The Alaska Department of Fish and Game has a long record of participating in marine salmon research as opportunities allow or information needs become apparent. Over the past year, the department instituted the Salmon Ocean Ecology Program (SOEP) in recognition that the marine portion of the salmon lifecycle is an important, but missing, piece for understanding salmon productivity in Alaska. The staff and resources of SOEP are specifically intended to stabilize existing marine salmon research and foster new opportunities, provide new information that can be used to aid in management decision-making, and provide necessary information on pressing questions related to drivers of Alaskan salmon productivity. Several initiatives have been undertaken by SOEP. Among these are research efforts in collaboration with trophic ecologists at NOAA's Alaska Fisheries Science Center to investigate the role of competition among salmon species/stocks and with other pelagic animals. We are jointly seeking funding to support this work from the North Pacific Research Board and, if funded, results of this research will be available over the next few years. A review of SOEP and recent developments in research, and a review of salmon-related competition in the ocean will be presented at the Board of Fisheries Hatchery Committee meeting in March 2022.

Another marine salmon research initiative supported by the department are the Gulf of Alaska winter expeditions of the International Year of the Salmon (IYS) program (https://yearofthesalmon.org/high-seas-expeditions/). The primary objective of these IYS surveys is to understand how increasingly extreme climate variability in the North Pacific Ocean, and the associated changes in the ocean environment, influence the distribution and survival of salmon. These surveys involve scientists from the Pacific salmon-producing countries (Japan, Russia, Korea, USA and Canada) of the North Pacific Anadromous Fish Commission (NPAFC) who are working collaboratively to fill important data gaps in our understanding of the marine life of salmon, particularly in the winter – a critical time for salmon survival. Gulf of Alaska winter expeditions occurred in 2019 and 2020, and the culmination of this initiative will be a survey spanning the North Pacific Ocean from Asia to North America in the winter of 2022 (originally this survey was scheduled for 2021 but was delayed due to difficulties associated with COVID-19). Preliminary findings of the 2019 and 2020 winter expeditions can be found in the attached reports published by the NPAFC (Attachments 1 and 2). Presentations associated with results of these initial winter expeditions are available online (website: https://www.ohboy.ca/salmonconf2021). The department has been a strong advocate and participant in the IYS winter expeditions and is dedicating considerable staff time and resources to furthering this work in the 2022 winter expedition. These expeditions provide unique opportunities to fill critical data gaps in the marine life of Alaskan salmon to better understand changes in productivity. More general information presented at an NPAFC/IYS workshop in May 2021 is also available in the recently released NPAFC Technical Report 17, *Linkages between Pacific Salmon Production and Environmental Changes* (https://npafc.org/wp-content/uploads/technical-reports/Tech-Report-17-DOI/Technical-Report-17.pdf)

Attachment 1.

Summary of Preliminary Findings of the International Gulf of Alaska Expedition Onboard the R/V *Professor Kaganovskiy* During February 16–March 18, 2019

NPAFC
Doc. 1858
Rev.

Summary of Preliminary Findings of the International Gulf of Alaska Expedition Onboard the R/V *Professor Kaganovskiy* During February 16–March 18, 2019

by

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NORTH PACIFIC ANADROMOUS FISH COMMISSION

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Canada[1], Japan[2], Korea[3], Russia[4], and USA[5]

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Abstract

The international expedition to the Gulf of Alaska was the first large-scale, integrated winter pelagic ecosystem research survey, with a particular focus on Pacific salmon. The expedition covered an area of approximately 700,000 km^2 between February 16 and March 18, 2019. The research team of 21 included scientists from Canada, Japan, Korea, Russia and the United States of America and was a major contribution to the International Year of the Salmon Program. The expedition leader, Dr. Richard Beamish of Canada, secured funding for the expedition from both governmental organizations and private individuals. The intent of the expedition was to demonstrate that international collaboration could be effective, to provide baseline measurements of major pelagic ecosystem components including abundance of Pacific salmon in the Gulf of Alaska in the winter season and to test key hypotheses on factors regulating salmon survival in the ocean during their seasonal activities. In total, 423 salmon (223 chum, 93 coho, 73 sockeye, 31 pink, and 3 Chinook salmon) were caught during trawl survey. In addition, two coho salmon caught with a live-box were tagged with NPAFC disc tags and released in the eastern Gulf of Alaska. Content below provides an overview of samples collected and some preliminary results from the survey.

Keywords: Pelagic ecosystem, Pacific salmon, Gulf of Alaska, international collaboration

INTRODUCTION

It is currently recognized that during winter about one third of all Pacific salmon inhabit the Gulf of Alaska (GoA), yet factors affecting their survival during the critical winter period have not been studied. In light of changing ocean ecosystems, there is an urgent need to research winter foraging conditions of Pacific salmon, particularly in the northeastern Pacific Ocean. Presently, there is no baseline information on this ecosystem, which adds uncertainty to current forecasts of salmon return and fish behaviour in the changing North Pacific ecosystem. In the short-term, a large number of major salmon related management issues in Alaska and British Columbia (BC) will benefit from the scientific studies in this area.

There is a growing recognition that a size-dependent mortality within the first ocean year regulates Pacific salmon production. A recent large environmental change event called the “Blob” had occurred in the GoA from 2014 to 2016. It has been speculated that poor returns to rivers around the GoA and in BC following this marine heatwave resulted from reduced summer growth and overall fish condition. As new and possibly even more extreme warming events may occur in the future, the expedition to the GoA was a timely study of the ecosystem levels effects on the survival of all Pacific salmon species. The expedition is particularly relevant to Pacific salmon science off the west coast of North America as a “proof of concept” to investigate the application of trawl studies integrated with comprehensive measurement of ocean conditions and prey fields, to determine abundance and distribution of Pacific salmon populations in the open ocean. Similar surveys are routinely carried out in the northwestern Pacific and are successfully used by Russian scientists to forecast salmonid returns. Furthermore, surveys to estimate the abundance and condition of Pacific salmon in their first ocean winter at sea are a logical extension of the early marine survival studies conducted in many nearshore areas.

Currently, there is a controversy about the carrying capacity of the GoA, which is needed to plan the hatchery enhancement programs in the North Pacific. There is a disagreement in opinions to support the large number of hatchery operations. The paucity of the available information calls for basic ecological information about prey availability, diet, species abundances and stock specific rearing areas of Pacific salmon. The expedition is the first major contribution to the International Year of the Salmon announced in the fall of 2018. This international collaboration is deemed to be a springboard for future multi-country, Pan-Pacific collaborative cruises involving all salmon producing nations.

The main objectives of the expedition thus were threefold:

(a) to demonstrate that scientists from salmon producing countries could work collaboratively to investigate factors regulating marine survival of Pacific salmons in shared international waters;

(b) to identify the stock specific rearing areas for all species of salmon, their abundances and their condition to test the hypothesis that the abundance of salmon is mostly determined by the end of first ocean winter; and

(c) to obtain baseline measurements of environmental parameters and ecosystem components in the GoA during winter.

MATERIALS AND METHODS

A trawl survey for overwintering Pacific salmon was conducted in the GoA in February and March 2019 onboard the chartered Russian R/V *Professor Kaganovskiy*, covering ~697,500 km^2 (Figure 1). Eleven scientists: six from Canada, three from the USA, one from Japan and one from South Korea joined ten Russians scientists already onboard the vessel. The science team included experts in oceanography, chemistry, zooplankton, micronekton and fish biology. The field sampling was designed to allow processing of as many samples onboard of the ship as possible.

The survey area and detailed protocols followed are described in the NPAFC Document 1807 Rev. 1 (NPAFC, 2018). In total, 58 stations were completed in the main research area (Figure 1). In addition, two trawl sets were completed in the Canadian EEZ (not considered as part of the survey grid) and four sets (including 2 of the sets in the Canadian EEZ) were conducted with a modified cod end at the end of the main survey. The modified cod-end was a large aluminum live box designed to capture salmon for tagging and release. These were trial sets with this gear and were 20–30 minutes in length.

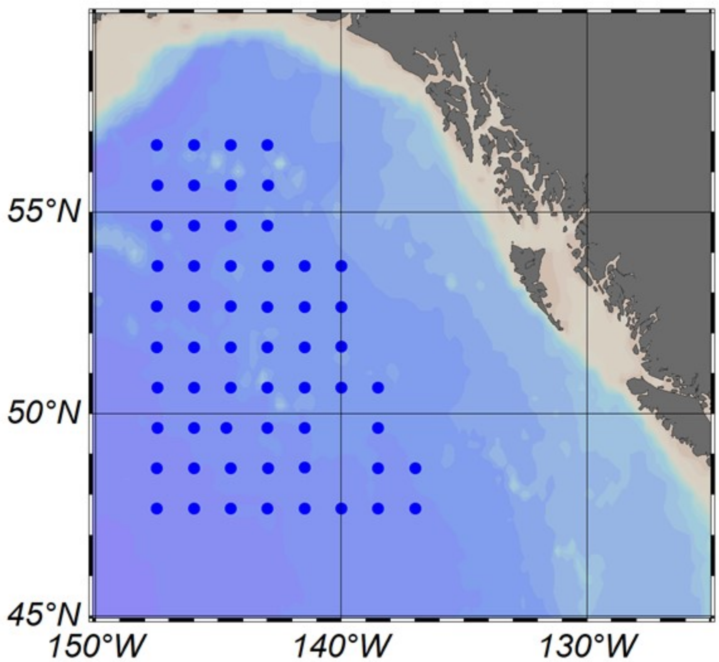

Figure 1. Expedition stations (n=58) sampled during the February–March 2019 in the Gulf of Alaska.

Typical survey stations conducted during both daylight and night times consisted of:

(1) a deployment of a 24-position rosette equipped with a SeaBird CTD 911 plus and Rinko CTD, turbidity, fluorescence and oxygen sensors, to a minimum depth of 600 m. At every other station, the rosette and a SeaBird CTD were deployed to 1000 m. Water samples for measuring salinity, chlorophyll and macronutrients were collected at standard depths of 0, 25, 50, 75, 100, 150, 200, 400, 600, 1000 m. Samples for oxygen concentration measurement were only collected at stations to 1000m;

(2) a vertical deployment of two Juday nets (0.1 m^2 mouth area, 160 µm mesh) to 50–0 and 200–0 m, and one Bongo net (0.5 m^2, 236 µm) to 250–0 m;

(3) a deployment of a surface (0–30 m) midwater trawl (~120 m^2, 30m depth x 40m width) for the duration of one hour at a speed of 4.5 knots.

(4) a deployment of a small neuston net from HydroBios (surface 0–20 cm, mesh size 300 µm) for 15 min at 2.5 knots.

At every trawl station, CTD48Mc (Sea&Sun Technology GmbH) and the ambient temperature by SBE-56 high accuracy thermometer were attached to the trawl.

Oceanographic samples (CTD, nutrients, chlorophyll and oxygen) and Juday net zooplankton samples were processed onboard the vessel. The samples from the Bongo nets were preserved and frozen for analysis at onshore laboratories in Canada. Neuston net samples were collected to provide information on micro-plastics in the surface waters of the GoA. However, in addition, the net provided information on larval and juvenile fish not retained in the larger trawl. These samples were preserved in formalin to be analysed in Canada.

From each trawl, all micronekton and nekton were processed. All salmon were identified and processed for length, weight, DNA, scales, otoliths, energy density, lipids, fatty acids and diet analysis. A subsample of the salmon catch (up to 10 per trawl) was processed for fish health diagnostics. Non-salmon nekton species were identified, enumerated, measured and a subsample was frozen or preserved for subsequent laboratory analysis in Canada and Russia. Micronekton (jellyfish, mesopelagic fish, squid) were identified to the species level, measured, counted, weighed and some frozen for subsequent lab analyses.

Additional sampling or procedures conducted during the survey included at-sea stock identification, macro-plastic enumeration (one hour periods daily), documentation of marine mammals (continuous), nighttime visual jellyfish enumeration (~10-minute intervals during sets), measures of solar radiation and reflectance to calibrate satellite measurement of phytoplankton blooms, and underwater video recording of fishes behaviour within the trawl net in day time (GoPro cameras).

PRELIMINARY FINDINGS

Water Dynamics and Chemistry

In the surveyed region, two current systems of the North-Eastern Pacific: Sub-Arctic Current (SAC) and Alaskan Current were observed, with the main dynamic irregularities shown in the geostrophic currents map (Figure 2). A divergence between currents to the west and east was visible at ~48ºN and 50ºN on most transects of the survey (Figure 2). Surface temperature and salinity showed a north-south gradient with coldest and saltiest waters at the northwestern part of the grid and warmest and freshest waters in the southeastern grid corner (Figure 3). The surface 7ºC isotherm demarcated the boundary between the colder and warmer parts of the survey (Figure 3).

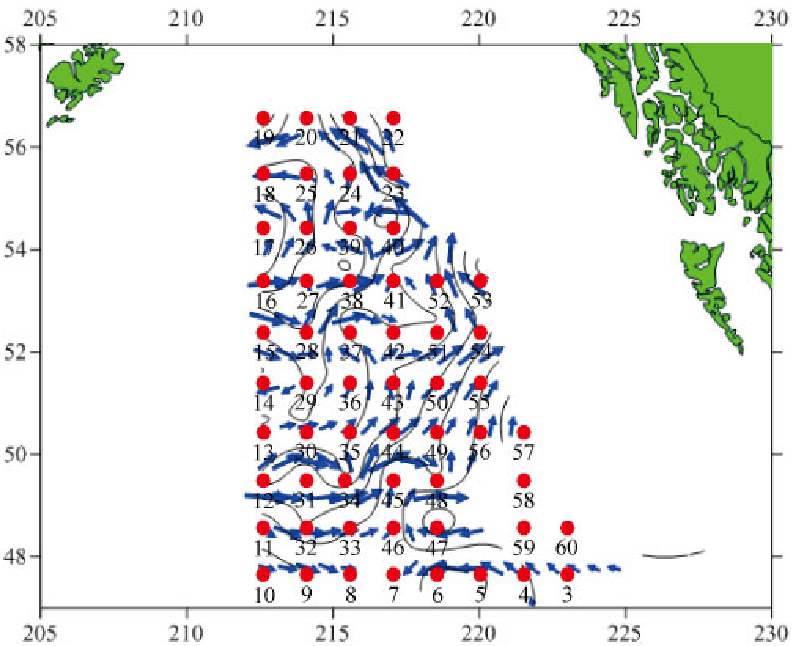

Figure 2. Geostrophic currents (0–1000 m) during February–March 2019 in the Gulf of Alaska.

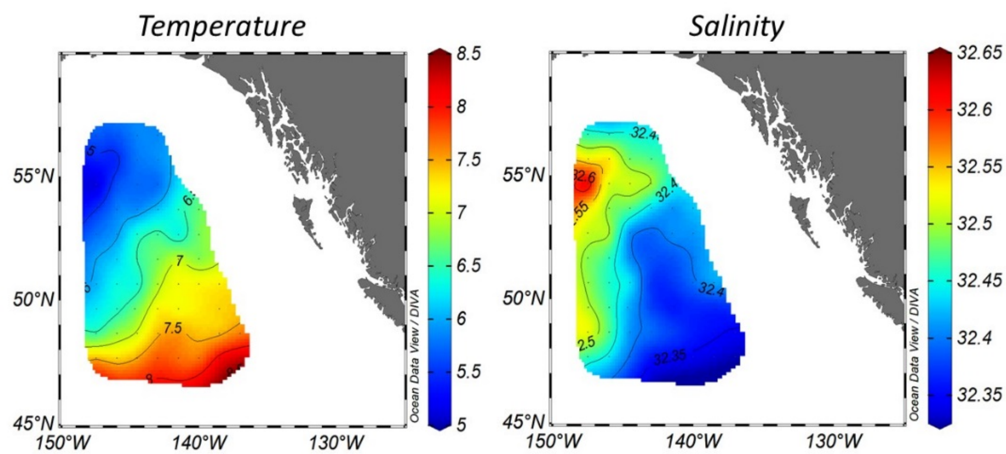

Figure 3. Surface temperature and salinity during February–March 2019 in the Gulf of Alaska.

A notable pattern observed during the grid work was the depth of the 2.5 $ml.l^{-1}$ oxygen horizon. Oxygen concentrations below this level may affect salmon and other micronekton physiological performance. According to our preliminary findings, the depth of the 2.5 $ml.l^{-1}$ threshold gradually increased from < 150 m at the northern part of the grid to ~ 300 m in the south (Figure 4). Other thermodynamics as well vertical stability parameters will be considered in detail in future analyses.

The spatial distribution of dissolve inorganic nitrogen (DIN) and phosphorus (DIP) as well as silica and ammonium showed very similar patterns, being the highest at the northwestern and lowest at the southeastern parts of the grid, closely tracking the coldest and warmest parts of the survey, respectively (Figure 5).

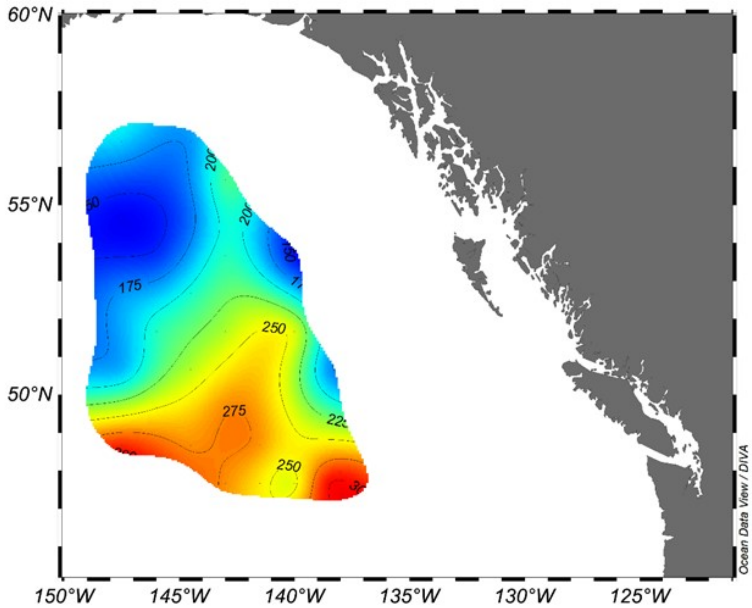

Figure 4. Depth of the 2.5 ml.l^{-1} oxygen concentration during February–March 2019 in the Gulf of Alaska.

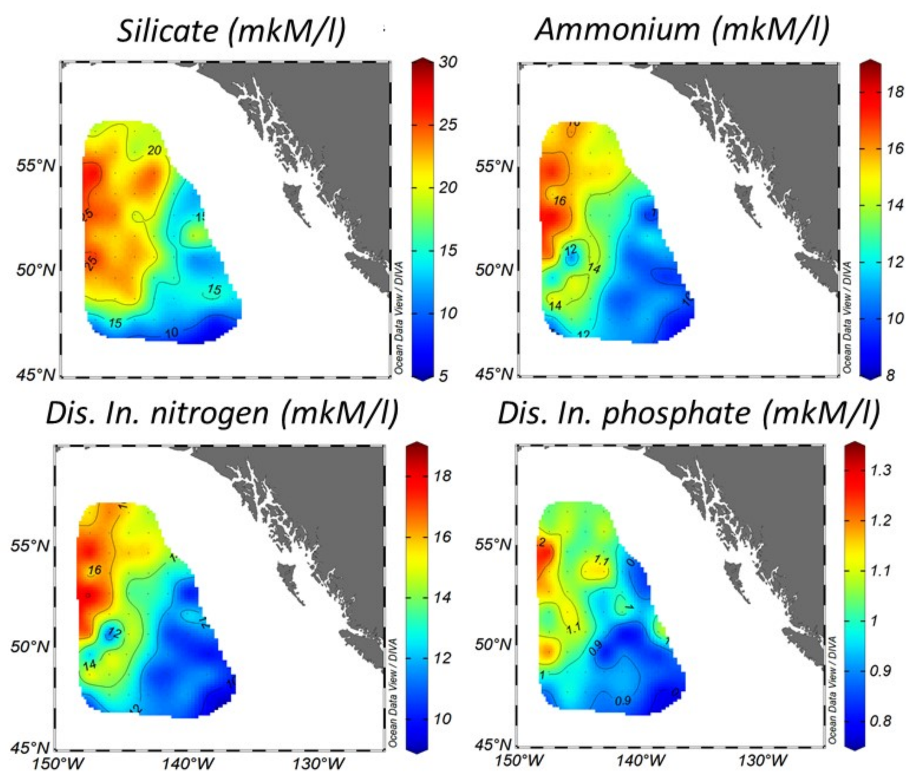

Figure 5. Surface distribution of macronutrients during February–March 2019 in the Gulf of Alaska.

Phytoplankton biomass (expressed as Chlorophyll-*a*)

In general, Chl-*a* concentrations did not exceed 0.9 mgChl-*a*.m^{-3} (or 90 mgChla.m^{-2}) (Figures 6–12). Phytoplankton biomass was unevenly distributed, with regions of high and low biomass across the survey area. In the north, high phytoplankton biomass was measured in the east and west of the survey grid, possibly associated with eddies. Elevated phytoplankton biomass was also observed in the central and south central part of the survey grid (Figure 6). Figures 7–12 illustrate sections across the depth range of chlorophyll samples (0–150 m) for the six major latitudinal grid lines of the survey. There was usually a subsurface maximum in Chl-*a* concentrations. The sections largely reflected the observations from the surface plots, and additionally demonstrated that elevated phytoplankton biomass in the regions highlighted above extended deep in the water column (to ~ 100 m), e.g., Figure 7 – Section 1, and Figure 9 – Section 3. This was indicative of a deep mixed layer. It appears that phytoplankton bloom development may have been initiated, due to calm weather conditions, in the southern central part of the survey in the beginning of March 2019.

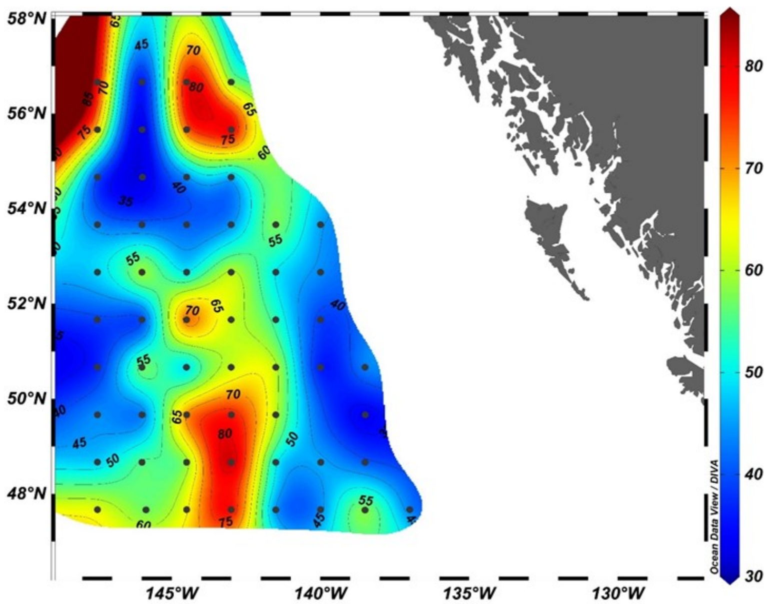

Figure 6. Depth integrated (0–150 m) chlorophyll-a concentration (mg $Chla.m^{-2}$) during February–March 2019 in the Gulf of Alaska.

Zooplankton biomass

Total and major zooplankton group biomass (corrected for avoidance) from the Juday net are presented on Figure 13. Total zooplankton biomass averaged 164.2 $mgWW.m^{-3}$. Highest biomass was observed at Station 8 (764.3 $mgWW.m^{-3}$) and was largely attributed to an unusually high biomass of chaetognaths (Figure 13A, F). Overall, the major zooplankton groups did not show overlapping distributions, and substantial spatial variation was evident in the distribution of all groups. Copepod biomass was highest in the south of the GoA (Figure 13B). Euphausiid biomass was high in the southeast and north GoA (Figure 13C). Pteropod biomass was high in the northeast, center and south-west of the GoA (Figure 13D). Hydromedusae had highest biomass in the southeast quadrant of the survey area (Figure 13E).

