document the sex and maturity of Eulachon sampled at sea will provide important life history information for Eulachon research, management and conservation efforts.

Methods

Eulachon specimens were collected as described in Dealy and Hodes (2019). To reveal the body cavity an incision was made on the ventral side from the anus to the pectoral fins. Sex (male or female) was assigned based on the gonad descriptions in this guide. Gonads were staged as follows: (1) undeveloped; (2) starting; (3) developing; (4) maturing; (5) mature; (6) spawned; (7) recovering. When Eulachon gonads were not visible, the sex of the specimen was deemed ‘undetermined’ and a maturity stage was not assigned. Maturity stages were adapted from those of Pacific Herring (Hay and Outram 1980) and modified to suit the characteristics of Eulachon.

Stage	Maturity State	**MALE** Gonad Description	**FEMALE** Gonad Description
1	Undeveloped	white; knife-edged (not rounded); thickness and width of dental floss; width <0.25 cm	clear; rounded (not knife-edged); string-like; width <0.25 cm
2	Starting	white, shiny, and very smooth; knife-edged (not rounded); width <0.5 cm	clear to pale pink; rounded (not knife-edged); width <0.5 cm
3	Developing	white, shiny, and very smooth; knife-edged (not rounded); width nearing 1 cm	cream or pale pink; beginning to appear lumpy (not perfectly smooth); vascularization present and eggs are visible (but very small); width nearing 1 cm
4	Maturing	white; milt is secreted when pressure is applied with knife; width >1 cm	cream or pale pink; eggs can be dislodged by gently scraping surface with knife; width >1 cm
5	Mature (Ripe)	white; milt flows from vent with slight pressure to abdomen; width >>1 cm	pale pink; eggs fill nearly all of body cavity; eggs flow from vent with slight pressure to abdomen; width >>1 cm
6	Spent	N/A	pink, thickened walls; often flaccid with large white eggs sparsely distributed; blood vessels may be pronounced
7	Recovering	N/A	pink; several large, transparent eggs sparsely distributed; small eggs (barely visible) all throughout; blood vessels may be pronounced

	MALE		FEMALE	
Stage	Gonad Appearance	Brief Description	Gonad Appearance	Brief Description
1		white knife-edge dental floss (<0.25 cm wide)		clear round string-like (<0.25 cm wide)
2		white knife-edge <0.5 cm wide		clear to pale pink round eggs not visible <0.5 cm wide
3		white smooth ~1 cm wide		cream/pale pink small eggs visible ~1 cm wide
4		white smooth secretes milt with pressure		cream/pale pink lumpy eggs can be dislodged
5		milt flows from vent with slight pressure to abdomen		eggs flow from vent with slight pressure to abdomen
6	N/A			pink flaccid some large, white eggs (scattered) blood vessels
7	N/A			clear/pink few large, transparent eggs many small eggs (barely visible)

APPENDIX 3. CUMULATIVE CATCH AND SPECIES COMPOSITION

Table 11. Cumulative catch and species composition from bottom trawl surveys (n=162 sets) conducted in Chatham Sound, British Columbia, from July 2018 to March 2019.

Common name	Scientific name	Total catch (kg)	Total catch (%)
Spotted Ratfish	*Hydrolagus colliei*	8,846.6	40.0
Walleye Pollock	*Gadus chalcogrammus*	2,237.6	10.1
Sidestripe Shrimp	*Pandalopsis dispar*	1,614.6	7.3
Flathead Sole	*Hippoglossoides elassodon*	1,572.1	7.1
Arrowtooth Flounder	*Atheresthes stomias*	1,505.6	6.8
Eulachon	*Thaleichthys pacificus*	1,218.3	5.5
Blackbelly Eelpout	*Lycodes pacificus*	775.7	3.5
Rex Sole	*Glyptocephalus zachirus*	558.4	2.5
Pink Shrimp (Smooth)	*Pandalus jordani*	490.6	2.2
Sablefish	*Anoplopoma fimbria*	468.6	2.1
Slender Sole	*Lyopsetta exilis*	308.1	1.4
North Pacific Spiny Dogfish	*Squalus suckleyi*	302.6	1.4
Brittlestars	Ophiuroidea	282.7	1.3
Longnose Skate	*Raja rhina*	271.0	1.2
English Sole	*Parophrys vetulus*	207.5	0.9
Pink Shrimp (Spiny)	*Pandalus borealis*	197.2	0.9
Dover Sole	*Microstomus pacificus*	124.8	0.6
Shortfin Eelpout	*Lycodes brevipes*	77.7	0.4
Quillback Rockfish	*Sebastes maliger*	74.6	0.3
Pacific Halibut	*Hippoglossus stenolepis*	61.3	0.3
Shortspine Thornyhead	*Sebastolobus alascanus*	59.6	0.3
Pacific Cod	*Gadus macrocephalus*	56.0	0.3
Anemone	Actiniaria	52.0	0.2
Scallop	Pectinidae	48.0	0.2
Inshore Tanner Crab	*Chionoecetes bairdi*	46.9	0.2
Rockfishes	*Sebastes sp.*	45.5	0.2
Big Skate	*Beringraja binoculata*	44.8	0.2
Schoolmaster Gonate Squid	*Berryteuthis magister*	39.6	0.2
Lingcod	*Ophiodon elongatus*	35.5	0.2
Sandpaper Skate	*Bathyraja interrupta*	35.4	0.2
Sponges	Porifera	31.1	0.1
Rougheye/Blackspotted Rockfish Complex	*Sebastes aleutianus/melanostictus* complex	27.8	0.1
Prawn	*Pandalus platyceros*	27.8	0.1
Red Urchin	*Mesocentrotus franciscanus*	25.1	0.1
Pacific Herring	*Clupea pallasii*	24.4	0.1
Pacific Tomcod	*Microgadus proximus*	21.6	0.1