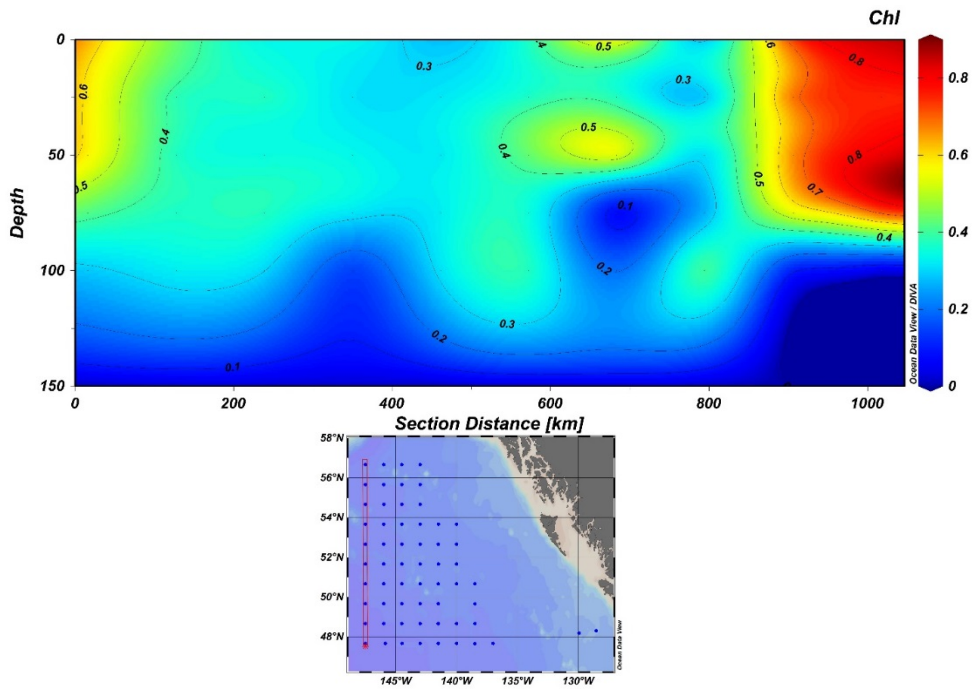

Figure 7. Vertical distribution of Chl-a along the Section 1 during February–March 2019 in the Gulf of Alaska. Section runs from south to north.

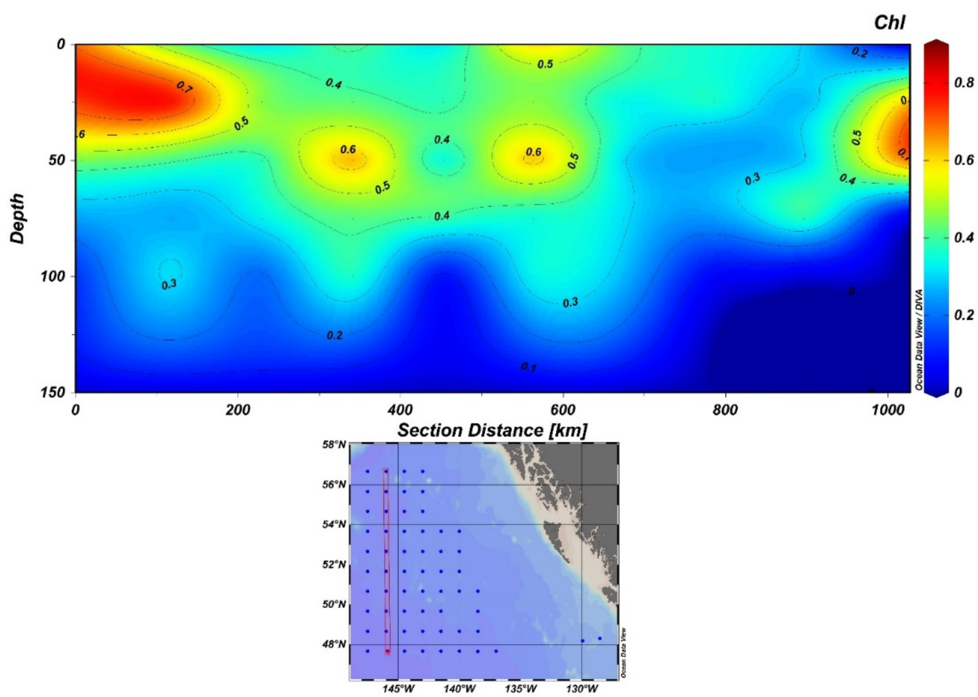

Figure 8. Vertical distribution of Chl-a along the Section 2 during February–March 2019 in the Gulf of Alaska. Section runs from south to north.

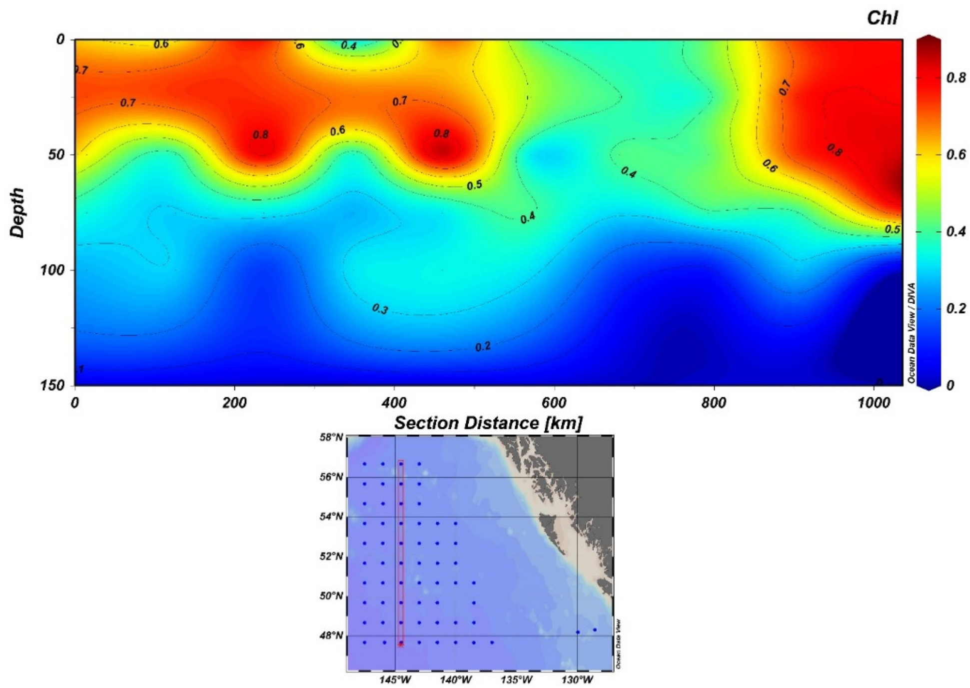

Figure 9. Vertical distribution of Chl-a along the Section 3 during February–March 2019 in the Gulf of Alaska. Section runs from south to north.

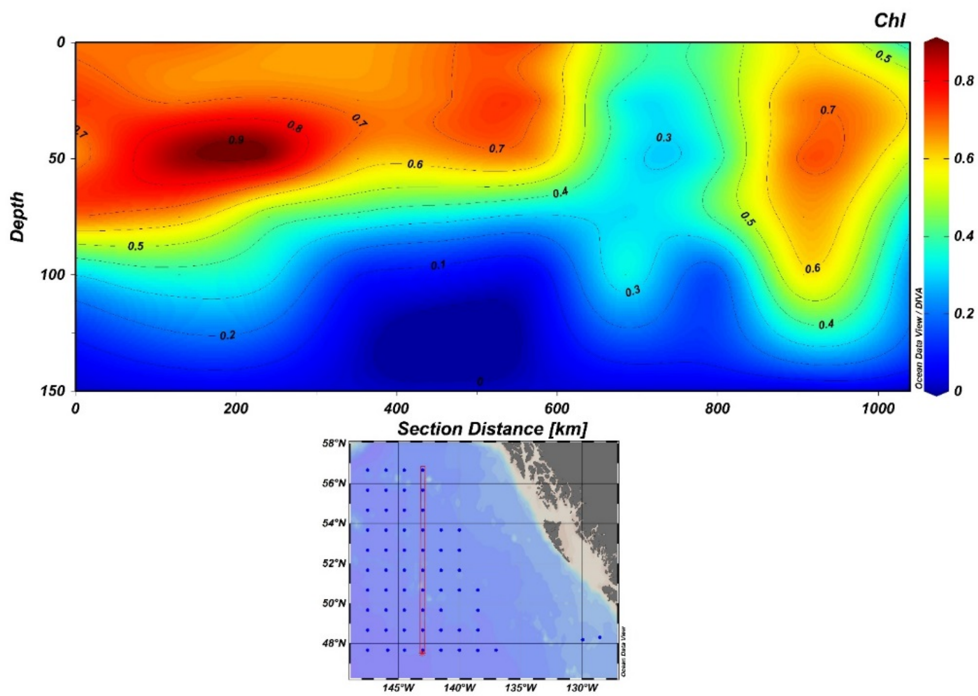

Figure 10. Vertical distribution of Chl-a along the Section 4 during February-March 2019 in the Gulf of Alaska. Section runs from south to north.

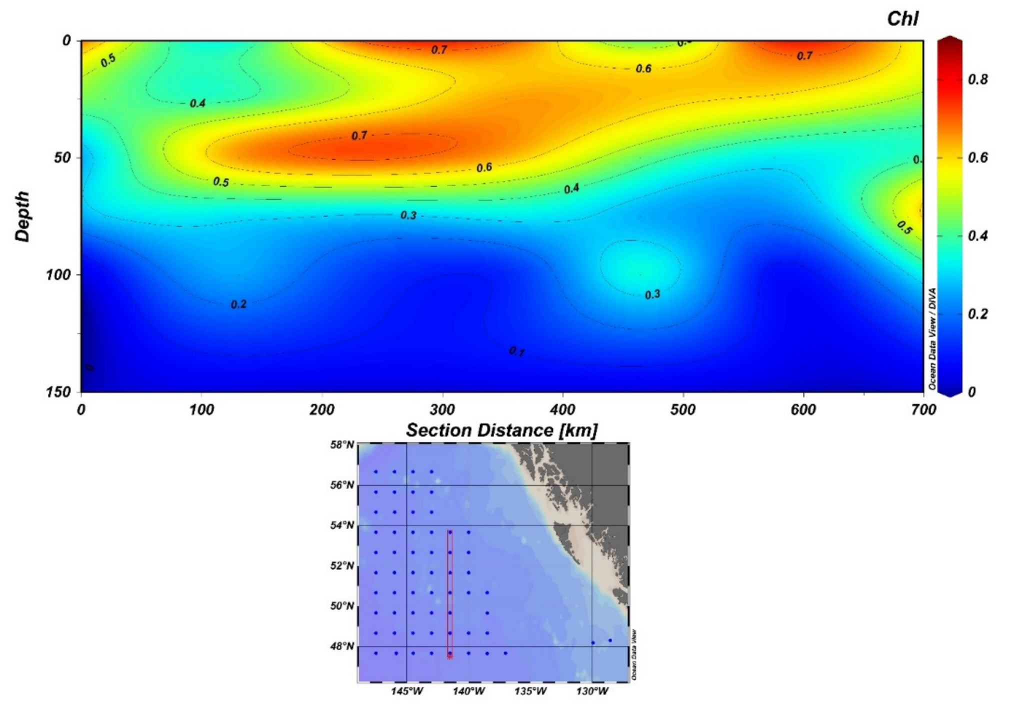

Figure 11. Vertical distribution of Chl-a along the Section 5 during February–March 2019 in the Gulf of Alaska. Section runs from south to north.

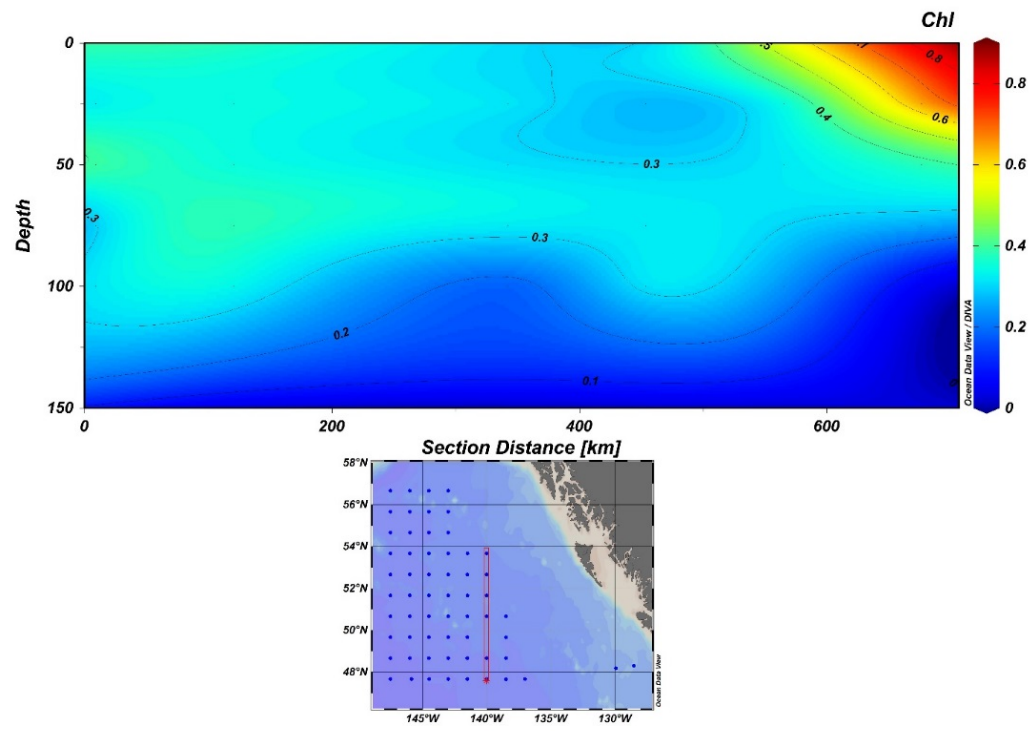

Figure 12. Vertical distribution of Chl-a along the Section 6 during February–March 2019 in the Gulf of Alaska. Section runs from south to north.

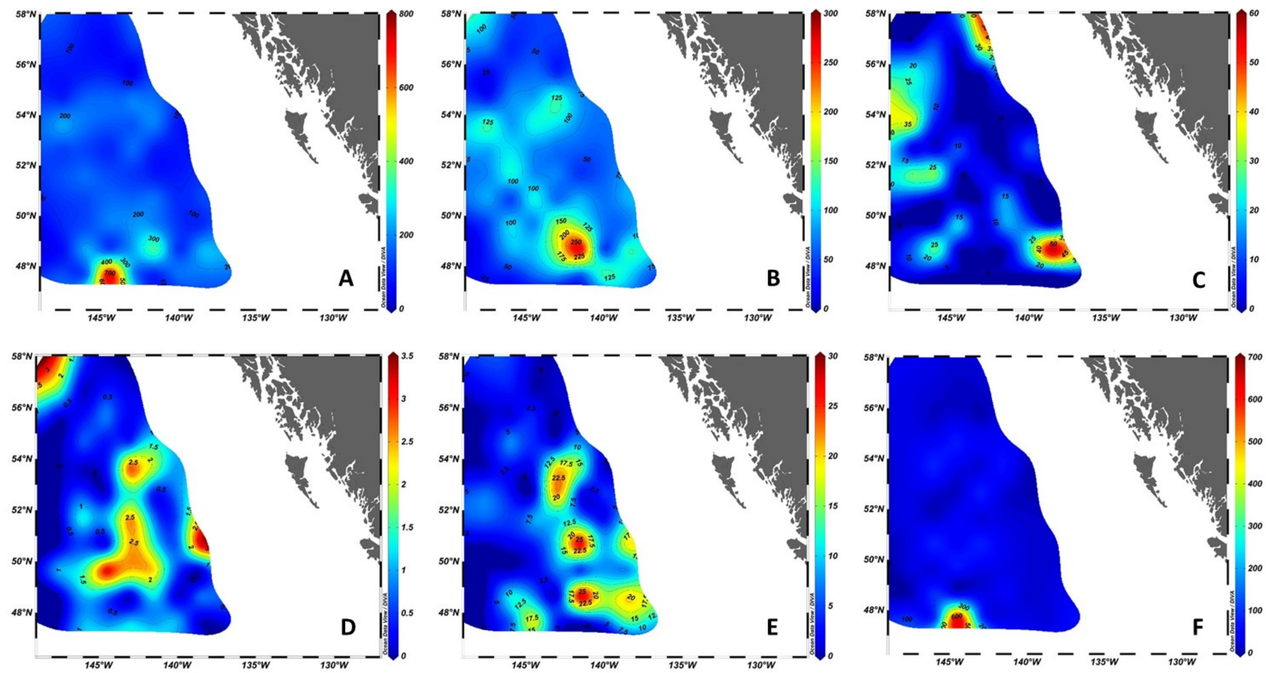

Figure 13. Epipelagic biomass (mgWW.m^{-3}) of total zooplankton (A), copepods (B), euphausiids (C), pteropods (D), hydromedusae (E) and chaetognaths (F) during February–March 2019 in the Gulf of Alaska.

The Bongo net samples were not analysed at sea and treated as follows:

Net 1 of the Bongo was preserved in a 4% formaldehyde seawater solution. At stations 3, 4, 7, and 16 the Net 1 sample was split in two and one half was preserved in 4% formaldehyde and the second half in 95% non-denatured ethanol. These samples are retained for detailed taxonomic analysis.

Net 2 was size fractionated using a sieve set of 4000, 2000, 1000, 500 and 250 µm. Individual organisms in the 4000 µm fraction were measured and transferred to numbered eppendorf tubes or wirlpak bags. We endeavoured to collect triplicate samples of three large calanoid copepods (*Neocalanus* sp.) from as many stations as possible, taking specimens from the 2000 µm fraction when there were none in the 4000 µm fraction. At some stations, this was not possible due to a lack of large calanoid copepods. The remainder of the size fractions were transferred in their entirety to numbered wirlpak bags. All net 2 samples were immediately transferred to a -40ºC blast freezer, and 12 hours later to a -40ºC storage freezer.

Net 2 samples were transferred to UBC at the end of the voyage. Most of the samples were stored at -20ºC. These samples are available for isotope, lipid, and energetic analysis. A subset will be stored at -80ºC to be suitable for fatty acid analysis (Samples from Station 3, 7, 8, 10, 12, 14, 19, 21, 22, 25, 26, 29, 31, 36, 43, 45, 54, 58). Stable isotope and fatty acid analyses are described in detail in the report on Biogeochemical Analysis of Food Webs. All size fractions and size fraction components will be weighed and measured to the nearest 0.01 mg prior to biogeochemical analysis. The resulting biomass dataset will be made available to the IYS GoA database.

ADDITIONAL SAMPLING

Particulate Organic Matter (POM) Carbon and Nitrogen Isotopes

These samples were collected at every grid station to (a) provide an isotope baseline for the Gulf of Alaska for application in trophic studies; (b) identify spatial variation in isotope signatures that can be used to trace salmon movement; and (c) validate existing predictive models for Gulf of Alaska isotopes (ISOSCAPES).

Sample collection procedure: approximately 5L of water was collected from the sea surface (~ 2m depth), using the Rosette, at every station. 2000ml was filtered onto a pre-combusted 25mm GF/F filter; and another 2000ml was filtered onto a pre-combusted 25mm GF/F filter and ACIDIFIED by immersion in 1M HCl for 30 seconds on the filter holder. After acidification, the sample was rinsed with 0.7 µm filtered seawater and dried by applying vacuum pressure to the filter. Each filter was transferred to its own Aluminum foil envelope and stored at -20ºC. Samples will be stored at UBC at -20ºC until processing.

Food web biogeochemistry

Stable carbon and nitrogen isotopes and fatty acids of all components of the pelagic food web in the Gulf of Alaska, representative of sub-regions identified based on physical, chemical and biological variables were collected whenever possible (usually at every grid station).

Sample collection included (all samples will be stored frozen at UBC until the time of analysis):

1. Particulate Organic Matter (POM) – collected at the sea surface using a Niskin rosette at every station (see above).
2. Zooplankton – collected using a Bongo net hauled through the upper 250 m of the water column (see above). Samples were split into size fractions and the largest size fraction (> 4 mm) spilt into species. The majority of samples will be stored at -20ºC but a subset will be stored at -80ºC to be suitable for fatty acid analysis.
3. Trawl salmon and bycatch – representative samples of all species in the trawl catch were collected at every station during the survey. The majority of samples will be stored at -20ºC but a subset will be stored at -80ºC to be suitable for fatty acid analysis.

Environmental DNA

Environmental DNA (eDNA) analysis uses the free DNA shed from organisms and available in the environment to assess fish species diversity and composition. Water samples for eDNA analysis were collected at all 58 stations throughout the cruise using a Niskin bottle mounted on the CTD rosette that was deployed just below the surface at approximately 2–4m of depth. Two litres of subsurface water (~ 2m; in duplicates) were filtered through a Sterivex filtration column and immediately frozen until further analysis in the Pacific Biological Station, Nanaimo. In addition, the eDNA database will provide overall composition of micronekton and zooplankton allowing estimation of salmon prey preferences.

PELAGIC TRAWL

Pacific salmon

Salmon were caught in 48 of the 58 stations fished (Figure 14). Overall, 425 salmons were caught and the largest catches corresponded to the southcentral part of the grid survey (Figure 14F). Chum salmon was the most common species encountered (n=223) and were also encountered in the most sets (81%, Figure 14A). Coho salmon were the second most common salmon species (n=95) with most (95%) caught south of 52ºN (Figure 14B). Conversely, the 73 sockeye salmon were primarily caught north of 52 ºN (84%, Figure 14C). Catches of Chinook and pink salmon were the lowest in the expedition with 3 and 31 caught respectively (Figure 14D, E).

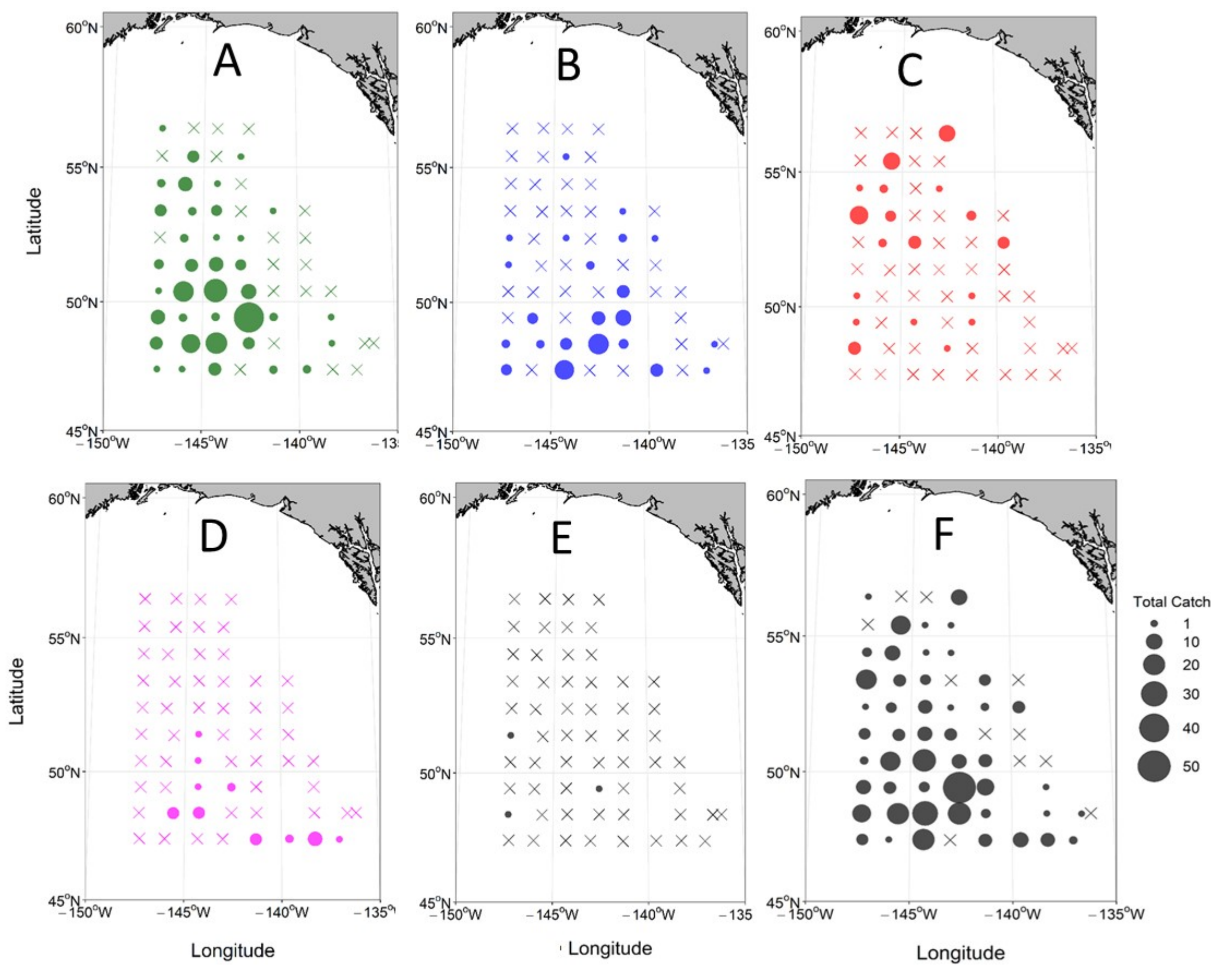

Figure 14. Salmon catches: (A) chum; (B) coho; (C) sockeye; (D) pink; (E) Chinook; (F) all five species; during February–March 2019 in the Gulf of Alaska. An 'x' indicates zero catch.

The size of salmon caught ranged from a fork length of 25 cm (chum salmon) to 75 cm (Chinook salmon). The largest salmon caught were Chinook salmon (>71 cm fork length) and the smallest salmon were chum salmon (~24 cm fork length). Based on length data, multiple age classes of chum, sockeye and chinook salmon were caught in the survey (Figure 15). Scale and otolith analysis will be conducted to verify ages of these salmon.

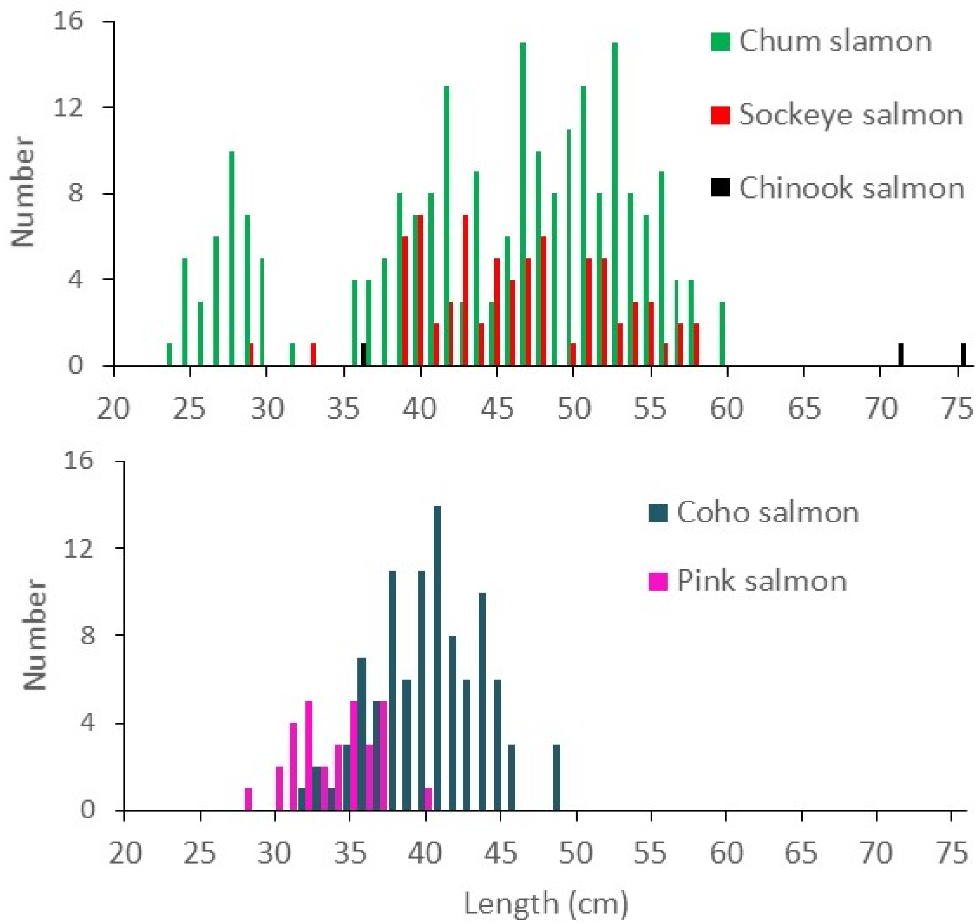

Figure 15. Length frequency of Pacific salmon caught in the Gulf of Alaska expedition February–March 2019.

Stomach analysis to examine salmon diet was conducted on all salmon captured during the survey. Preliminary analysis indicted that key diet categories by volume included euphausiids, pteropods, larval fish, and squid. Stomach contents have been preserved (frozen) and will undergo additional analysis in laboratories in Canada and the US.

Abundance and biomass of Pacific salmon

The survey area calculated with the 30-mile buffer (the half of average distance between neighboring stations) totaled 697,500 km^2. Fifty-eight stations are regularly distributed throughout the survey area. It is conditionally accepted that the catch value on each station characterises abundance and biomass of fish, squid and other pelagic animals within the Voronoi polygon calculated for this station. The area of calculated polygons ranged from 10,200 to 16,800 km^2, with an average of 12,000 km^2 (Figure 16).

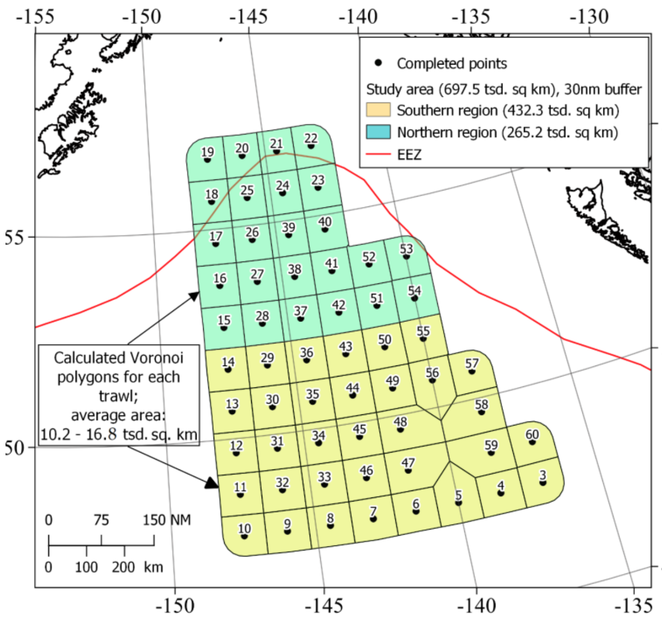

Figure 16. The Gulf of Alaska survey area and integrated survey stations, 21.02–15.03.2019. Red line shows the boundary of Canadian and U.S. exclusive economy zone (EEZ)

Total numbers and biomass of all species in the trawl catches were calculated as a sum of their numbers and biomass within the polygons. Within each polygon, numbers and biomass were calculated as the catch value multiplied by the ratio of polygon area and area swept by the trawl net during one-hour haul divided by species. For some species a group-specific catchability coefficient (q) was applied, e.g., the trawl catchability coefficient for maturing and immature Pacific salmon aged n.1+ or older is 0.3; for juvenile salmon of first marine year is 0.4. For quickly growing pink and coho salmon spending one year at sea, the trawl catchability coefficient equals 0.3 (Table 1). The catchability coefficients for major nekton species are presented in Shuntov & Bocharov (2003) and the pros and cons of applied method analysed in Volvenko (1998, 1999).

Chum salmon *Oncorhynchus keta*

Chum salmon was the most abundant salmon species in the Gulf of Alaska during winter 2019. Chum salmon occurred in almost two thirds of trawl catches, and its numbers and biomass exceeded 50% of total Pacific salmon abundance estimates (Table 1). Based on the size of fish, it appears that chum salmon were represented by all marine-age groups including fish of first marine year. Their abundance calculated with the catchability coefficient q = 0.4 totaled 3.56 million fish. Based on fish size and the relative size of gonads, maturing fish that will return to spawning grounds later this year were not abundant. Their numbers contributed about 3% of the total estimated abundance.

Although chum salmon distribution undoubtedly continues beyond the western limits of the survey area, within the study area chum salmon distribution was the widest latitudinally of any salmon species and covered the entire area. Chum salmon distribution density was highest in vicinity of 50ºN (Figure 17).

Chum salmon occurred in the trawl catches as far south as 46ºN near 130ºW in April 1990 and 43ºN near 150ºW in early May 1990.

Table 1. Frequency of occurrence in trawl catches, estimated numbers and biomass of Pacific salmon species in the upper epipelagic layer (0–30 m) throughout the investigated area in the GoA during winter 2019. q is the catchability coefficient

Salmon species	q	Frequency of occurrence (%)	Numbers (million fish)	Biomass (thousand tons)
Oncorhynchus gorbuscha	0.3	17.2	4.21	1.63
Oncorhynchus keta	0.3	55.2	24.17	26.96
	0.4	20.7	3.56	0.74
	total	63.8	27.73	27.70
Oncorhynchus nerka	0.3	31.0	8.94	10.28
	0.4	1.7	0.10	0.02
	total	31.0	9.04	10.30
Oncorhynchus kisutch	0.3	37.9	13.59	10.37
Oncorhynchus tshawytscha	0.3	5.17	0.37	1.32
All species	total	82.8	**54.95**	**51.33**

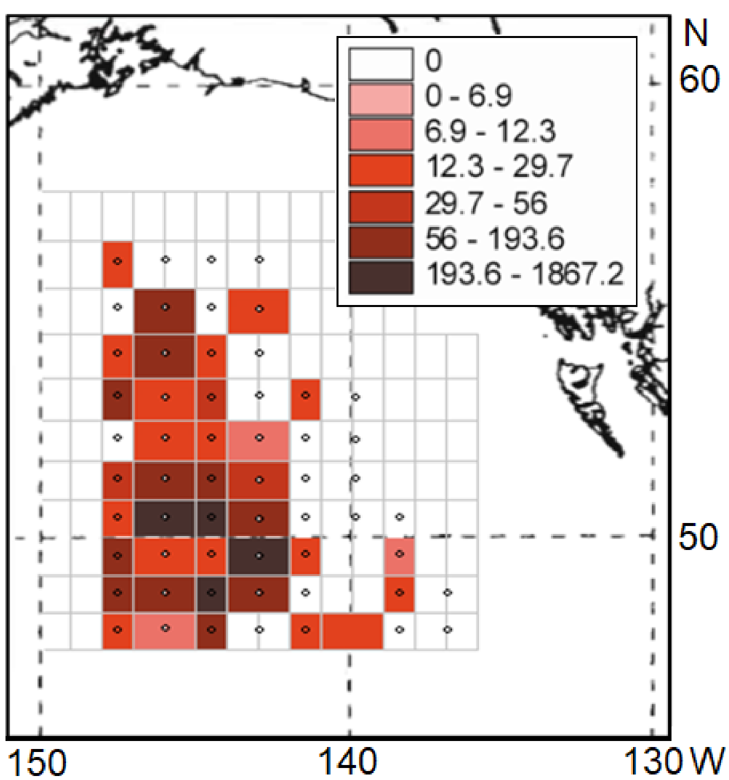

Figure 17. Estimated chum salmon distribution density in the upper pelagic layer in the Gulf of Alaska in winter 2019. The color grade is in fish per km^2.

Coho salmon *Oncorhynchus kisutch*

Coho salmon were the second most abundant salmon species caught during the survey and their density was higher in southern part of survey area (Figure 18). The total preliminary estimated abundance was 13.6 million fish. These catch levels are high compared to prior studies in the region, which reported coho salmon were minor species (Myers et al. 2016).

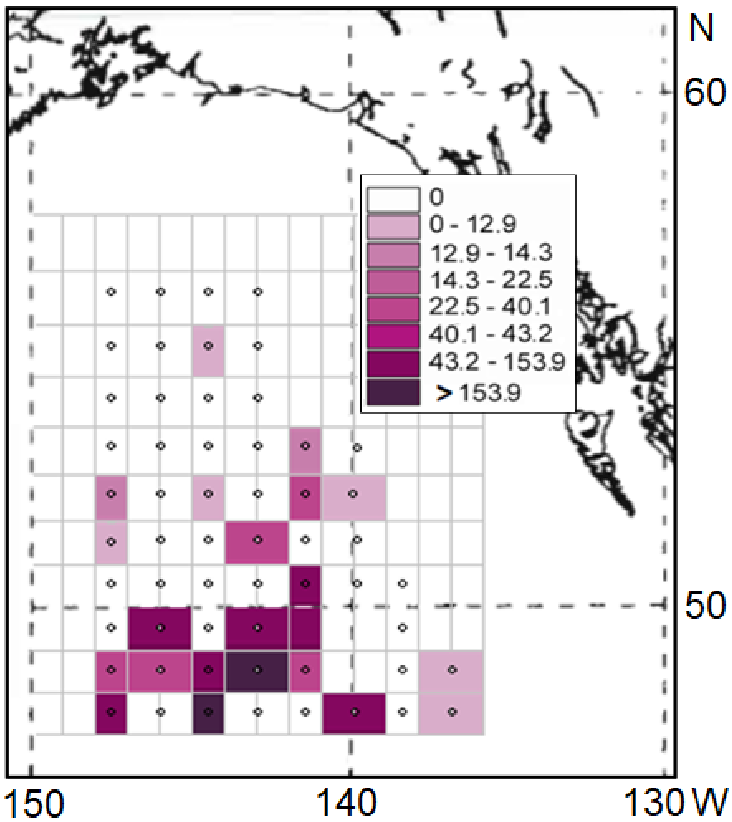

Figure 18. Estimated coho salmon distribution density in the upper pelagic layer in the Gulf of Alaska in winter 2019. The color grade is in fish per km^2.

Sockeye salmon *Oncorhynchus nerka*

Sockeye salmon mostly occurred in the northern part of survey area with SST less than 7ºC. Nine out of ten sockeye catches larger than 1 fish/hour occurred northwards of latitude 52ºN (Figure 19). In the northern part of survey area, sockeye salmon estimated abundance contributed 81.3% of total salmon abundance and 87.0% of total estimated salmon biomass.

Catches of sockeye salmon were somewhat lower than expected given the large size (i.e., millions of adults) of sockeye populations in British Columbia and Alaska that may rear in the Gulf of Alaska in winter. It is possible that some sockeye salmon over winter farther west of our survey area. Survey data in the northwestern Pacific collected by TINRO in 1986-1992 and 2009-2010 also revealed significant sockeye concentrations in the central Pacific Ocean in winter. Sockeye salmon appear to have a Pan-Pacific distribution and need ocean surveys that span the Pacific Ocean to fully understand their distributions, abundance, and condition.

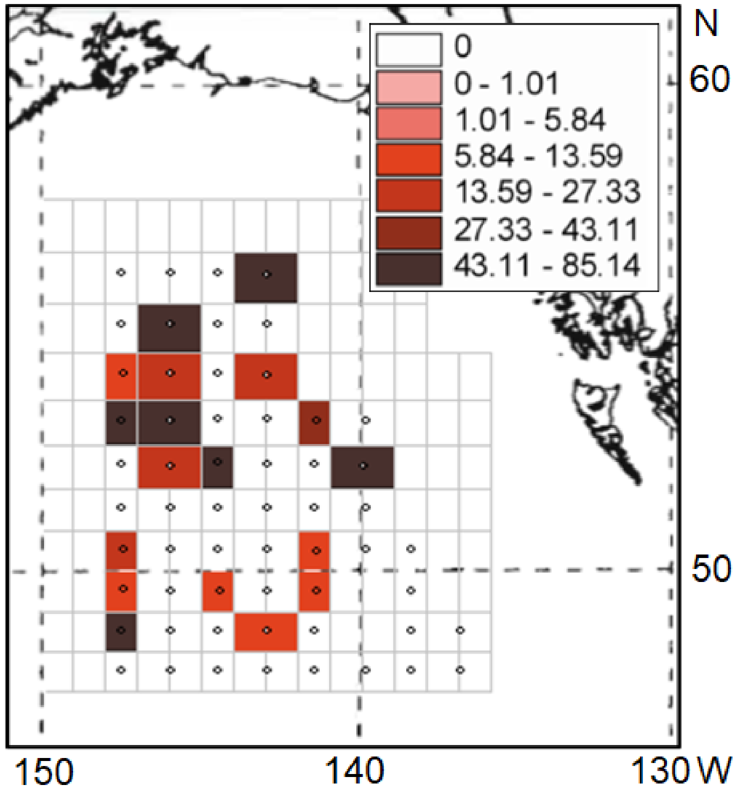

Figure 19. Estimated sockeye salmon distribution density in the upper pelagic layer in the Gulf of Alaska in winter 2019. The color grade is in fish per km^2.

Pink salmon *Oncorhynchus gorbuscha*

Pink salmon distribution density in the upper pelagic layer of the Gulf of Alaska in winter 2019 was low – from 11.4 to 107.4 fish per km^2 (Figure 20). In the north-western and central Pacific Ocean, wintering pink salmon dwell in the vicinity of the Subarctic Current with their main concentrations along both the northern and the southern fronts (Radchenko et al., 2018). During this survey, satellite altimetry data showed a well-expressed branch of the Subarctic Current in the south-eastern corner of survey area (Figure 21), where almost all pink salmon specimens were caught. Based on our survey, pink salmon in February-March mainly dwell along the southern branch of the Subarctic Current, and possibly farther south.

Chinook salmon *Oncorhynchus tshawytscha*

Very few Chinook salmon were caught in the study area (n=3). This is likely because Chinook salmon have the deepest distribution in the water column of any salmon and may not be effectively caught by the near-surface trawl. Catches of Chinook salmon were too low to produce reliable estimates of abundance across the study area. We may only conclude that, in the upper epipelagic layer, Chinook salmon remain widely distributed in winter high seas and likely epitomizes the individual (non-schooling) behaviour postulated for Pacific salmon.

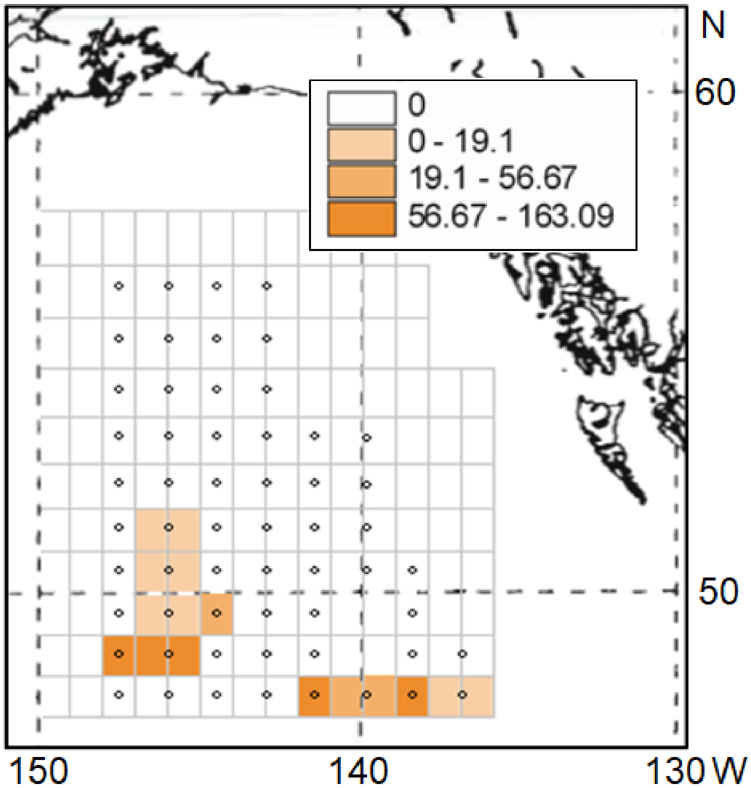

Figure 20. Estimated pink salmon distribution density in the upper pelagic layer in the Gulf of Alaska in winter 2019. The color grade is in fish per km^2.

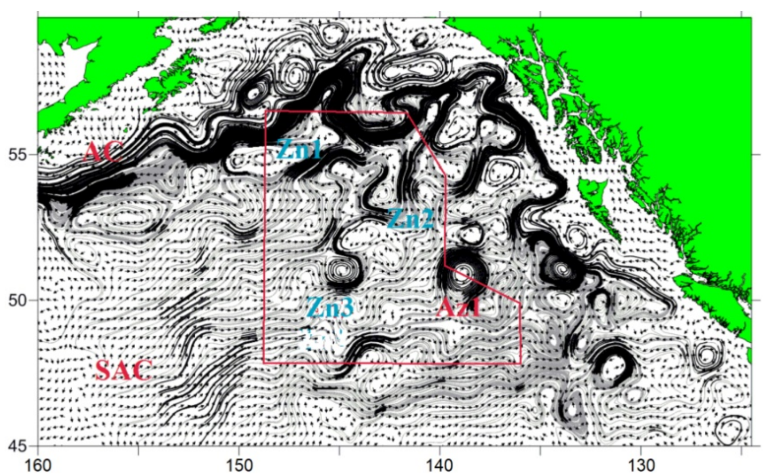

Figure 21. Currents in the Gulf of Alaska in March 2019 based on OSCAR data (https://www.esr.org/research/oscar/) SAC – the Subarctic Current, three cyclonic eddies and one anticyclonic eddy are also indicated

In-field genetic stock identification

Among important objectives of the expedition was the deployment and implementation of an in-field genotype-by-sequencing technology for genetic stock identification by single nucleotide polymorphism sequencing (SNP GSI) of salmon utilizing the Oxford Nanopore Technologies minION third generation sequencer. Such technology is desirable to enable next to real-time information for stock specific management and research approaches. This approach currently relies on high throughput genetic stock identification methods that require samples to be transported to a laboratory for analysis.

Preliminary stock composition analysis suggests that coho salmon stocks dominated by populations residing in the close proximity to the study area. These include the coast of British Columbia, with a largest fraction coming from the northern coastal streams, followed by individuals from the further south (Southern coastal Streams, Queen Charlotte Straight, Johnston Straight and Southern Fjords, and Nahwitti). Other contributing stocks covered a broad geographic range from southeast Alaska to Washington State and the Columbia River. Interestingly, stock composition was largely independent of capture site, suggesting that distant stocks readily mix in the open ocean and do not segregate according to origin. The field-based results will be validated with results replicated at the genomics lab at the Pacific Biological Station, DFO, Nanaimo, BC on the established Ion-Torrent based workflow as well as the data read from one of the coded-wire tagged individuals included in this analysis.

DNA tissue samples were also collected from all salmon species and are being processed by laboratories in Canada, the US and Japan to identify stock origin. These results are expected to be available during 2019. Additionally, thermal marks from the otoliths of chum and pink salmon are being assessed by laboratories in Japan and will provide additional information on stock origin.

Biological sampling of salmon to assess fish health

To assess the health of salmon captured during the expedition, tissue samples from all species, up to ten individuals per trawl, were collected during the expedition with the help of other expedition members. A total of 255 salmon (80 coho, 3 Chinook, 27 pink, 61 sockeye, and 84 chum) were dissected and tissue and blood samples collected. Aseptic tissue samples (gills, brain, heart, kidney, liver, spleen, and muscle) were preserved in RNAlater for later analysis of pathogen burden, stress, and inflammation markers on a high throughput nanofluidics qPCR platform. Additionally, samples from the same tissues, as well as pyloric caeca, were also preserved in formalin for histological analysis. Finally, blood was collected from all individuals for assessment of IGF-1 (growth), stress indices (cortisol, glucose, lactate), ionoregulation (osmolality, ions). All samples will be analyzed utilizing the high throughput pipeline established at the Molecular Genetics Laboratory at the Pacific Biological Station in Nanaimo. These results will corroborate data collected by other researcher on the condition of salmon by providing a molecular insight into the infection and inflammation status of individuals.

Additional muscle samples collected from the salmon will be analyzed in laboratories in Canada and the US to measure the energy density, fatty acid composition and stable isotope values.

Tagging experiment

During the last days of the expedition, two coho salmon were captured by a trial of trawl operation with a live box in the cod end. The live coho salmon (both FL= 420 mm) were tagged with NPAFC disc tags (numbers NA6001 and NA6002) and immediately released in the eastern Gulf of Alaska (48º42'N, 134º23'W) on March 15, 2019 (WGSM 2019).

Catch and abundance of non-salmon fish, squid and macroplankton species

Myctophiid species were the most common non-salmon fishes captured in the survey. The species encountered (Table 2) were caught almost exclusively at night. Samples of these groups of fish have been retained and will be further analyzed in laboratories in Canada and Russia. Other fish caught in the survey are listed in Table 2 and include larger mature fish, including *Squalus acanthias* (Spiny dogfish), to larval samples of *Microstomus pacificus* (Dover sole). Samples of these fish have been retained for further analysis in laboratories in Canada, US and Russia.