Common name	Scientific name	Total catch (kg)	Total catch (%)
Pacific Ocean Perch	*Sebastes alutus*	21.6	0.1
Pacific Hake	*Merluccius productus*	20.6	0.1
Heart Urchin	*Brisaster latifrons*	16.9	0.1
Lions Mane	*Cyanea capillata*	16.8	0.1
Darkblotched Rockfish	*Sebastes crameri*	15.2	0.1
Giant Pacific Octopus	*Enteroctopus dofleini*	14.1	0.1
Giant Red Sea Cucumber	*Apostichopus californicus*	14.0	0.1
Southern Rock Sole	*Lepidopsetta bilineata*	11.6	0.1
Sand Star	*Luidia foliolata*	11.3	0.1
Yellowleg Shrimp	*Pandalus tridens*	10.3	0.0
Darkfin Sculpin	*Malacocottus zonurus*	9.9	0.0
Sweet Potato Sea Cucumber	*Molpadia intermedia*	9.0	0.0
Dungeness Crab	*Metacarcinus magister*	8.6	0.0
Spinyhead Sculpin	*Dasycottus setiger*	8.2	0.0
Opalescent Inshore Squid	*Doryteuthis opalescens*	8.1	0.0
Silvergray Rockfish	*Sebastes brevispinus*	7.9	0.0
Whitebarred Prickleback	*Poroclinus rothrocki*	7.6	0.0
Wattled Eelpout	*Lycodes palearis*	7.0	0.0
Fragile Urchin	*Allocentrotus fragilis*	6.4	0.0
Pink Short-spined Star	*Pisaster brevispinus*	6.3	0.0
Redstripe Rockfish	*Sebastes proriger*	5.2	0.0
Fried Egg Jellyfish	*Phacellophora camtschatica*	5.0	0.0
Black Eelpout	*Lycodes diapterus*	4.8	0.0
Humpback Shrimp	*Pandalus hypsinotus*	4.5	0.0
Moon Jelly	*Aurelia aurita*	4.5	0.0
Spiny Red Sea Star	*Hippasteria spinosa*	4.4	0.0
Green Urchin	*Strongylocentrotus droebachiensis*	4.1	0.0
Gastropods	Gastropoda	3.9	0.0
Sea Cucumbers	Holothuroidea	3.3	0.0
Shiner Perch	*Cymatogaster aggregata*	3.1	0.0
Snake Prickleback	*Lumpenus sagitta*	3.1	0.0
Yellowtail Rockfish	*Sebastes flavidus*	3.0	0.0
Common Two-Spined Crangon	*Neocrangon communis*	2.7	0.0
Butter Sole	*Isopsetta isolepis*	2.3	0.0
Sea Whip	*Balticina septentrionalis*	2.1	0.0
Cushion Star	*Pteraster tesselatus*	1.9	0.0
Redbanded Rockfish	*Sebastes babcocki*	1.3	0.0
Northern Smoothtongue	*Leuroglossus schmidti*	1.3	0.0
Pallid Urchin	*Strongylocentrotus pallidus*	1.2	0.0
Bocaccio	*Sebastes paucispinis*	1.1	0.0
Northern Ronquil	*Ronquilus jordani*	1.0	0.0

Common name	Scientific name	Total catch (kg)	Total catch (%)
Brown Box Crab	*Lopholithodes foraminatus*	0.9	0.0
Fish-eating Star	*Stylaster forreri*	0.8	0.0
Longsnout Prickleback	*Lumpenella longirostris*	0.8	0.0
Slender Bladed Shrimp	*Spirontocaris holmesi*	0.7	0.0
Water Jellyfish	*Aequorea victoria*	0.6	0.0
Sea Urchin	*Strongylocentrotus sp.*	0.6	0.0
Squat Lobster	*Munida quadrispina*	0.4	0.0
Red Irish Lord	*Hemilepidotus hemilepidotus*	0.4	0.0
Blackfin Sculpin	*Malacocottus kincaidi*	0.4	0.0
Greenstriped Rockfish	*Sebastes elongatus*	0.3	0.0
Threadfin Sculpin	*Icelinus filamentosus*	0.3	0.0
Blacktip Poacher	*Xeneretmus latifrons*	0.3	0.0
Splitnose Rockfish	*Sebastes diploproa*	0.2	0.0
Pacific Staghorn Sculpin	*Leptocottus armatus*	0.2	0.0
Large Eyed Eualid	*Eualus macropthalmus*	0.2	0.0
Rosy Tritonia	*Tritonia diomedea*	0.2	0.0
Whelks	Buccinidae	0.2	0.0
Pacific Sanddab	*Citharichthys sordidus*	0.2	0.0
Soft Coral	*Primnoa sp.*	0.1	0.0
Gunpowder Star	*Gephyreaster swifti*	0.1	0.0
Barbed Eualid	*Eualus barbatus*	0.1	0.0
Bluespot Shrimp	*Pandalus stenolepis*	0.1	0.0