More than nine species of squid were identified in the catch although *Boreoteuthis borealis* was the most commonly encountered (Table 2). Similar to myctophiids, these were predominantly caught at night. In addition, several gelatinous species and other invertebrates were documented in the catch. The gelatinous species were numerous, especially at night and in some regions. This group included jellyfish, ctenophores, salps and gelatinous gastropods. Other invertebrates captured included pelagic octopods, euphausiids and shrimp (Table 2).

Trawl catch indicates that beside salmon, very few species are present in the upper epipelagic during the day-time but increase substantially during the night (Table 2). During the day, total biomass of non-salmonid fishes, squid and macroplankton species is less than the salmon biomass itself. At night, the abundance of upper epipelagic layer inhabitants increased by more than 700 times and reached at least one animal per sixteen square meters. Considering the amount of sea nettle *Chrysaora melonaster*, observed from visual observations from the vessel at night and which contributed 89.0% of the group biomass, the estimated abundance is likely an underestimate.

Table 2. Catch, catch weight, frequency of occurrence, estimated numbers and biomass for fish (excluding Pacific salmon), squid and macroplankton species in the upper epipelagic layer (0–30 m) throughout the entire study area in the Gulf of Alaska in winter 2019. Species that were primarily caught during day- and night-time trawls are indicated. q is the catchability coefficient.

Species	Catch number	Catch weight	q	Frequency of occurrence (%)	Numbers (million fish)	Biomass (thousand tons)
Day-time species						
Anotopterus nikparini	1	0.018	*0.3*	*1.7*	*0.14*	*>0.005*
Aptocyclus ventricosus	1	0.057	*0.5*	*1.7*	*0.08*	*>0.005*
Gasterosteus aculeatus	1	0.002	*0.5*	*1.7*	*0.07*	*>0.005*

Microstomus pacificus, larv.	20	0.016	*0.1*	*10.3*	*8.16*	*0.01*
Sebastes melanops	1	3.288	*0.5*	*1.7*	*0.07*	*0.22*
Squalus acanthias	2		*0.5*	*3.5*	*0.16*	*0.72*
Thalassenchelys coheni, larv.	1	0.61	*0.1*	*1.7*	*0.37*	*0.23*
Zaprora silenus	1	0.09	*0.5*	*1.7*	*0.08*	*0.01*
All fish species			total		9.13	1.20
Gonatus madokai	7	0.254	*0.1*	*8.6*	*2.60*	*0.09*
Gonatidae gen. sp.	1	0.001	*0.1*	*1.7*	*0.40*	*>0.005*
All squid species			total		3.00	0.09
Aequorea sp.	26	50.651	*0.1*	*82.8*	*6.96*	*16.97*
Aurelia labiata	77	12.326	*0.1*	*41.4*	*27.63*	*4.21*
Aurelia limbata	2	0.639	*0.1*	*3.5*	*0.74*	*0.24*
Corolla calceola	4	0.003	*0.1*	*5.2*	*1.86*	*>0.005*
Phacellophora camtshchatica	32	44.558	*0.1*	*29.3*	*11.05*	*15.89*
All jellyfish species			total		48.24	37.31
All species			total		**60.37**	**38.60**
Night-time species*						
Diaphus theta	320	1.077	*0.1*	*27.3*	*303.32*	*1.02*
Icichthys lockingtoni	1	0.012	*0.3*	*1.7*	*0.32*	*0.00*
Lestidium ringens	2	0.01	*0.2*	*4.6*	*0.95*	*0.01*
Lipolagus ochotensis	1	0.01	*0.1*	*4.6*	*0.48*	*>0.005*
Paralepididae gen. sp., juv.	10	0.02	*0.1*	*4.6*	*106.05*	*0.21*
Stenobrachius leucopsarus	356	0.319	*0.1*	*31.8*	*317.66*	*0.27*
Symbolophorus californiensis	3	0.022	*0.1*	*9.1*	*3.18*	*0.02*
Tarletonbeania crenularis	5337	12.914	*0.1*	*44.8*	*14,260.59*	*34.57*
All fish species			total		14,992.55	36.10
Abraliopsis felis	12	0.041	*0.03*	*18.2*	*39.50*	*0.13*
Belonella borealis	`1	0.899	*0.1*	*1.7*	*1.00*	*0.89*
Boreoteuthis borealis	1482	25.482	*0.1*	*95.5*	*1,504.42*	*26.62*
Boreoteuthis borealis, juv.	333	0.677	*0.01*	*81.8*	*3,544.26*	*7.46*
Chiroteuthis calyx	12	0.056	*0.1*	*22.7*	*22.54*	*0.07*
Gonatus onyx	104	0.627	*0.1*	*45.5*	*66.70*	*0.39*
Gonatus onyx, juv.	5	0.015	*0.01*	*9.1*	*52.22*	*0.16*
Gonatus sp.	1	0.003	*0.1*	*1.7*	*1.06*	*>0.005*
Japetella diaphana	1	0.006	*0.1*	*1.7*	*0.95*	*0.01*
Moroteuthis robusta	1	1.07	*0.1*	*1.7*	*0.22*	*0.24*
Onychoteuthis borealijaponica	288	17.271	*0.1*	*68.2*	*262.73*	*15.52*
All cephalopod species			total		5,495.60	51.49
Calycopsis sp.	30	0.087	*0.01*	*36.4*	*284.48*	*0.81*
Chrysaora melonaster	5886	1451.85	*0.1*	*51.7*	*5,021.54*	*1,233.49*
Hormiphora cucumis	548	10.157	*0.1*	*37.9*	*507.02*	*10.55*
Periphylla periphylla	11	0.013	*0.1*	*3.5*	*11.52*	*0.01*
Salpa sp.	23151	79.162	*0.1*	*15.5*	*15,988.21*	*52.61*
Sergestes similis	39	0.01	*0.1*	*3.5*	*303.33*	*0.08*
Siphonophora gen. sp.	1	0.007	*0.1*	*1.7*	*1.43*	*0.01*

Thysanoessa spinifera	4779	0.477	*0.1*	*5.2*	*44.88*	*0.01*
All other macroplankton					22,162.41	1,297.57
All species			total		**42,650.56**	**1,385.16**

Remark: *Some species were caught during both day- and night-time trawls. However, because their abundance was several orders of magnitude higher at night than during the day, they are included in the night-time species list. Their numbers and biomass are calculated by night-time trawl sets only, while frequency of occurrence calculation based on the whole survey sets. The list of such species includes *Icichthys lockingtoni, Tarletonbeania crenularis, Belonella borealis, Gonatus sp., Japetella diaphana, Moroteuthis robusta, Periphylla periphylla, Calycopsis sp., Chrysaora melonaster, Salpa sp., Hormiphora cucumis, Siphonophora gen. sp., Sergestes similis, and Thysanoessa spinifera*

SUMMARY

This document provides preliminary findings of the GoA winter (February-March) 2019 expedition. This survey is first of its kind in this part of the North Pacific and established a baseline of environmental and ecosystem-level measurements for future comparisons. The success of the collaborative research initiative is clear and should serve as an example for future international expeditions. Catches of salmon showed large spatial variation across study area. Species differences may be the strongest signal. For example, pink salmon had limited distribution and low numbers, while coho salmon were encountered in higher numbers across the survey area. Those two species dominated salmon catches at the southern and westerly stations. By contrast, sockeye salmon was mainly caught in the coolest waters (northern parts) of the survey. Chum salmon were widely distributed but varied in their body condition both within a set and between sets with individuals of low weight (skinny) and more robust (normal condition) fish encountered. North-south differences in salmon species distributions appeared to correlate with the environmental characteristics of water masses as well as productivity, mesozooplankton composition and macroplankton/micronekton distributional patterns.

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Attachment 2.

Preliminary Findings of the Second Salmon Gulf of Alaska Expedition Onboard the R/V *Pacific Legacy* March 11–April 7, 2020 as Part of the International Year of the Salmon

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Preliminary Findings of the Second Salmon Gulf of Alaska Expedition Onboard the R/V *Pacific Legacy* March 11–April 7, 2020 as Part of the International Year of the Salmon

by

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Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

Russia[1], Canada[2], and USA[3]

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Abstract

The second expedition to study the mechanisms that regulate the production of Pacific salmon in general and returning to North America in particular covered an area of approximately 648,000 km^2 between March 11 and April 7, 2020 with an international research team of 12 scientists from Canada, Russia and the United States. The expedition leaders, Dr. Richard Beamish and Dr. Brian Riddell of Canada, secured funding for this expedition from governmental, industry and private individuals. A major objective was to determine if the high-seas catches could be used as an early indication of future returns to the North American rivers. In total, 566 salmon (234 Chum salmon, 118 Coho salmon, 51 Sockeye salmon, 136 Pink, 26 Chinook salmon, and 1 Steelhead trout) were caught during the trawl survey. The total catches were larger but more patchy than in the 2019 expedition. There were larger catches of immature first winter fish of several species which complicates the comparison between years, but provides larger samples needed to test hypotheses that the early ocean growth is the major factor regulating salmonids production. Oceanographic analyses need to be completed to help explain the distributions and differences between 2019 and 2020 surveys. These two expeditions were the first major studies of the winter ecology of Pacific salmon in decades and were in association with the International Year of the Salmon, which is planning a third study in 2021. Together, these expeditions highlight the need for continued international research to identify the mechanisms that regulate the production of Pacific salmon rearing in the Gulf of Alaska.

Keywords: Pacific salmon, Sockeye salmon, Chum salmon, Pink salmon, Coho salmon, Chinook salmon, Steelhead trout, myctophids, pelagic community, squid, winter salmon ecology, *Tarletonbeania crenularis*

Introduction

This is the second, privately organized study of the factors affecting the production of Pacific salmon in the Gulf of Alaska in the winter. The first expedition in the Gulf of Alaska in February–March 2019 (Pakhomov et al., 2019) was the first comprehensive study of the factors affecting the production of Pacific salmon in the winter in the Gulf of Alaska, where many Pacific salmon, including most salmon originating from British Columbia, spend their winter. Winter is the least studied and thus least understood period in the life history of Pacific salmon, yet it is believed to be a time when their abundance is strongly affected. There is a general understanding that ocean and climate conditions are major factors regulating salmon abundances. However, the reasons for increasing and decreasing trends in abundance are not known (Beamish et al. 2004). Thus, there is a critical need to study Pacific salmon in winter in the open ocean to identify the fundamental mechanisms regulating salmon production and increase accuracy of forecasts. The International Year of the Salmon was established to demonstrate the opportunities for discovery by working together as a team of international researchers (NPAFC Special Publication No. 1). The first expedition and this second expedition are part of this international effort.

The second International Gulf of Alaska winter expedition was carried out in March–April of 2020. This survey was a continuation of the first scientific effort. The main goals were to gather information on salmon winter ecology including stock specific biomass estimations, spatial distribution, biological (fish health, food availability, and species interaction) and oceanographic conditions. The specific objectives for the second Gulf of Alaska winter expedition as outlined in Beamish and Riddell (2020) were as follows:

a) To determine if the winter abundance of Pacific salmon in the Gulf of Alaska is an early indication of future adult returns to rivers on the west coast of Canada and the United States;

b) To test hypotheses that the abundances of adult Pacific are strongly influenced by an ability to survive the first ocean winter;

c) To assess this unknown portion of the life cycle of Pacific salmon and the factors determining the variability of production of Pacific salmonids in the North Pacific;

d) To establish a greater research capacity and network of international scientists to determine the mechanisms that regulate the production of Pacific salmon in a future of changing ocean ecosystems.

This is a preliminary report of the results of the second expedition with a brief comparison of results of the two expeditions. Analyses of the first expedition are continuing and just beginning for this second expedition. It is planned to have participants of both expeditions meet sometime in the future when it is safe (COVID-19 impacts) to finalize the interpretations and prepare a final peer reviewed report. All participants agreed that all data collected will be publicly available.

Materials and Methods

Survey logistics

A trawl survey focused on overwintering Pacific salmon was conducted in the Gulf of Alaska (GoA) from March 11 to April 7, 2020 onboard the 37 m long chartered trawler *Pacific Legacy*. The survey area covered ~648,500 km^2 (Figure 1). The expedition was supported through private fundraising by R.J. Beamish and B. Riddell with support primarily from the commercial fishing industry and private donors as well as some support from governmental and academic institutions. An international science crew consisted of twelve specialists: six from Canada, three from the USA and three from Russia. The science team included experts on Pacific salmon, other associated fishes, plankton and oceanography.

The survey area and sampling protocols followed the NPAFC Documents 1807 Rev. 1, 1808, and 1870 (Beamish, Riddell 2020, NPAFC 2018, Somov 2018). The field sampling was designed to maximize processing of samples at sea. The expedition was divided into two legs with a midway port call in Prince Rupert, BC. Station sampling order was determined based on 2019 GoA expedition catch data and weather systems. The first leg (March 11 to 25) covered the southern part of the study area and focused areas where the largest catches of Chum salmon, Pink salmon and Coho salmon were encountered in 2019. The second leg (March 26 to April 7) was intended to target the northern GoA where the largest catches of Sockeye salmon had been encountered in 2019 and with added stations within the USA Exclusive Economic Zone EEZ (US EEZ). However, the departure of USA scientists (due to the COVID-19 pandemic at the port call in Prince Rupert) meant that the fishing permit to operate in the US EEZ was void. Augmented by bad weather conditions in the northern GoA, the northern stations were cancelled. Consequently, the observations during the second leg focused on the southeastern GoA with replication of high catch stations and with fishing south of the original study grid. This focus on the southern stations allowed a greater effort to try to locate abundances of pink salmon which were not in the northern area of the 2019 survey. In total, 49 stations and 52 trawl sets were completed in the main research area with an average distance between stations of 60 nmi (Figure 1).

The typical survey stations conducted during both daylight and night times consisted of:

(1) CTD and water samples to 300m using Niskin bottles with messengers
(2) Environmental DNA (eDNA) water sample from 3–5 m depth
(3) Bongo net (0.5 m^2, 250 µm mesh) vertical tow down to 250 m
(4) Juday net (0.1 m^2 mouth area, 160 µm mesh) vertical tow down to 200 m
(5) Surface trawl net and deeper trawl net set
(6) Fish behaviour observation using GoPro cameras attached to net
(7) Acoustic recording – ongoing throughout expedition
(8) Marine mammal and bird recording – ongoing throughout expedition

CTD deployment and processing

At each station a SeaBird 19 CTD equipped with fluorescence and oxygen sensors was deployed to 300 m depth at 1 m s^{-1}. Data were processed onboard and binned into 1 m depth intervals.

Water sample collection

In conjunction with each CTD, water was collected using Niskin bottles at 3.5 m, 5 m, 25 m, 50 m, 100 m, and 300 m depths. The 3.5 m sample was exclusively used for eDNA analysis (4000 ml). Nutrient samples (13 ml) were collected from all other depths. In addition to nutrients, water samples from 5 m depth were collected for phytoplankton pigments (HPLC; 2000 ml), phytoplankton taxonomy (200 ml), and Particulate Organic Matter (POM; 4000 ml). At some stations only 3.5 m and 5 m water samples collected due to sea conditions.

Oceanographic water processing

Samples were taken below deck for onboard processing, within 30 minutes of collection. For HPLC, water was stored in dark bottles until filtration when 2000 ml was filtered through a 0.7 mm Whatman GF/F 47 mm filter. Filters were immediately transferred to a cryo-vial, flash-frozen in liquid nitrogen, and transferred to dry ice for long-term storage. Samples for phytoplankton taxonomy comprised 200 ml of water preserved with 6 drops of Lugol's solution. POM samples comprised replicate 2000 ml samples were filtered onto different pre-combusted Whatman GF/F 25 mm filters. After filtration, 2.5 ml of 1 M HCl was added to one of the filters and let to stand for 30 seconds before draining and rinsing the funnel with filtered seawater. Each filter was folded in half within a piece of tinfoil and stored in the -20 °C freezer. Nutrient samples (13 ml) were stored in the -20 °C freezer immediately post-collection. POM samples are designated to be analyzed for carbon / nitrogen content and stable carbon and nitrogen isotopes.

eDNA water processing

Samples were processed immediately after collection in 10 L carboys. To collect eDNA, sample water was filtered through duplicate 0.22 µm Sterivex filters (EMD Millipore) by using a peristaltic pump with a 10 ml single-use plastic pipettes inserted into the carboy connected to re-usable tubing. After filtering 2 L of water through each filter, the filter ends were dried by pumping air through them. Finally, the filters were closed with a Luer-Lock adapter on one and Hemato-Seal on the other port, wrapped in parafilm, placed in small whirl packs and kept at -80 ºC until DNA extraction. All bench work was conducted in a sterile, clean environment and all tubing and collection bottles were cleaned between sites using 2% NaOCl for 20 min, followed by rinsing with dH2O, rinsing in 0.1 mM sodium thiosulfate, and a final rinsing with dH2O.

Bongo net zooplankton collection

Zooplankton were collected using a bongo net at each oceanography station. The net (250 µm mesh, 50 cm diameter) was deployed to a depth of 250 m and retrieved vertically at 1 m s^{-1}. Volume filtered was determined using General Oceanics flowmeters by multiplying effective distance travelled (m) by the mouth area (m^2). At some stations the bongo net was not deployed due to marine conditions.

After deployment, the bongo net contents were rinsed down into the cod end. Using filtered seawater, samples from one cod end were rinsed into a jar and preserved in 4 % formaldehyde for future taxonomic analysis. The other cod end was rinsed into a sieve and transferred below deck where it was subsequently size fractionated (250–500 µm, 500–1000 µm, 1000–2000 µm, 2000–4000 µm, and >4000 µm) onto pre-weighed and pre-combusted 47 mm GF/F filters. Individuals larger than 4000 µm were identified to species level, measured, and transferred to individual Eppendorf tubes. All size fractionated zooplankton samples were stored on dry ice.

Juday net zooplankton collection

To ensure comparability with previously obtained data in Russian high-seas expeditions zooplankton was also sampled at each station using the Juday net with mouth area 0.1 m^2 and filtering mesh size 0.168 µm. Vertical tows 0–200 m were conducted at every station. The net was towed at a speed ~1 m/sec. Samples were preserved in 4% formalin for further laboratory analysis (Volkov, 2008).

Trawl operations

Trawl sets conducted using the NPAFC 1142 research trawl net with a 3 mm codend mesh size. This new net was built to have an opening similar to the RT 80/396 trawl (10 mm codend mesh) net used by northwest Pacific high-sea research in Russia and used during the 2019 GoA expedition and the net fished by NOAA in coastal surveys in Alaska that is proposed to be used by the US team in the 2021 expedition (NPAFC Doc. 1922 (Rev. 1)). The net was designed to be fishable from the Canadian new research vessel CCGS Sir John Franklin. The net was constructed with support of the IYS research plan for 2021 surveys. To keep the effective trawl opening near the surface, two large floats (72 cm in diameter each) were attached to the headrope with two pairs of smaller floats (39 cm in diameter each) attached to the wing tips. To increase the vertical opening of the net, two chains (272 kg) were attached to the footrope. Thyboron type 15 trawl doors (4.5 m^2 and 1135 kg each) were attached to the trawl via 46 m door legs rigged in a configuration to sustain horizontal opening. Declared opening of this net (according to supplementary documentation) was 45.7 m in horizontal and 30 m in vertical directions. The actual vertical opening (measured using 2 RBR sensors attached to both head- and footrope) was typically 18–22 m during surface sets and 8–10 m during deep sets (at 30 m headrope depth). Horizontal opening was not measured directly, and calculated using the formula designed for the similar RT 80/396 trawl:

$$a = \frac{v^{0,83514} \cdot l^{0,91807}}{1,01031^{b} \cdot 1,17307^{v} \cdot (h+1)^{0,02745} \cdot 1,32616^{(\lg l)^2}}$$

where a – horizontal opening (m), b – measured vertical opening (m), v – trawling speed (kt), h – headrope depth (m), l – warp length (m) (Shuntov, Bocharov et al. 2006)

Where repeated high salmon catches were encountered during a surface set, a deeper set was also carried out to increase the number of samples. Three deep sets were performed over the course of the expedition.

Throughout the survey, the average calculated horizontal opening range was 42–45 m for surface sets and 50–51 m for deep sets; average trawling speed was 4.9–5.2 knots; warp length averaged 245 m for surface trawls and 391 m for deeper sets; averaged swept area using estimated horizontal opening was 0.40 km^2 for surface trawls and 0.43 km^2 for deeper trawls; trawl mouth opening averaged 650 m^2 for surface trawls and 394 m^2 for deeper trawls; filtered volume averaged $6.1*10^{-3}$ km^3 for surface trawls and $3.5*10^{-3}$ km^3 for deeper trawls.
For comparison, during 2019 expedition averaged technical trawl parameters were the following: horizontal opening - 38.4 m, vertical opening - 32.2 m, speed - 4.4 knots, warps - 250 m, swept area

- 0.31 km^2, trawl mouth opening - 969 m^2 and filtered volume - $7.8*10^{-3}$ km^3. Technical parameters of each trawl are represented in table 4.

Catch processing

All salmon and bycatch species were processed immediately following each trawl. All salmon were identified to species, fitted with a floy tag on the caudal peduncle (to identify the specimen) and measured for fork length, standard length, and weight. Numerous samples were taken from each salmon: fin clips for genetic analysis; scales for ageing and growth rate; otoliths for ageing and early marine growth, checking for hatcheries marks and tags; muscle samples for energy density, lipids, stable isotopes, fatty acid analyses and stomachs for diet analysis. A subsample of the salmon catch (up to 15 specimens per species per trawl) was processed for fish health diagnostics. Non-salmon nekton species were identified, enumerated, measured, and a subsample was frozen or preserved in formaldehyde for subsequent laboratory analyses in Canada and Russia. Micronekton (mesopelagic fish, squid) and jellyfishes were identified to the species level, counted, measured, weighed, and a subset preserved for subsequent lab analyses.

Trawl bycatch and salmon biogeochemistry sampling

Muscle samples for stable isotope and fatty acid analyses were collected from up to 100 individuals per salmon species per set. Stable isotope samples were preserved in a -20°C freezer and the fatty acid samples were preserved on dry ice.

Stable isotope and fatty acid samples were also collected from most bycatch species from most trawls. If individuals were small (< 20 cm), up to 10 individuals from each size class from a trawl were collected for isotopes and up to five individuals from each size class were collected for fatty acid analysis. If individuals were large (≥ 20 cm), a piece of the muscle was taken for isotope and /or fatty acid analyses. Isotope samples were preserved in the -20 °C freezer and fatty acid samples were preserved on dry ice.

Samples of non-gelatinous micronekton were collected for all common species for traits analysis (morphological traits - body shape and size, categorized behavioral traits – diel vertical migration). Up to 10 individuals per species were preserved in the -20 °C freezer.

Salmon health sampling

Up to 15 salmon per set, 145 salmon total during the expedition, were dissected in an aseptic environment to assess the health of Pacific salmon during the winter. Tissue samples from gill, heart, kidney, spleen, pyloric caeca, liver, muscle, and brain were preserved in RNAlater. These samples will be tested for the presence of pathogen nucleic acid and host gene expression using a high throughput qPCR screen on the Fluidigm microfluidics platform (Miller et al. 2016). Tissue samples from gill, heart, anterior and posterior kidney, spleen, pyloric caeca, liver, muscle, and brain were preserved in 10% neutral buffered formalin for future histopathological evaluation. Additionally, tissue samples from the head kidney were frozen for analysis of key pathogens, blood samples were collected for analysis of IGF1 were frozen for parasite studies. All processed carcasses and whole body carcasses of salmon that were not sampled were frozen whole for additional analysis in the laboratory.

Salmon and nekton abundance estimations

Total salmon and nekton abundance and biomass were calculated using the formula:

$$N (B) = Q * S / 1,000,000$$

where N, B is the number and biomass of species (thousand tons and million fish); Q is the average distribution density of species within the survey area (individuals or kg per km^2); and S is the survey area (km^2). The distribution density index Q is calculated using number and weight of each individual species in the given catch (n or b), the trawl swept area (s), and the catchability coefficient of the species (k) according to the formula: $q = n (b) / k * s$. For more details on the applied method see two technical reports (Volvenko 1999, Volvenko 2000). Catchability coefficients for major nekton species are presented in a series of Atlases issued by the TINRO-Center (Shuntov, Bocharov et al. 2003) and will need to be adapted to the survey on the *Pacific Legacy*. Given the 3 mm mesh size in the NPAFC 1142 trawl codend, catchability coefficients for individuals less than 2 cm in length (e.g. squid juveniles, myctophids) were restricted to 0.1 (Table 3). Trawl catchability coefficient for maturing and immature Pacific salmon aged n.1+ or older was 0.3, and most juvenile salmon in their first marine year had a catchability coefficient of 0.4. However, quickly growing Pink salmon and Coho salmon spending one year at sea had a trawl catchability coefficient equal to 0.3 (Table 1).

Salmon diet analysis

Stomach contents were collected and analyzed onboard following an express method (Чучукало, Волков 1986; Чучукало 2006; Volkov 2008). In short, 10–20 stomachs from each salmon size group (<30, 30-40, 40-50, >50 cm) were collected and the fullness of each stomach was estimated (from 0 – empty to 4 – very full). The stomach contents were weighed and identified to the lowest taxonomic level possible and the digestion state was estimated visually (from 1 - fresh food to 4 - completely digested). Diet composition was visually estimated, and nekton and planktonic components were weighted separately. The feeding intensity index (ISF) was calculated as weight of the stomach contents divided by fish weight and multiplied by 10,000 (Volkov 2008). To ensure the accuracy of the onboard analysis, individual stomach contents were frozen and kept for laboratory confirmation at UBC. To calculate condition factor (CF) we used Fulton's formula: $CF=W*100000/FL^3$, where W - weight, g, FL - full length, cm.

Salmon scale analysis

To estimate the marine age of salmon, scale analysis was done onboard for Sockeye salmon, Chum salmon, and Chinook salmon. Since Coho salmon and Pink salmon spend only one winter in the ocean, their scales were not analysed. Several scales of each fish (2-4) were placed between two microscope slides. Photos of scale samples for fish larger than 35 cm fork length (FL) were taken through a microscope. Marine age was estimated by counting ocean annuli separated by narrow, closely-spaced circuli. Salmon less than 35 cm FL were assumed to be first ocean winter. Salmon that are caught in the trawl net lose many of their scales which results in most scale samples not taken from the preferred area (above or below lateral line between dorsal and anal fins). Consequently, it was not possible to estimate freshwater age and only marine age was distinguished. Thus, for species that spend several years in both freshwater and ocean (Sockeye salmon, Chinook salmon) age was defined as n.1, n.2 etc., where n – is unidentified freshwater age, and digit – marine age. The age of Chum salmon, which spend less than one year in freshwater, was defined as 0.1, 0.2, etc.

Additional activities

Additional sampling and procedures conducted during the survey included documentation of marine mammals and birds (continuous), underwater video recording of fish behaviour within the trawl net, and video recording of marine mammals during daylight hours (GoPro cameras).

Sampling data entry and organization

All data collected in this second expedition will be available through the Tula Foundation and Hakai Institute (NPAFC Doc. 1913 Rev. 3 2020) with arrangements within the Global Ocean Observing System (GOOS) which will be identified as IYS-GOOS.

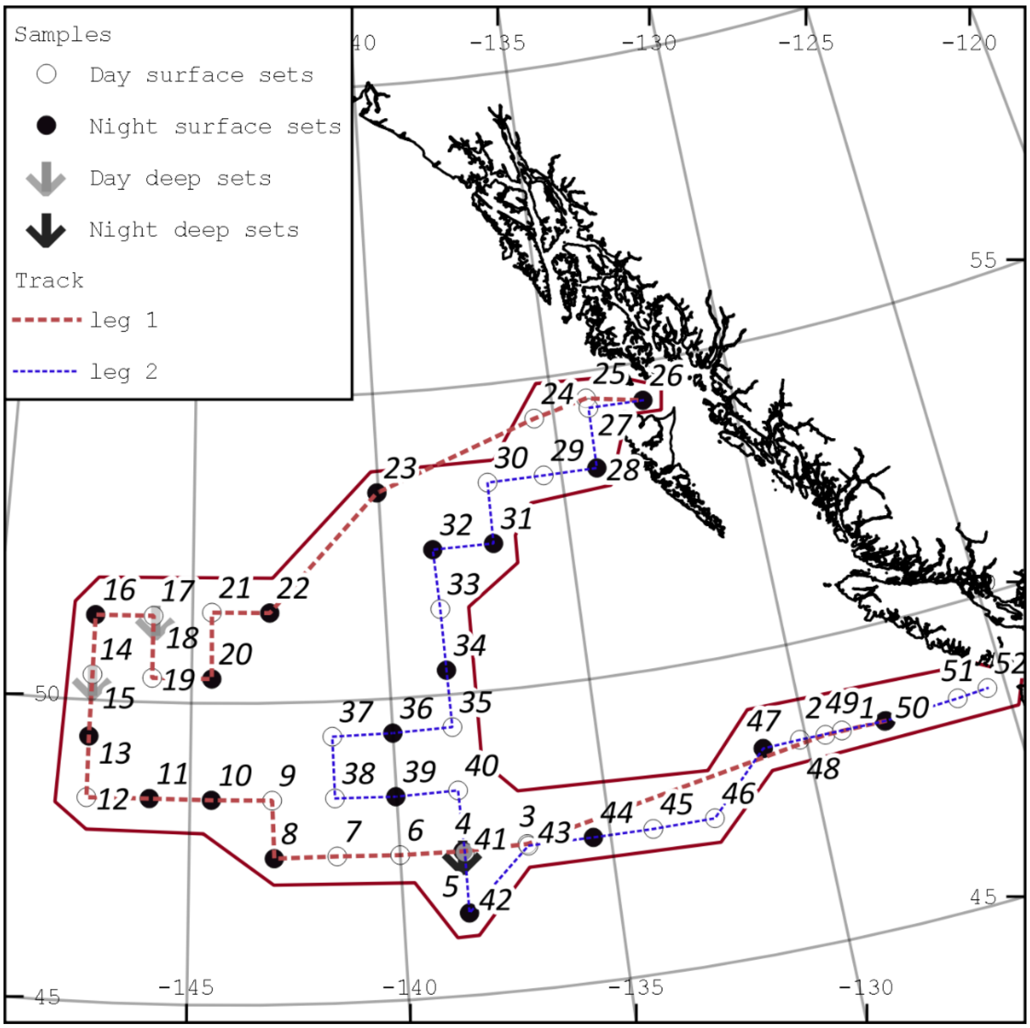


Figure 1. Expedition stations sampled during March-April 2020 in the Gulf of Alaska.

Preliminary findings

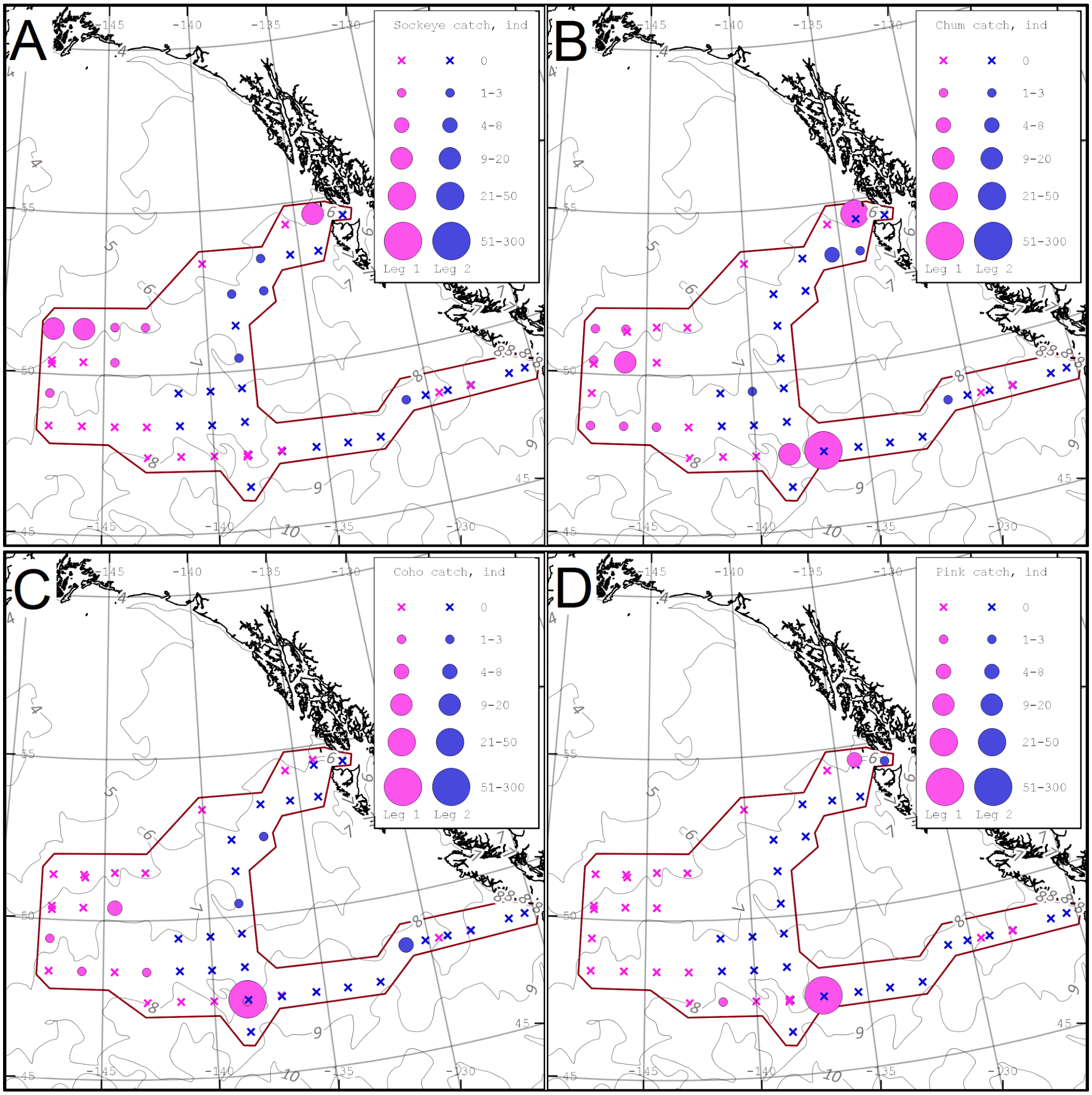
Pacific salmon

Salmon were caught in 29 out of 52 trawl sets (Figure 2). Of the 52 sets completed in 2020, 49 were surface trawls and salmon catches from those trawls were used to estimate average catch, frequency of occurrence, and total abundance and biomass (Table 1, Table 3). In total, 566 salmon were caught, including 234 Chum salmon, 118 Coho salmon, 51 Sockeye salmon, 136 Pink salmon, 26 Chinook salmon and 1 Steelhead trout. Despite fewer trawls in 2020 (n=52) compared to 2019 (n=58), 140 more salmon were caught. Salmon distribution in 2020 was very irregular, with the majority of specimens (n=397, 70%) being caught during two trawls (Figure 2, Table 4). The average salmon catch in 2020 was 11.5 individuals (5.9 kg) per trawl compared to 7.3 individuals (6.8 kg) per trawl in 2019. However, when the two largest sets of 2020 (trawl 3 and 4) were excluded, average in 2020 was only 3.4 individuals (2 kg) per trawl, average salmon catch in 2019 without two the most abundant sets were 6.1 individuals (5.5 kg). Similar to the 2019 survey, Chum salmon was the most abundant salmon species (234 fish, 29% of total salmon catch), followed by Pink salmon (136 fish, 28%), and Coho salmon (118 fish, 18%). Sockeye salmon was predominantly caught at northern stations with sea surface temperature (SST) <7 °C (Figure 2). Juvenile and immature Chinook salmon were only caught at two stations in close proximity to Vancouver Island. One Steelhead trout was caught in set 8, approximately 600 nm from the shore. Some of the most interesting preliminary results included high salmon catches, especially for fish in their first marine year, on the shelf:

- in trawl 25 near Dixon Entrance, 34 salmon were caught: 7 Pink salmon, 14 juvenile Sockeye salmon, 19 juvenile Chum salmon, and 3 large maturing Chum salmon,
- in trawl 52, close to Vancouver Island, 26 salmon were caught – all Chinook salmon, 24 of which were juveniles.

An important observation was that salmon caught on the shelf were in better condition (higher CF and ISF) than fish caught off the shelf (see species sections).
Also notable was the absence of salmon in trawls 41 and 43, set at the same locations as the sets with the highest catch numbers (trawl 3 and 4) completed 17 days earlier. An additional trawl was set 60 nm south of these locations to test whether salmon had migrated south, however, no salmon were encountered there either. Salmon were caught again only after moving 250 nm northeast (trawl 47), suggesting high salmon migration activity during the winter-spring period. It is plausible that salmon schooling behaviour may have contributed to differences in catches at the same location 17 days apart. DNA analyses and underwater camera recordings could provide additional evidence to support or reject this hypothesis.

Three deep sets were completed during the survey (headrope depth - 30 m). The original plan was to have three deep sets in the southern and three deep sets in the northern region of the study area. However, due to the loss of fishing in the north, only three deep sets were completed. Deep sets were done just after surface trawls № 4, 14 and 17 (sets 5, 15 and 18). Two Coho salmon were caught in set 5, while 96 Coho salmon and 10 Chum salmon were caught in the preceding surface set 4 (Table 3). There were not enough deep sets to determine if salmon were resident in deeper water as observed in the western Pacific where salmon can be abundant in 0-30 m, 30-60 m and even 60-90 m (Starovoytov et al. 2009; Glebov et al. 2011; Shuntov, Temnykh 2011).


A
Sockeye catch, ind
0
1-3
4-8
9-20
21-50
51-300
Leg 1
Leg 2
B
Chum catch, ind
0
1-3
4-8
9-20
21-50
51-300
Leg 1
Leg 2
C
Coho catch, ind
0
1-3
4-8
9-20
21-50
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Pink catch, ind
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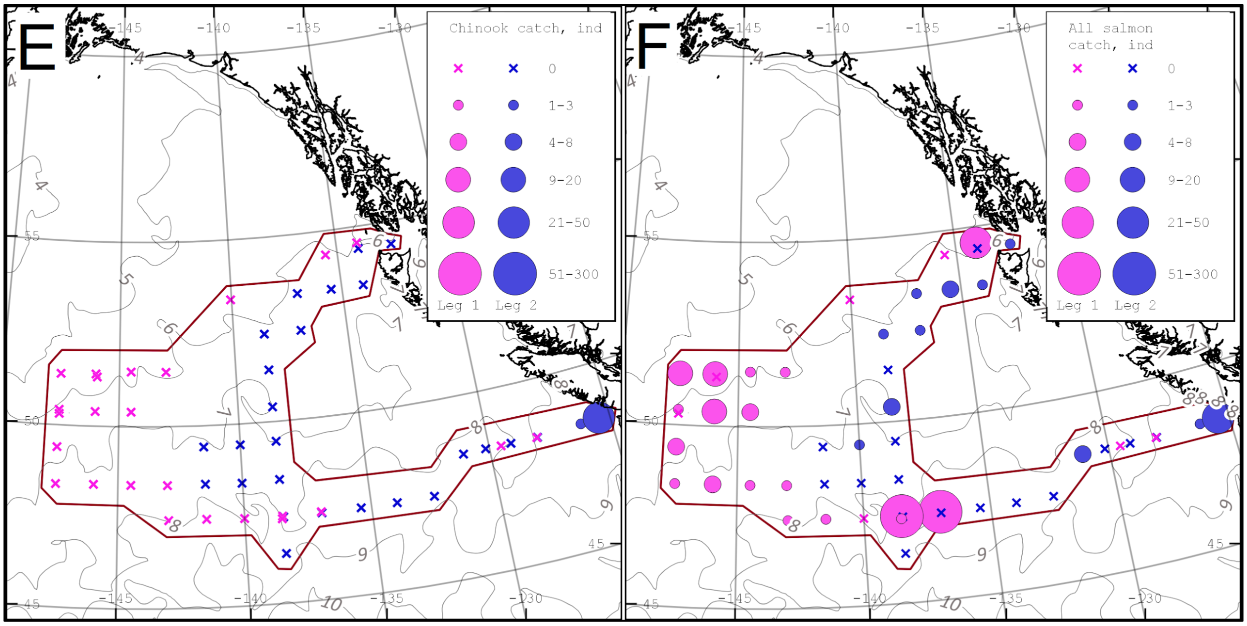


Figure 2. Pacific salmon catches (numbers): (A) Sockeye salmon; (B) Chum salmon; (C) Coho salmon; (D) Pink salmon; (E) Chinook salmon; (F) all five species; during March–April 2020 in the Gulf of Alaska. An "x" mark indicates zero catch.

Abundance and biomass of Pacific salmon

The survey area calculated with a 30-mile buffer (half the average distance between neighboring stations) totaled 648,500 km^2. The 52 stations were not uniformly distributed throughout the survey area, therefore, total abundance and biomass estimates were calculated as relative abundance/biomass multiplied by the total area covered with stations. This calculation is coarser compared to the Voronoi polygon method used in the 2019 expedition (Pakhomov et al. 2019), but the latter method requires evenly distributed stations. Total salmon abundance was estimated as 51.3 million fish with a biomass of 28 thousand tonnes (Table 1). The 2020 salmon abundance estimates were similar to 2019, however biomass estimates were lower than the 2019 estimates due to a higher proportion of juvenile fish caught in 2020.

Chum salmon (*Oncorhynchus keta*)

Chum salmon was the most abundant salmon species captured in the Gulf of Alaska 2020 expedition. Lengths ranged from 25 to 70 cm (Figure 3). The total catch of 234 represented an abundance of 19.3million fish and biomass - 13.3 thousand tons. This estimation represented more than 47 % and 38 % of the total Pacific salmon abundance and biomass, respectively (Table 1). The Chum salmon catches included all marine-age groups (marine ages 1 to 5), based on the size structure (Figure 4A) and subsequent scale analysis for fish over 35 cm FL. In contrast to 2019, most of the Chum salmon averaged 35 cm (first marine year fish). Chum salmon distribution was uneven (Figure 2B) with the highest catch recorded during trawl 3 (165 fish). This catch was dominated by first marine year fish (<35 cm) and larger immature fish. Conversely, only 1 or 2 large immature (> 40 cm) Chum salmon were regularly caught in the western part of the study area. On the shelf, first marine year Chum salmon and large maturing fish were caught. The condition factor of Chum salmon in 2020 ranged from 0.7 to 1.2 and averaged 1.01, whereas, in 2019 it averaged

0.95. Individuals with the highest condition factor were caught on the shelf (set 25) though there was considerable variation (Figure 3). The fact that the 2020 survey was conducted one month later than the 2019 survey must be taken into account while interpreting these results.

Chum salmon scale analysis was completed for 119 fish. Chum salmon total age ranged from one to six years. Fish smaller than 35 cm FL was considered as first marine year without analysis. The majority of the fish were first marine year (46.2 %), with the remaining fish being in either their second, third, fourth, or fifth years (7.6 %, 25.2 %, 15.1 %, and 5.9 %, respectively).

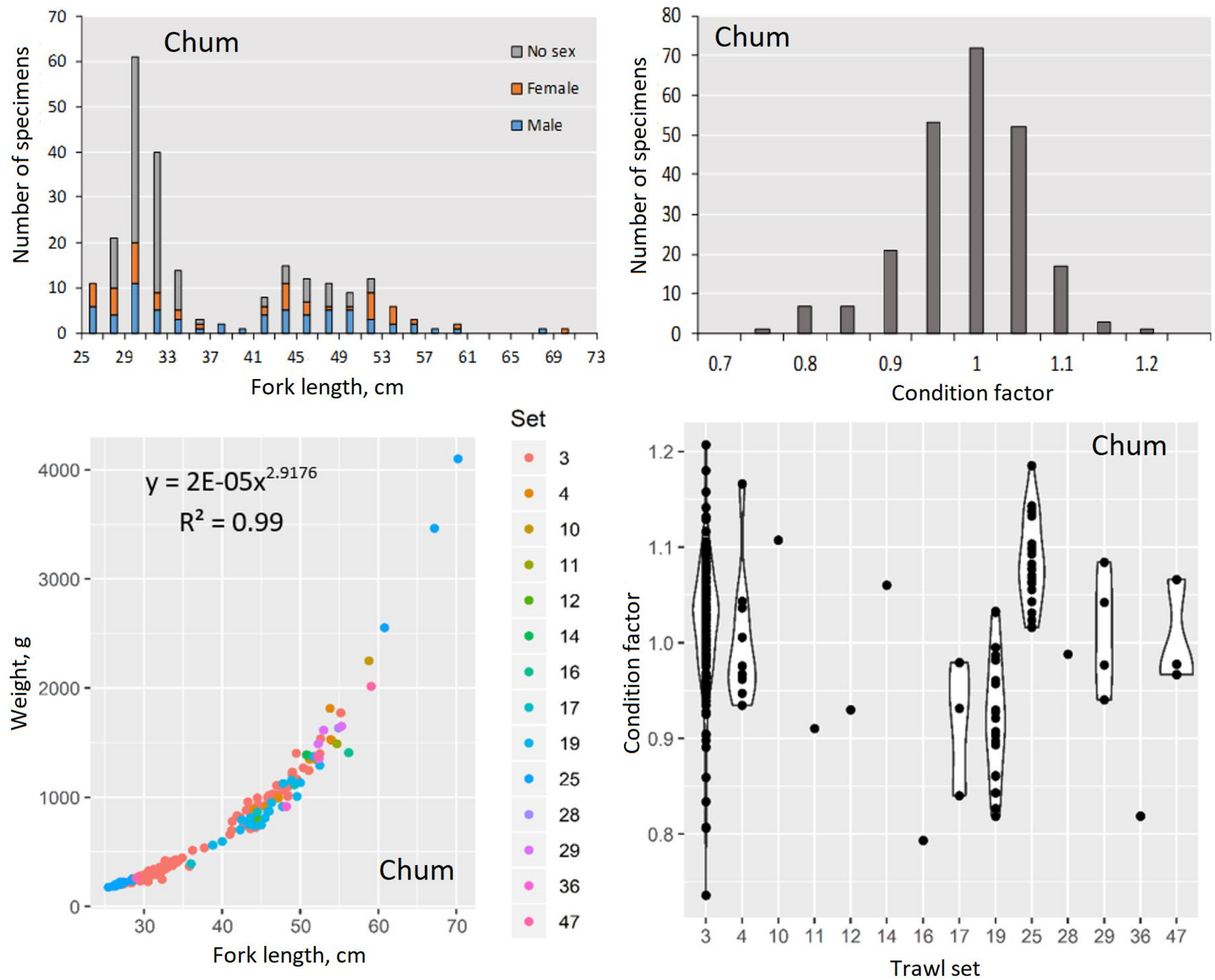


Figure 3. Biological characteristics of Chum salmon

The most common prey items by weight in Chum salmon stomachs were jellies (Coelenterata) - 44 %, euphausiids (*Thysanoessa* spp. and *Euphausia pacifica*) – 24 %, appendicularia (*Oikopleura*) - 15 % and pteropods (*Limacina helicina* and *Clione limacina* - 10 % (Figure 8). Pteropods were especially abundant in fish caught on the shelf. Amphipods (*Themisto pacifica*) and pelagic polychaetes (*Tomopteris* spp.) were frequently noted in the stomachs, but were a minor proportion of the overall diet. In general Chum salmon ISF was low, ranging from 40 ‰ during deep sets to 181 ‰, in fish caught on the shelf, and averaging 53.9 ‰ overall.

Table 1. Average biomass (kg) and abundance of Pacific Salmon in the Gulf of Alaska 2020 using different catchability coefficients (q): 0.4 - first marine year, 0.3 - second marine year and older.

Species	q	Average catch, ind.	Average catch, kg	Relative biomass, kg/sq.km	Relative abundance, ind./sq.km	Total biomass, 10^3 t.	Total abundance, mln. ind.
Oncorhynchus gorbuscha	0.3	2.8	0.7	5.3	19.7	3.5	12.8
Oncorhynchus keta	0.3	1.8	2.0	15.8	13.5	10.2	8.7
	0.4	3.0	0.9	4.7	16.2	3.1	10.5
Oncorhynchus kisutch	0.3	2.4	1.6	12.7	18.5	8.2	12.0
Oncorhynchus mykiss	0.3	0.0	0.0	0.1	0.2	0.1	0.1
Oncorhynchus nerka	0.3	0.3	0.2	1.7	2.7	1.7 .1	1.8
	0.4	0.7	0.1	0.9	4.5	0.6	2.9
*Oncorhynchus tshawytsch*a	0.3	0.2	0.2	1.3	1.4	0.9	0.9
	0.4	0.4	0.1	0.5	2.3	0.4	1.5
All species		11.5	5.9	43.1	79.1	28.0	51.3

Sockeye salmon (*Oncorhynchus nerka*)

A total of 51 Sockeye salmon were caught in 12 stations. Sockeye salmon were 47% female and ranged in length from 240–480 mm. Sockeye salmon mainly occurred in the northwestern part of the survey area with SST less than 7ºC (Figure 2). The area of GoA where most Sockeye salmon were expected to be caught was not fished in 2020. However, total Sockeye salmon abundance and biomass in 2020 for the area that was sampled were estimated as 4.7 million individuals and 1.7 thousand tons, respectively. In contrast to 2019, most of the Sockeye salmon caught were of age n.1 and n.2. In 2020, surface waters in the northwestern GoA were about 1 °C cooler compared to 2019. In 2020 Sockeye salmon were caught at stations approximately 100 nm south of stations that caught Sockeye salmon in 2019.

Another notable difference between the 2019 and 2020 Sockeye salmon catches was the high abundance of n.1 age fish (<35 cm; Figure 4). Scale analysis (fish smaller than 35 cm FL were considered as first marine year without scale analysis) showed - 72.5% of Sockeye salmon were in their first ocean winter, 25.5 % in their second winter in the ocean, and only 2 % were in their third winter. The average condition factor for Sockeye salmon was 1.03, and specimens with the highest condition factor (1.1) were caught on the shelf area near Dixon Entrance (Figure 4).

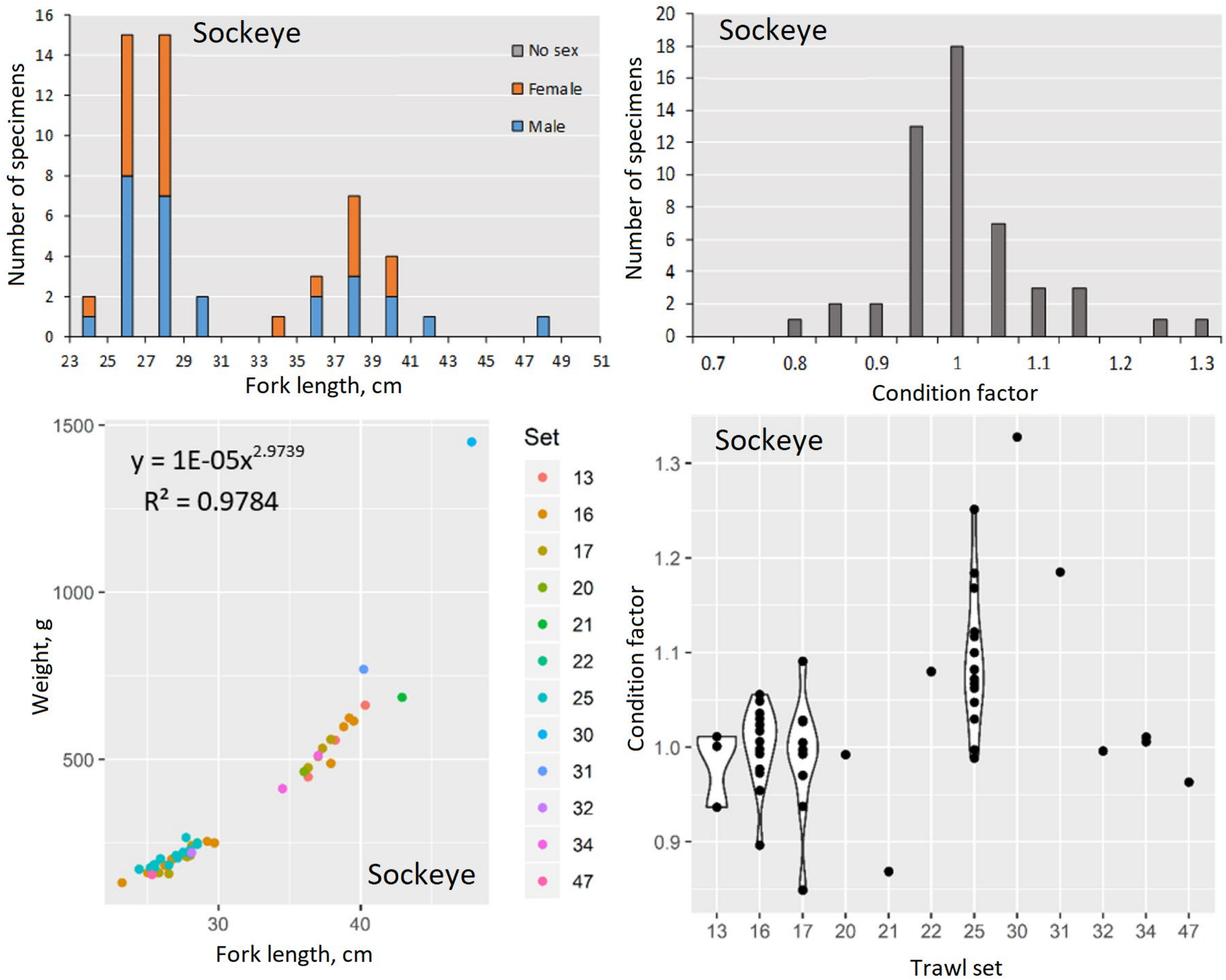


Figure 4. Biological characteristics of Sockeye salmon

The most common food items by weight in Sockeye salmon stomachs were euphausiids - 58% (*Thysanoessa* spp. and *Euphausia pacifica*), followed by pteropods 16% (mostly *Limacina helicina*), and amphipods 11% (*Themisto pacifica* and *Primno macropa*; Figure 8). Feeding intensity was 88.3 ‱ and was higher than for other salmon species with the exception of Chinook salmon. The highest stomach fullness (ISF 224.0 ‱) was recorded in individuals caught on the shelf where stomachs were mostly full to very full (3–4 fullness index). In the case of deep sets, average ISF was 59.0 ‱ and stomachs were mostly semi-empty (1–2 fullness index).

Coho salmon (*Oncorhynchus kisutch*)

Coho salmon was the second most abundant salmon species caught during the 2020 GoA expedition despite previous assumptions that Coho salmon is not abundant in GoA (Myers et al. 2016). Total Coho salmon catch was 118 fish, with an estimated abundance and biomass of 12 million fish and 8.2 thousand tons, respectively. Lengths of Coho salmon ranged from 31 to 46 cm, with most fish between 38 and 42 cm. Almost 80% of Coho salmon were caught in trawl 4, in the southern part of the grid (Figure 2C), but none were caught at the same location 17 days later.

Only seven fish had adipose fins removed and one had a coded wire tag (CWT), suggesting the contribution of hatchery origin fish could be low. However, fin clipping is not standard for hatchery fish from northern BC and therefore the proportion of hatchery origin fish might be larger.

Condition factor varied from 0.8 to 1.3 and averaged 1.09 (Figure 5). Stomach contents was dominated by squid (*Okutania anonycha*)—91 % (Figure 8). ISF was relatively low (34.7 ‱) due to the high number of empty stomachs. In contrast, in 2019 Coho salmon stomach contents were dominated by pteropods (*Clio pyramidata*) and average ISF was four times higher, at 136 ‱ (Сомов и др. 2019).

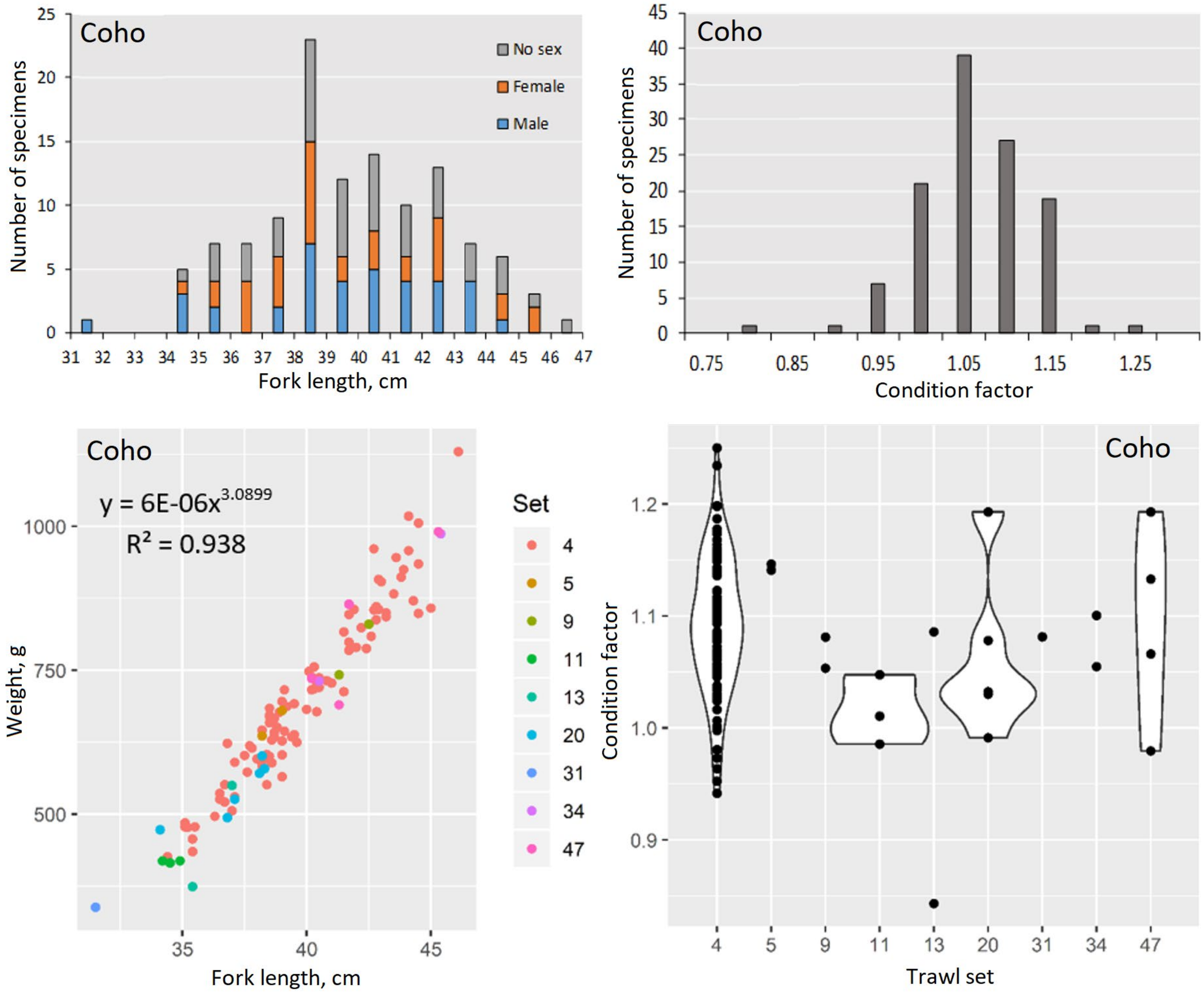


Figure 5. Biological characteristics of Coho salmon

Pink salmon (*Oncorhynchus gorbuscha*)

The total catch of Pink salmon was 136 fish, with an estimated abundance and biomass of 12.8 million fish and 3.5 thousand tons, respectively. Most of the Pink salmon were caught in trawl 3 (n=126) followed by trawl 25 on the continental shelf (n=7), trawl 7 offshore (n=2), and trawl 26 on the continental shelf (n=1). Similar to the 2019 expedition, we were unable to determine the general distribution patterns of Pink salmon. It is expected that wintering pink salmon are concentrated along the northern and southern fronts of the Subarctic Current during winter (Radchenko et al. 2018). In 2019 and 2020, pink salmon occurred mainly along the southern front of the Subarctic Current in February–March, and possibly farther south. Another possibility is that abundances were very low. This appears to be one explanation for 2019 as the final Pink salmon returns along the west coast of North America were low (Velez-Espino et al. 2020). As with Coho salmon, no Pink salmon were caught during repeat trawls at stations with high Pink salmon catches 17 days earlier possibly indicating that Pink salmon were in large schools that moved throughout the survey area. Genetic identification should help determine their migration routes. Interestingly, pink salmon abundance was significantly higher in 2020, despite their odd-even cycle dynamics suggesting the opposite.

Pink salmon stomach contents were dominated by euphausiids (50 %), fish larvae (24 %) including small proportion of flatfish eggs, the last of which was especially prominent in fish caught on the shelf. Pteropods and amphipods constituted 12 % and 10 % of pink salmon diet, respectively (Figure 8). Stomach fullness index and condition factor were poor at the deep set stations (ISF = 5.5 ‱; condition factor – 0.87), and good at the stations on the shelf (ISF = 352 ‱; condition factor – 1.1). Notably, results for Coho salmon and Pink salmon fullness and ISF may be skewed by data from the ‘super abundant’ trawls data (sets 3 and 4).

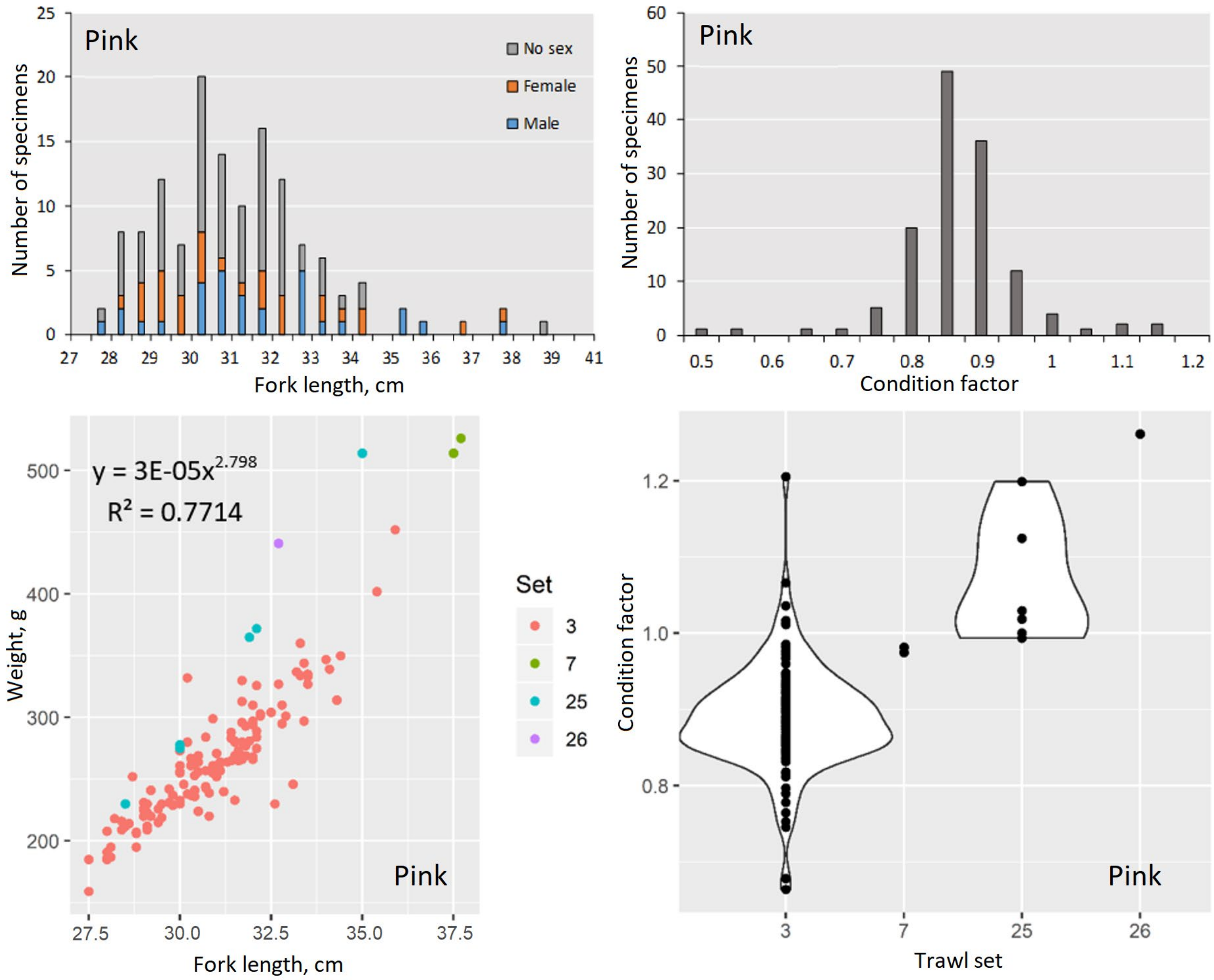


Figure 6. Biological characteristics of Pink salmon

Chinook salmon (*Oncorhynchus tshawytscha*)

Chinook salmon were caught in the last two trawls of the survey, in sets 51 and 52. Two immature adults were caught at set 51. Two immature adults and 24 juveniles in their first ocean winter (<35 cm in length) were caught in set 52 (Figure 7). In 2020, 58 % of Chinook salmon were adipose fin clipped and 4% carried a coded wire tag. Chinook salmon stomach contents were dominated by euphausiids (65%), squid (15%), and fish (13%); pteropods and crab zoea were also present.

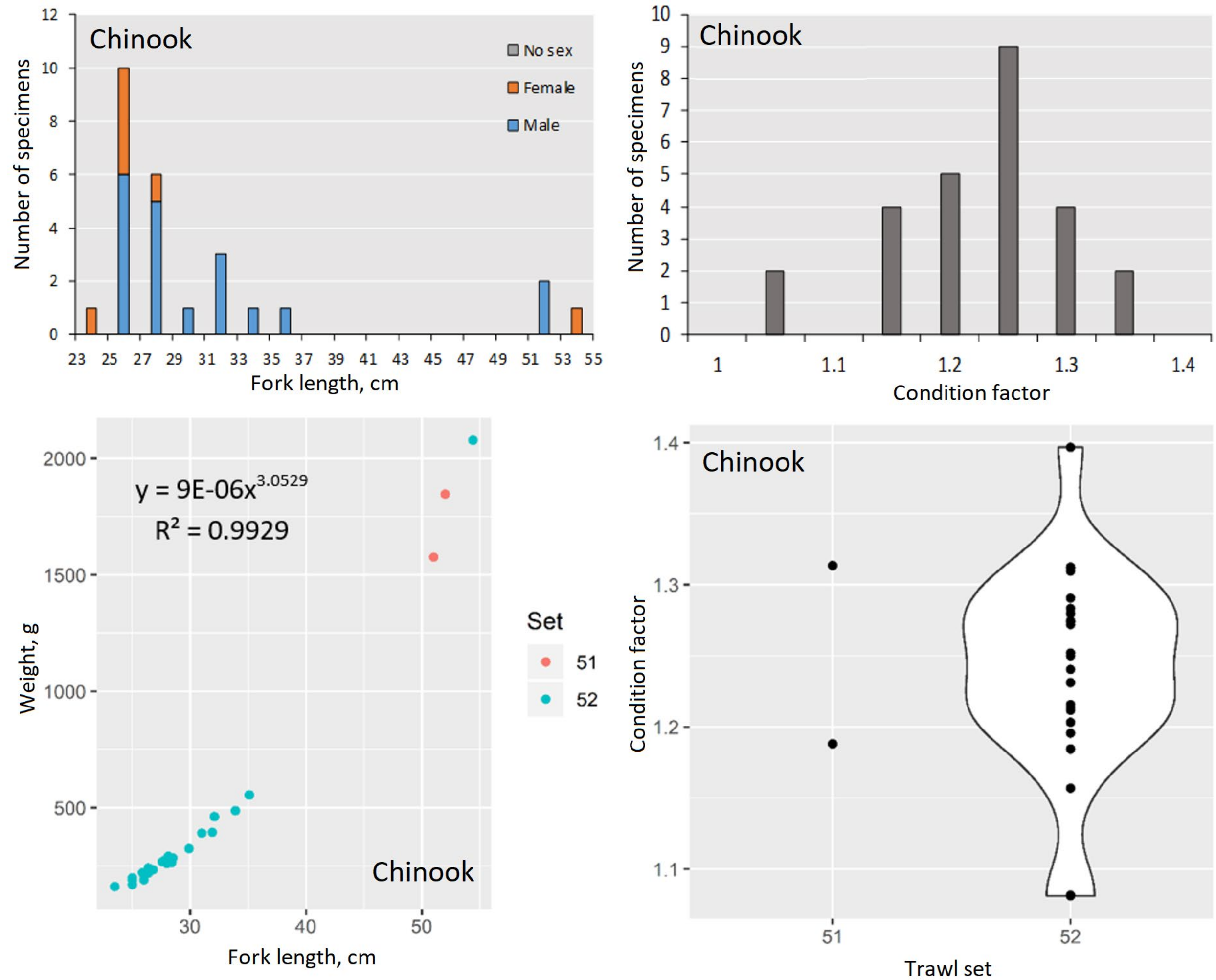


Figure 7. Biological characteristics of Chinook salmon

Steelhead trout (*Oncorhynchus mykiss*)

A single individual of Steelhead trout (40.1 cm FL and weight - 0.555 kg) was caught in the trawl 8 approximately 600 nm from the shore. Stomach content consisted predominantly of squid (*Abraliopsis felis*) and Euphausiids (*Euphausiidae gen. sp.*). ISF was 36.0 ‱; condition factor – 0.86.

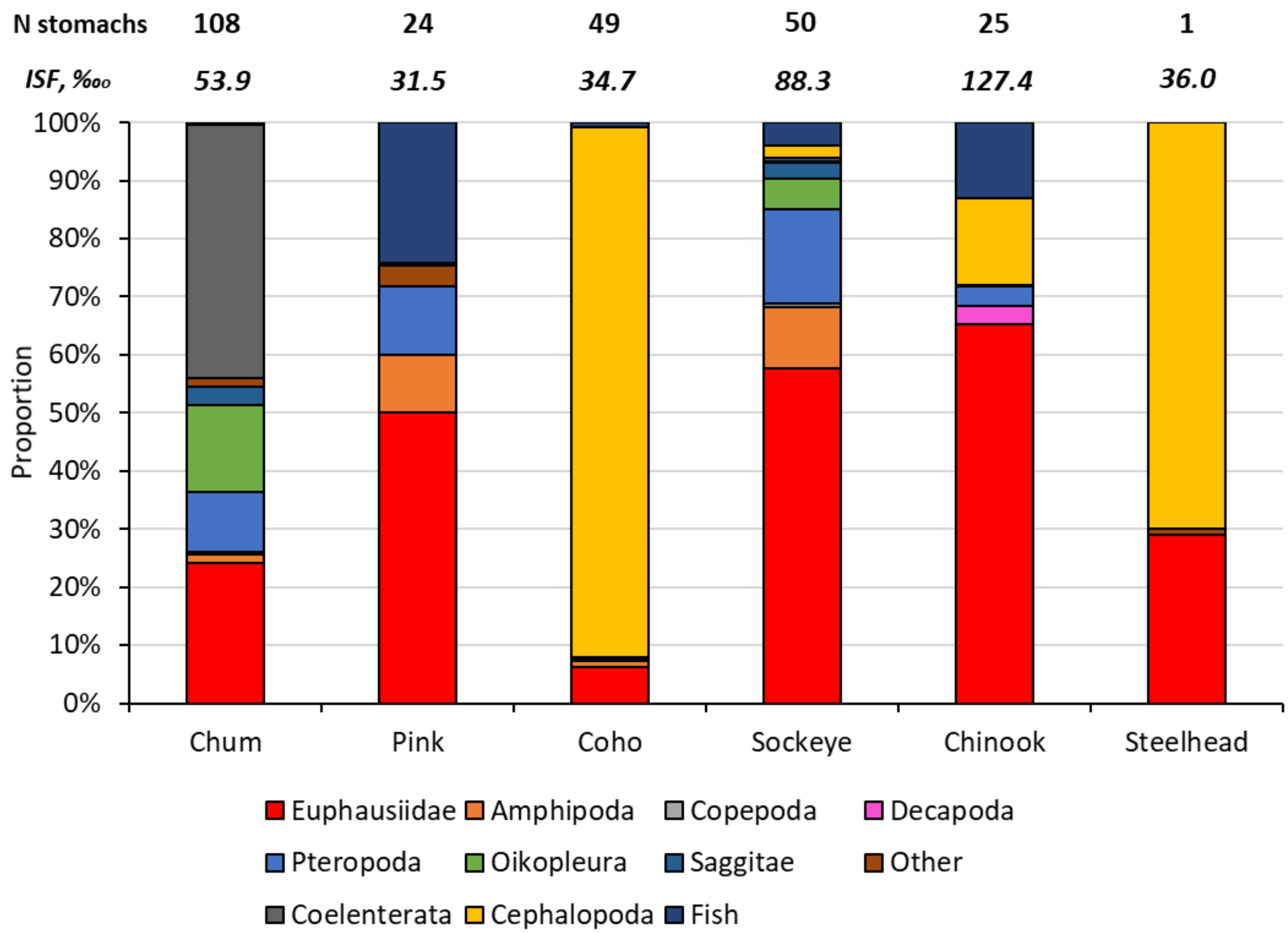


Figure 8. Preliminary results of onboard diet analysis of Pacific salmon species caught in the Gulf of Alaska expedition March–April 2020.

Predation and Parasitism on Salmon

Marine survival of salmon in both the eastern and western Pacific Ocean is undoubtedly affected by predator-prey relationships (Bugaev and Shevlyakov 2007, Sviridov et al. 2004, Welch et al. 1991) and parasitism that may negatively influence the health of salmon (Sviridov et al. 2004). The degree to which wounding and infestation affect Pacific salmon abundance is an increasing concern for researchers who often report lacking sufficient data to assess the impacts on stocks (Beamish et al. 2005; Bugaev and Shevlyakov 2007; Welch et al. 1991). For instance, pink salmon in the western Pacific can lose 3.9–17.8 % of its abundance (2.0–49.2 million fish) while migrating to spawning grounds in July-August; total losses of pink salmon abundance caused by salmon shark (*Lamna ditropis*), daggertooth (*Anotopterus nikparini*) and long snouted lancetfish (*Alepisaurus ferox*) can reach 25–30 % of its total abundance (Мельников 1997).

Wounds

Wounds were documented on 3.4% of salmon with all species represented. Wound types included both healed and open injuries, lesions, and abrasions (superficial marks) such as those associated with sea lice. Sockeye and Coho salmon had the highest incidence of wounds by species at 7.8% and 6.8% respectively. Wounds were observed 3.8% of Chinook while chum and pink showed a lower incidence of 2.1 and 0.7%, respectively. Scarring was more prevalent than fresh wounds (63%) and abrasions were least common wound type.

Predator Wounding

Only one predator of salmon, the daggertooth, was caught during the 2020 GoA survey. This piscivorous fish is wide spread in the Pacific Ocean and has been of interest to salmon researchers due to evidence of its ability to attack both immature and mature salmon (Radchenko and Semenchenko 1996; Welch 1991). Daggertooth attack wounds demonstrate a characteristic single slash mark on one side of the body often located posteroventral from the dorsal fin, running at a 45° angle (Beamish et al. 1999, Welch 2007). Daggertooth were caught in four trawls in the northwestern and northeastern regions of the study area. Total catch was 4 individuals, all immature, the lengths of which ranged from 288 mm to 410 mm and averaged 331 mm. Average weight of the daggertooth catch was 44 g and ranged from 17 g to 80 g. Salmon species were present in two of the four trawls containing daggertooth, specifically 1 chum and 1 sockeye, both 3 year-olds. Neither salmon exhibited signs of wounding associated with the daggertooth which is consistent with the size of the daggertooth specimens and their limited capabilities to damage salmon at this size. Daggertooths can reach an average length of 85 cm (Beamish et al. 2005) and weight of 1 kg; larger individuals are more equipped to attack and injure salmon. A notable observation is the presence of a partially digested fish in the stomach of a daggertooth in trawl 37. This fish was difficult to identify but probably belonged either to family Microstomatidae or Bathylagidae.

Parasitism: Sea lice and Black Spot Disease

Observations of sea lice were done both onboard during sampling of catches and through review of video footage from GoPro cameras installed in the trawl net while fishing. Several species, including the hatchery steelhead caught in trawl 8, were documented as having a higher number of sea lice attached to their bodies while in the net than afterwards, thus the incidence of sea lice infestation is undoubtedly higher than the calculations based on direct observation of researchers onboard. This inconsistency is also noted by Beamish et al. (2005) in a report outlining sea lice prevalence in the coastal waters of British Columbia.

The presence of sea lice was documented in 75 % of trawls containing salmon with a broad distribution across the study area with no clear pattern overall. Infestations were observed on all six species of salmon (5.1 % of total salmon catch) (Table 1). Sockeye and Chinook salmon presented the highest proportion of infestations of sea lice (7.8 and 7.7 %, respectively) with the exception of the only steelhead represented in the survey (100 %). Differences in average size between infested and untouched fish suggest that generally larger fish are more subjected to sea lice infestation. Coho salmon and Pink salmon had no significant difference in sizes, whereas fish spending more than 1 winter in the high seas (Sockeye, Chum and Chinook salmon) have a higher frequency of infestation (Table 2). One explanation for this could be that the longer the marine period is, the longer fish is exposed to favorable conditions for infestation; thus, are more likely to be affected. However, the high rate of sea lice loss of trawled fish could severely bias the quantitative data upon infestation incidence.

Black spots, likely caused by the trematode fluke, *Cryptocotyle lingua*, were apparent in 11 % of trawls containing salmon on 3.2% of the total salmon catch. The metacercaria of this complex organism encapsulates in the skin of salmon resulting in melanisation of the cyst (Cairns et al. 2005). This marine parasite may increase susceptibility of salmon to other diseases and is known to affect condition factor if heavily infected (Bruno et al. 2013). Chinook salmon caught on the continental shelf in the last trawl of the survey presented with the highest incidence of black spots (13 %). Chum and pink salmon were the only other species observed with this infestation (3 and 4.9 %, respectively). Despite the lower incidence of black spots than Chinook, chum presented the highest intensity of black spots with one individual showing more than 100 spots on the left side of its body. Apart from wounding and parasitism, one sockeye salmon and the steelhead trout showed signs of bacterial infection causing fin rot and the loss of a pectoral fin on both specimens.

Table 2. Sea lice incidence on salmon with average fork length

Species	Number	Average Fork Length (mm)		Incidence	Total Incidence
		No sea lice observed	Sea lice observed	(% of species)	(% of total catch)
Steelhead	1		401	100	0.2
Sockeye	26	302	401	7.8	0.7
Chinook	51	298	515	7.7	0.4
Pink	136	396	462	4.7	1.9
Chum	234	316	322	4.4	1.1
Coho	118	398	391	4.4	0.9

Comparison of salmon condition in the Gulf of Alaska in 2019 and 2020

The present data allowed a preliminary comparison of salmon condition factors from the 2019 and 2020 GoA expeditions.

Pink salmon were smaller in 2020 and showed lower average body condition compared to the 2019 survey (Figure 9, Figure 10). The lower body condition was mostly due to the large number of small, low body condition pink salmon caught in set 3.

Similar to pink, trawl sets 3 and 4 captured a large number of first winter Chum salmon that skewed the overall catch to a smaller size class (Figure 9). Large adults seemed to be in slightly better condition in 2020 than in 2019 (Figure 10).

Coho salmon exhibited similar size, weight, and body condition indices in both years (Figure 9, Figure 10). Both 2019 and 2020 had the same proportion of fish with an adipose fin clip or CWT (6% ad-clipped, 1% CWT).

Since the 2020 expedition was unable to sample the northwest GoA where most adult Sockeye salmon were caught in 2019, the 2020 Sockeye salmon size distribution is skewed towards smaller individuals in their first and second ocean winter (Figures 9 and 10).

In 2019, only three Chinook salmon were captured. In 2020, 28 Chinook salmon, mostly juveniles, were caught on the shelf off Vancouver Island. Due to differences in abundance, age class, and catch location, direct comparison is not possible for Chinook salmon from these two surveys (Figure 9, Figure 10). Most of the Chinook salmon caught in the GoA on the shelf were hatchery marked. In 2019, 2 of the 3 Chinook salmon were hatchery marked, but none carried a coded wire tag. In 2020, 58 % of Chinook salmon were adipose fin clipped and 4% carried a coded wire tag.

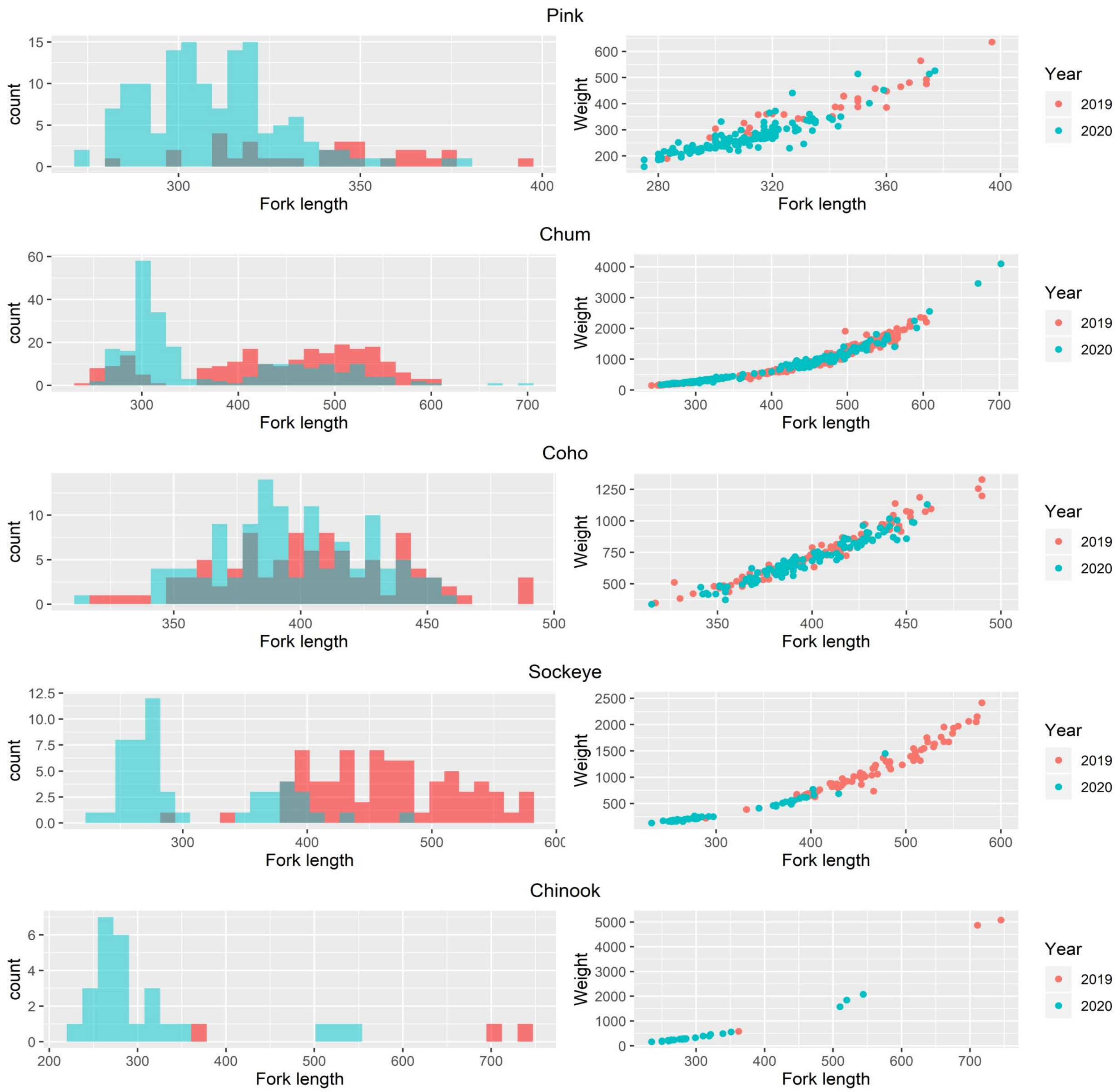


Figure 9. Size and weight comparison of salmon captured during the 2020 and 2019 GoA expeditions. 2019 catches shown in red, 2020 catches in blue.

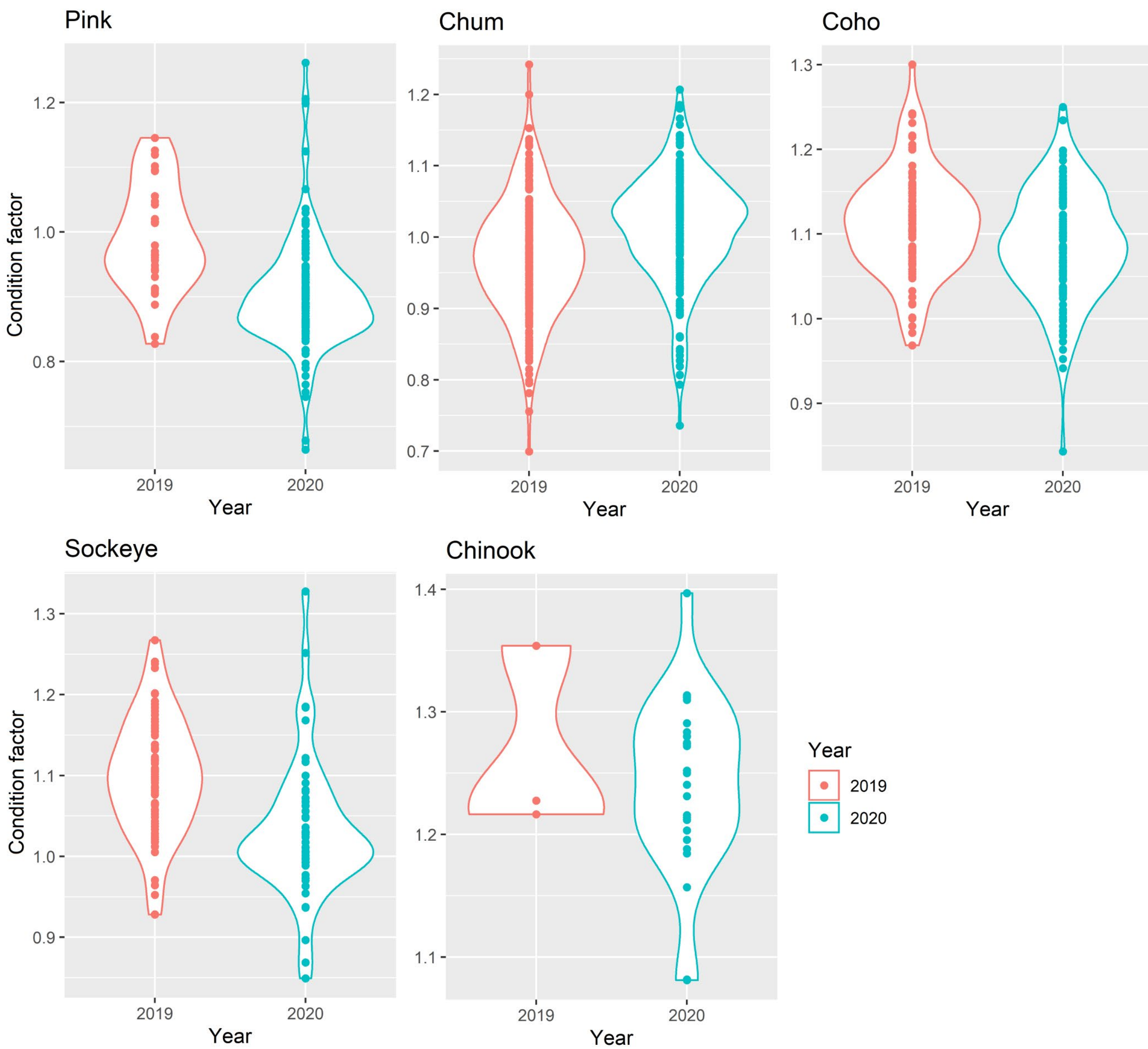


Figure 10. Comparison of Fulton's condition factor of salmon captured during the 2020 and 2019 GoA expeditions. 2019 catches shown in red, 2020 catches in blue.

Abundance of non-salmon fish, squid and macroplankton species

Mesopelagic fish

Mesopelagic fish were a significant component of the bycatch and mostly occurred in night-time trawls (Figure 11A-F). Five species from two families (Myctophidae—*Tarletonbeania crenularis, Stenobrachius leucopsarus, Diaphus theta, Symbolophorus californiense* and Bathylagidae – *Lipolagus ochotensis*) were encountered. The average catch of all mesopelagic fish was 0.65 kg in 2020, which is comparable to the average catch of 0.61 kg in 2019.

Tarletonbeania crenularis was the most abundant mesopelagic fish. The average catch during night-time was 372 individuals (0.49 kg) per trawl, while in 2019 it was 229 individuals (0.54 kg). Biomass and abundance were estimated as 7.9 thousand tonnes or ~6 billion individuals (Table 3).

While *T. crenularis* occurred in almost every night trawl, the highest catches (> 1 kg) were observed in the southwest and low catches (< 0.5 kg) were observed in the northeast sector (Figure 11A). Unlike 2019, the 2020 survey caught a high proportion of small *T. crenularis* (< 30 mm SL) due to the smaller mesh cod end (see below). Overall, body length (Standard length - SL) varied from 18 to 82 mm (Figure 12). Among all mesopelagic fish caught, *T. crenularis* was the only species in which sex could be determined (based on the presence/absence of caudal photophore). The sex ratio of the sampled population was 30 % males and 70 % females.

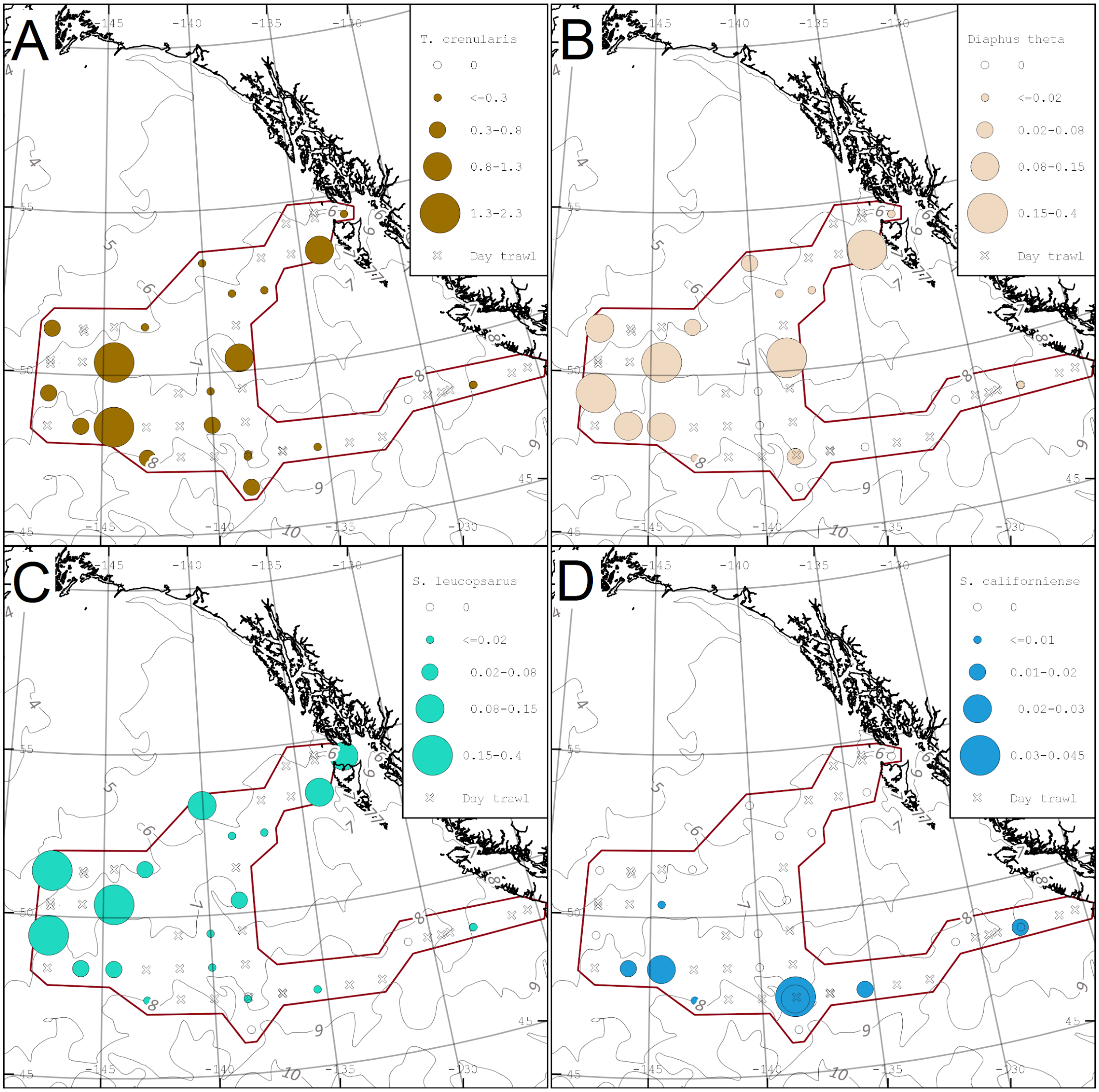
The second most abundant mesopelagic species was *Stenobrachius leucopsarus* with an average catch of 336 individuals (0.06 kg) in the night-time trawls, occurring in 95% of night sets. The average catch in 2019 was only 16 individuals (0.014 kg) and the frequency of occurrence was only 36 %. The estimated biomass and abundance of *S. leucopsarus* in 2020 were 0.99 thousand tonnes and 5.5 billion fish, respectively (Table 3). Standard length ranged from 14 to 90 mm. A large proportion of fish (~50 %) were small individuals (< 30 mm SL) due to the 3 mm mesh size in the trawl codend (Figure 12). For comparison, when 10 mm mesh was used in 2019, fish less than 30 mm SL individuals comprised only 4 % of the total catch, and the smallest size was 25 mm. The most abundant catches in 2020 were in the northwestern part of the study area with SST < 7 ºC (Figure 11).

Diaphus theta occurred in 15 out of 22 night sets with an average catch of 36 individuals (0.071 kg) per night trawl. Total biomass and abundance were estimated as 1.1 thousand tonnes and 583 million fish, respectively. Spatial distribution was similar to *S. leucopsarus* with the highest catches observed in areas with SST below 7ºC (Figure 11). Size (SL) varied from 22 to 86 mm, with most individuals having SL between 52–56 mm.

Symbolophorus californiense was the least abundant myctophid with an average catch of 0.7 individuals per night trawl (0.006 kg) and was present in 8 of 22 night sets on the southern boundary of the study area (Figure 11). Total biomass and abundance were estimated as 0.09 thousand tonnes and 10.3 million individuals, respectively. Standard lengths ranged from 90 to 150 mm.

The only mesopelagic fish of the Bathylagidae family caught in the upper 20 m was *Lipolagus ochotensis.* On average, night-time catch was 4.3 individuals (0.024 kg) with estimated total biomass of 0.37 thousand tonnes and an abundance of 66.2 million fish. Standard length (SL) varied between 60–180 mm (Figure 12). All catches (n=7 sets) were found in the southwestern corner of the study area where SST was equal to or higher than 8 ºC (Figure 11).

Besides mesopelagic fishes, a variety of fish larvae were also found in night trawls, including benthic fishes from families such as Sebastidae, Xenocongridae, Pleuronectidae, Paralichthyidae (Table 3). The highest combined catches (0.3–0.6 kg) were in the southernmost stations in the deep sets as well as on the shelf. Relatively small catches (< 0.1 kg) of larvae were encountered in the central and northeastern parts of the study area and no catches in the northwest (Figure 13).


A
T. crenularis
0
<=0.3
0.3-0.8
0.8-1.3
1.3-2.3
Day trawl
B
Diaphus theta
0
<=0.02
0.02-0.08
0.08-0.15
0.15-0.4
Day trawl
C
S. leucopsarus
0
<=0.02
0.02-0.08
0.08-0.15
0.15-0.4
Day trawl
D
S. californiense
0
<=0.01
0.01-0.02
0.02-0.03
0.03-0.045
Day trawl

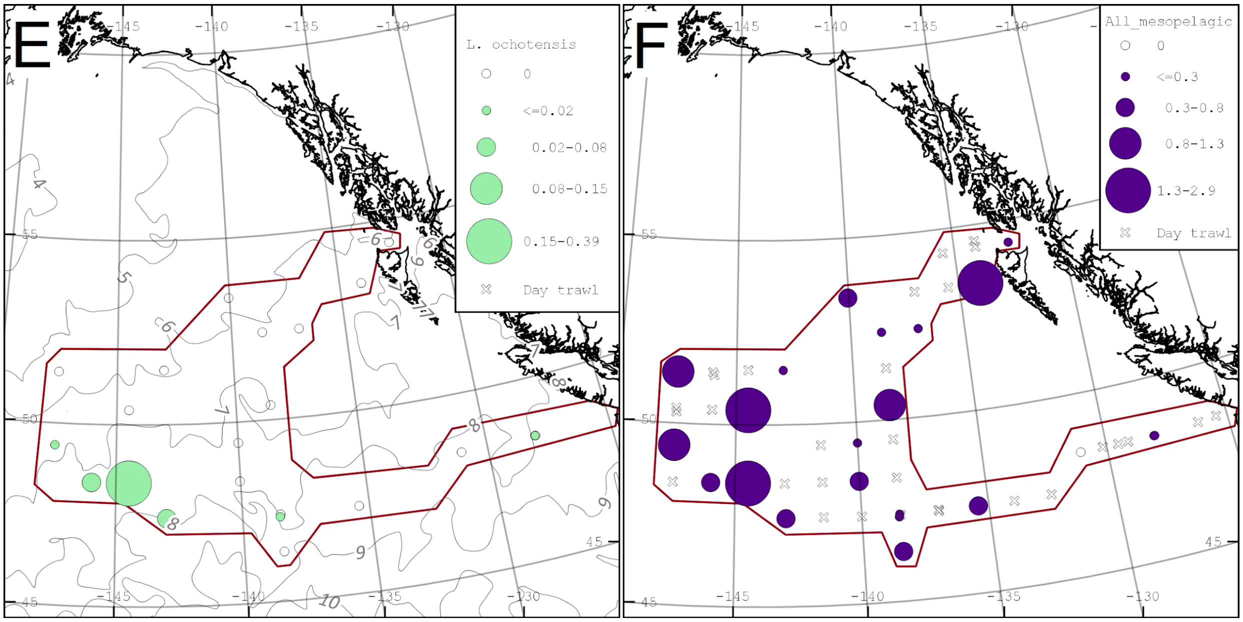


Figure 11. Mesopelagic fish catches (kg): (A) *Tarletonbeania crenularis*; (B) *Diaphus theta*; (C) *Stenobrachius leucopsarus*; (D) *Symbolophorus californiense*; (E) *Lipolagus ochotensis*; (F) all five species; during March–April 2020 in the Gulf of Alaska

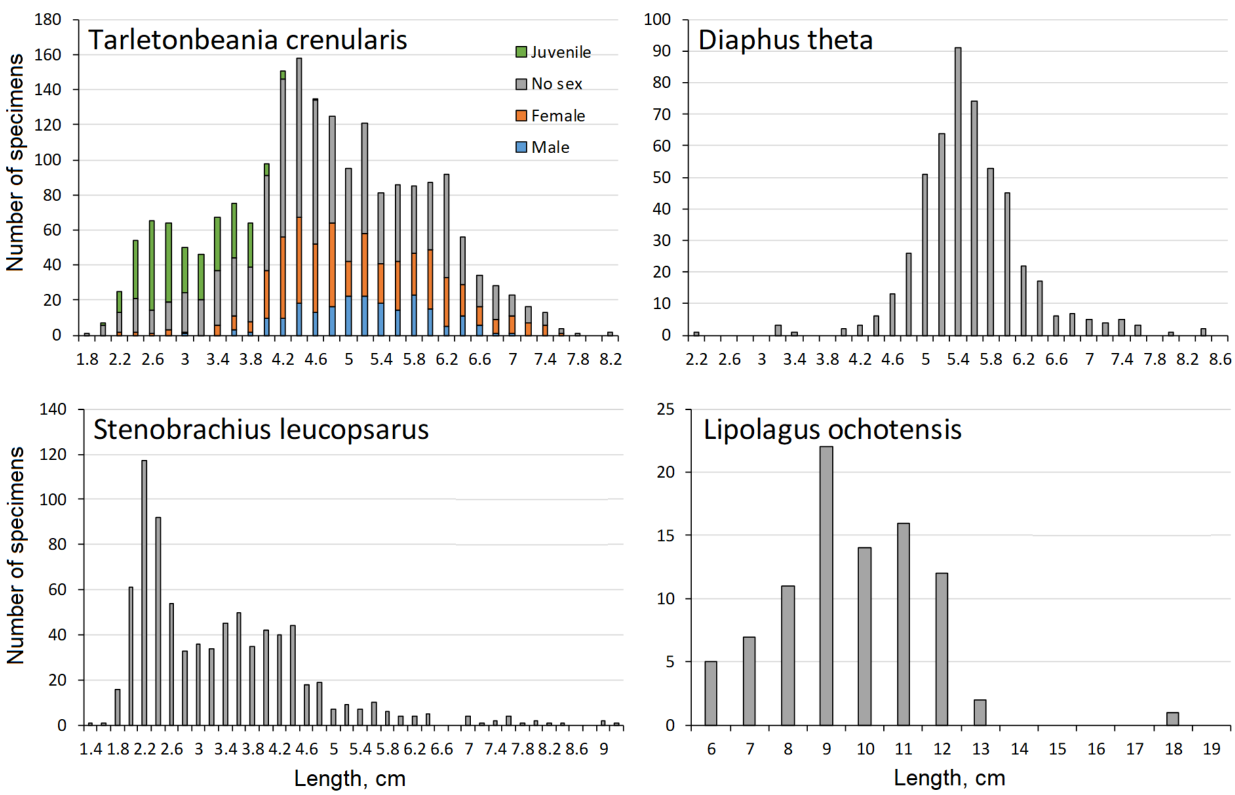


Figure 12. Length frequency of the most common mesopelagic fishes during March–April 2020 in the Gulf of Alaska

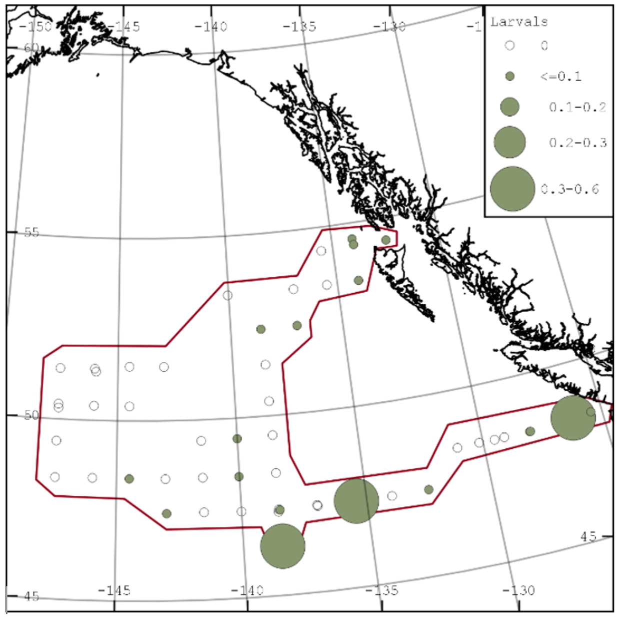


Figure 13. Fish larvae catches (kg) during March–April 2020 in the Gulf of Alaska.

Cephalopods

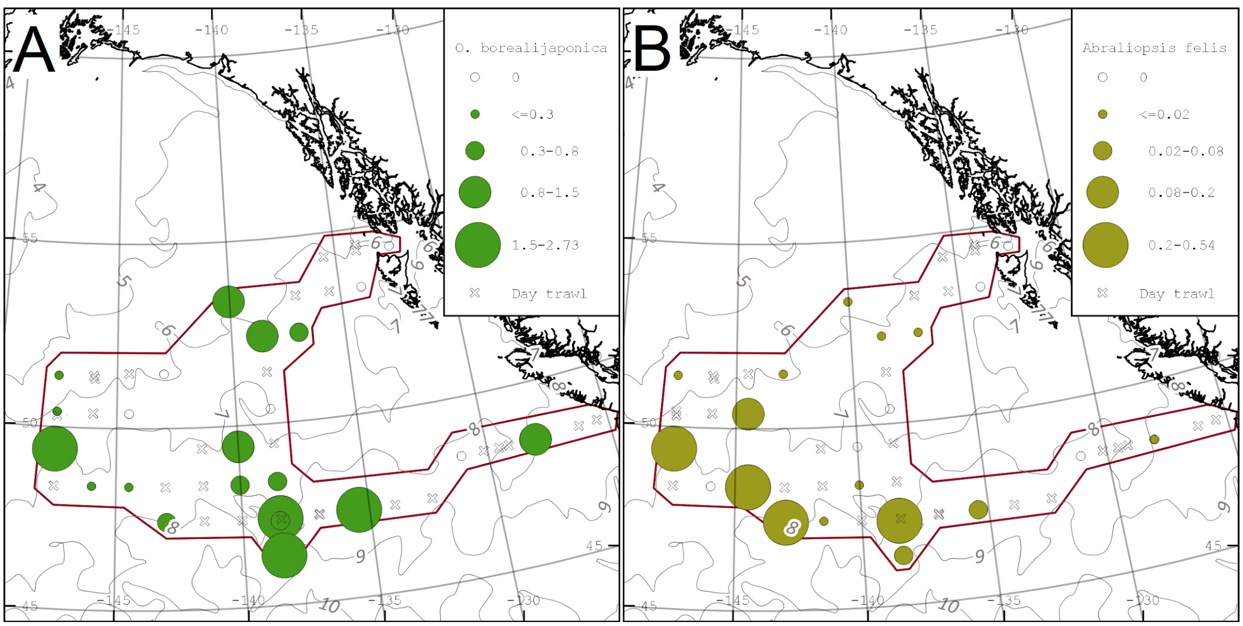
Squid are a major diet item of Pacific Salmon in offshore waters and therefore are an important component of the growth and survival of salmon in high seas (Davis et al. 1998; Kaeriyama et al. 2004). Squid are particularly important component of the diet of higher trophic level species—Coho salmon, Chinook salmon, and Steelhead (Aydin 2000; Davis 2003; Atcheson et al. 2012). Despite their importance, very little is known about squid in high seas with the winter period being particularly understudied. Gulf of Alaska winter expeditions of 2019 and 2020 are the first major studies of squid in the Gulf of Alaska in the winter.

During the GoA 2020 expedition, Cephalopods were represented by seven squid species from six families and one pelagic octopus *Japetella diaphana* (Table 3). Almost all cephalopods were caught at night. The most common species were: *Onychoteuthis borealijaponica, Abraliopsis felis*, and *Boreoteuthis borealis.* By biomass, squid catches were dominated by the large *O. borealijaponica* with an average night-time catch of 0.78 kg (6.8 individuals). *A. felis* was the most abundant squid, with an average catch of 0.071 kg (25.2 individuals) per trawl. The average catch of *B. borealis* was 0.054 kg (9.1 individuals). In addition, gonatid larvae were found in 7 trawls.

Other cephalopods occurred in trawls sporadically. *Okutania anonycha* were caught in five trawls on the southernmost sample area with the highest catch in close proximity to the continental slope. Notably, salmon were present in all trawls with *O. anonycha* in the catch. This species is an important prey of Coho salmon and Chinook salmon and it was commonly observed in Coho salmon stomachs in the 2020 expedition (Figure 8). During the GoA 2019 expedition, no *O. anonycha* were caught in trawls and were only sporadically seen in Coho salmon and Chinook salmon stomachs (Сомов и др. 2019). Opalescent inshore squid (*Doryteuthis opalescens*) was caught in one trawl, 25 nm from the Juan de Fuca Strait. Juvenile Humboldt squid (*Dosidicus gigas*) (preliminary ID) were caught in Dixon Strait. Fragments (arms) of *Taonius borealis* were found in the stomach of Black rockfish (*Sebastes melanops*), but were not observed in any trawl catches. *T. borealis* is a deep water (> 400 m) species and is almost never caught in surface trawls.

The main catches of *O. borealijaponica* were in the eastern and south-eastern parts of the study area. Conversely, *A. felis* occurred mostly in the south-western parts. The spatial distribution of *B. borealis* did not have a clear pattern (Figure 14).

Compared to the GoA 2019 expedition, fewer squid species were encountered in 2020 as *Gonatus madokai, G. onyx, Moroteuthis robusta*, and *Taonius borealis* were not observed in 2020 trawls. The most abundant squid in 2019 was *Boreoteuthis borealis* with an average catch of 1.1 kg, which is 20 times higher than in 2020. *O. borealijaponica* was the second most abundant squid in 2019 with an average catch of 0.76 kg, followed by *A. felis* with an average catch 0.086 kg. During the 2020 expedition, catches of *B. borealis* were much lower while catches of *O. borealijaponica* and *A. felis* were at the similar level. Low catches of *B. borealis* in 2020, which was expected to be the most abundant squid, may have been due to the shallow vertical opening of trawl gear that rarely exceeded 20 m. Several studies suggest that during nighttime upward migrations *Boreoteuthis borealis* mostly occupy the 20–60 m layer and only occur in the upper 20 m layer sporadically (Bower and Takagi 2004, Watanabe et al. 2006), hence this species could have been missed due to the difference in trawling depth.



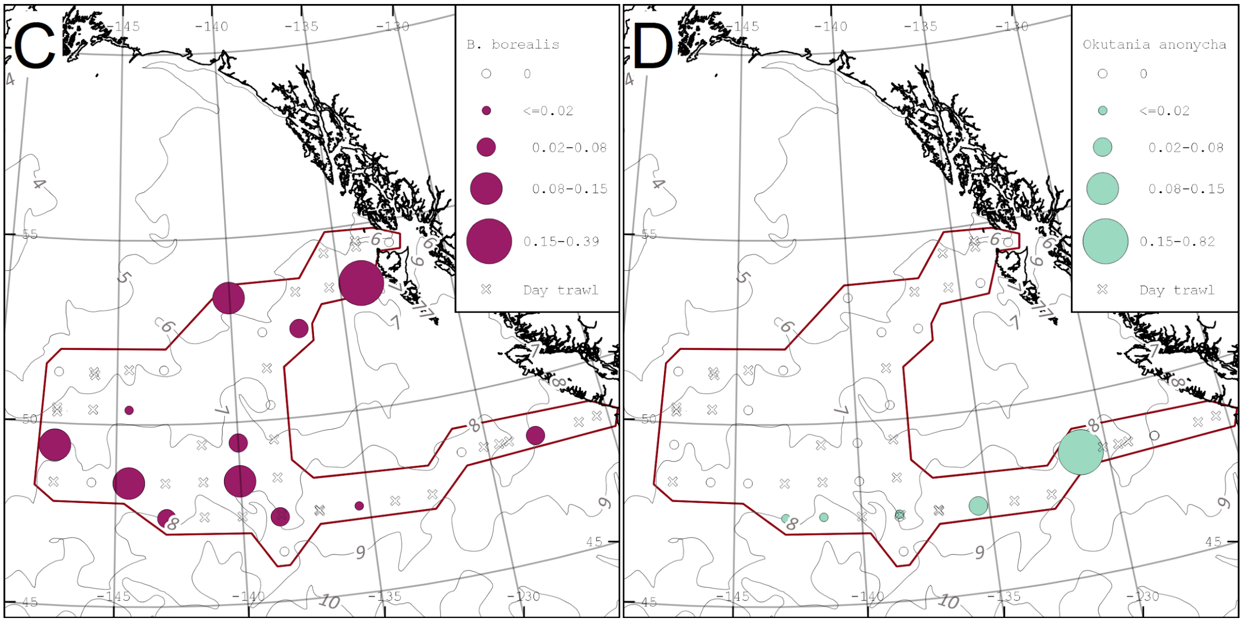


Figure 14. Squid catches: (A) *Onychoteuthis borealijaponica*; (B) *Abraliopsis felis*; (C) *Boreoteuthis borealis*; (D) *Okutania anonycha*; during March–April 2020 in the Gulf of Alaska

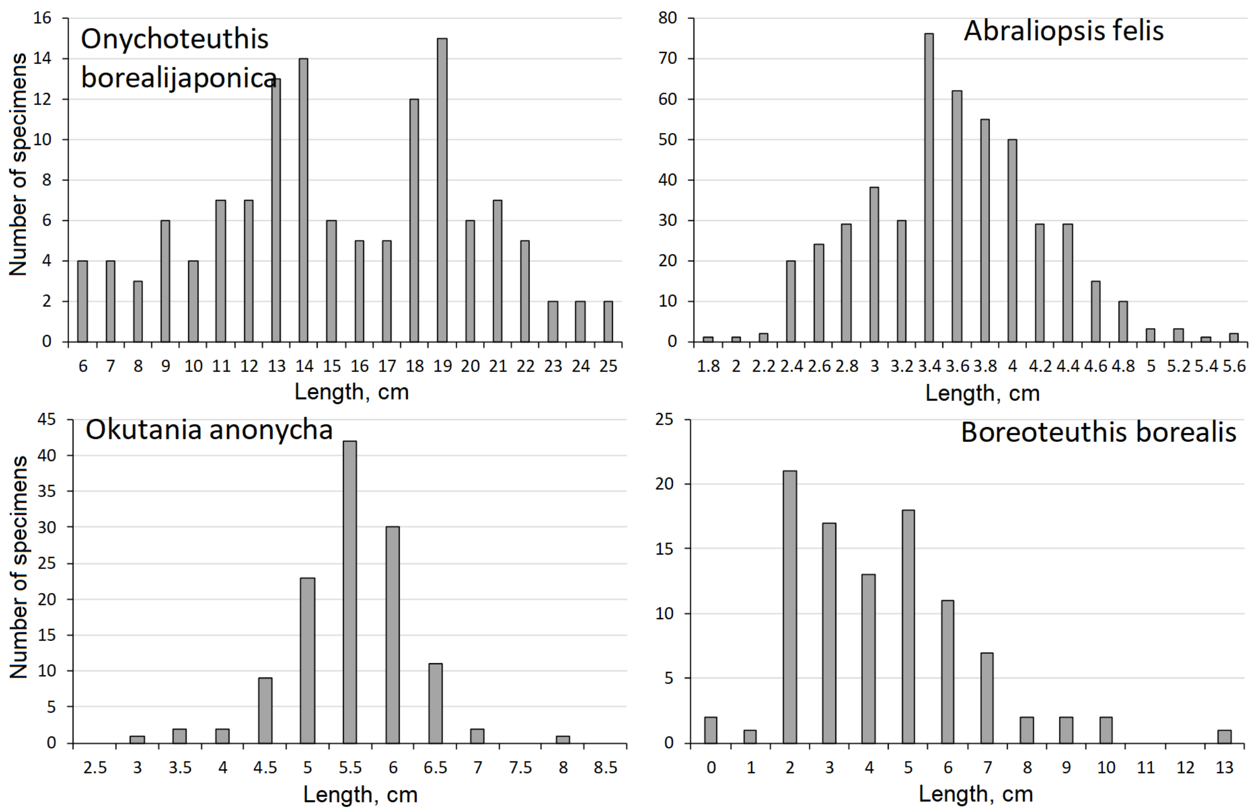


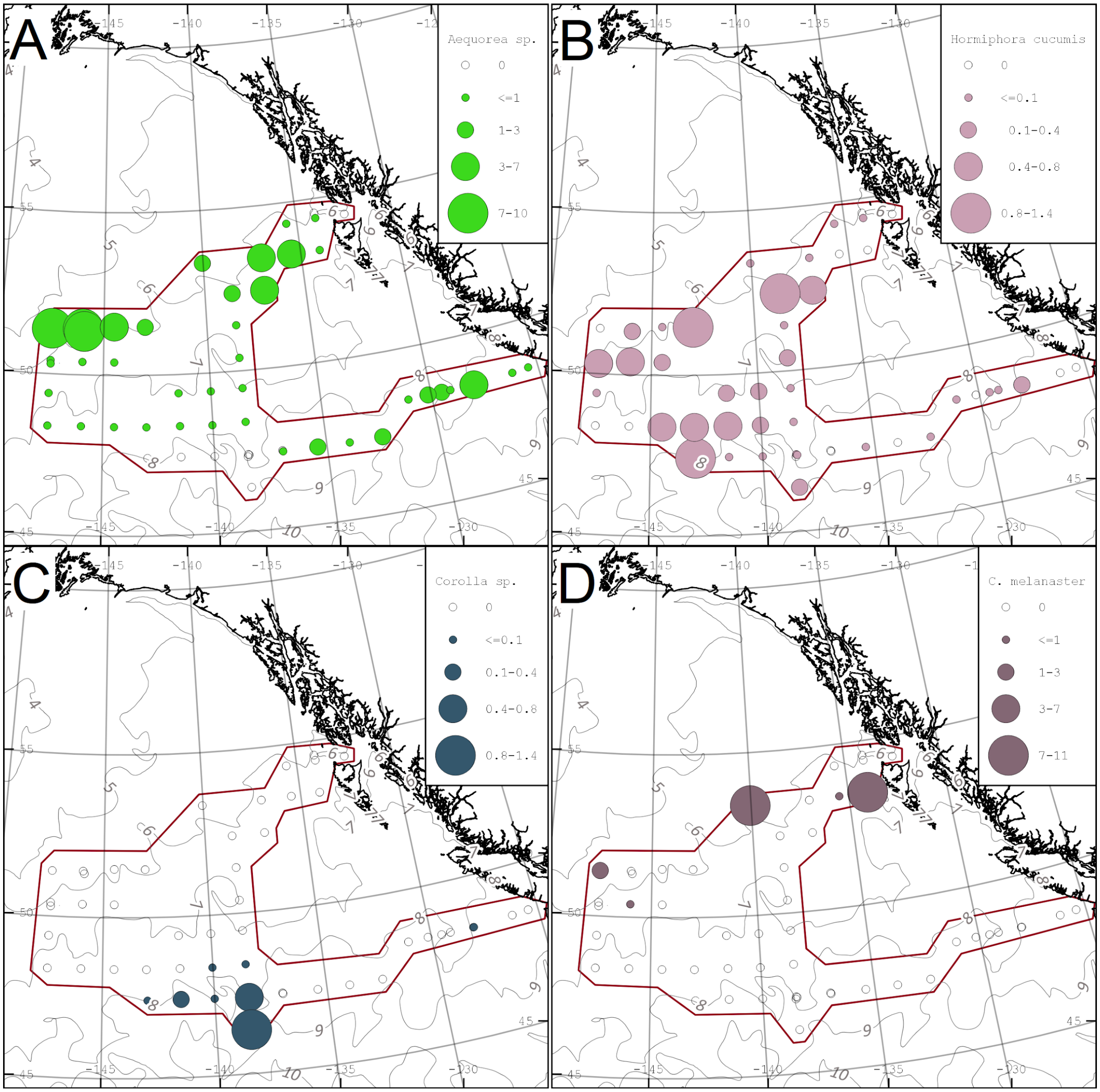
Figure 15. Length frequency of main squid species during March–April 2020 in the Gulf of Alaska

Gelatinous, crustacean, and molluscan plankton and micronekton

Hydrozoan and scyphozoan jellyfish were observed in nearly every trawl, with a maximum catch of 23 kg (Figure 16). The most common taxa were *Aequorea* sp. with 83 % frequency of occurrence and an average catch 1.2 kg, there was a clear distribution pattern with the highest catches in the north and northwest (Figure 16A). The second most abundant jellyfish was *Phacellophora camtschatica* which was encountered in 32 % of trawl sets, average catch was 0.734 kg with no distinct distribution pattern (Figure 16E). *Chrysaora melanaster* was caught only in 10 % of trawl sets, average catch was 0.49 kg; all catches located in the northern areas with SST below 7 °C (Figure 16D). For comparison, *C. melanaster* was the most abundant species in 2019 with average catch—22.6 kg; center of its distribution was 54.2 N 143.8 W which was beyond the 2020 study area. Less frequently observed jellyfishes were *Calycopsis nematophora, Periphylla periphylla, Aurelia* spp.

Among other gelatinous macroplankton, the ctenophore *Hormiphora cucumis* was the most abundant with average catch 0.16 kg and 75 % of occurrence. This taxon was mostly encountered in the central and northern parts of the survey area (Figure 16B). The mollusc *Corolla* spp. showed a clear distribution pattern by being caught only in the southern GoA (Figure 16C) where SST was 8–9 °C, its average catch within the whole study area was 0.05 kg and frequency of occurrence—14%. Less frequently observed species included *Salpa aspera*, *Pterotrachea* spp., *Limacina helicina*, and *Clione limacina*.

Euphausiids were present in almost all night catches (predominantly *Thysanoessa* spp. and *Euphausia pacifica*). Most of the euphausiid catches occurred in waters with SST < 7 °C and on the shelf (Figure 17). On average, 9.1 kg of euphausiids were caught at every night trawl in 2020, substantially more than the average of 0.1 kg per trawl in 2019. An important contributing factor in this would have been the smaller cod end mesh size used in 2020 (3 mm) vs 2019 (10 mm). Quantitative analysis of the bongo net samples can help to reveal if euphausiid biomass did indeed differ between 2019 and 2020.


A
Aequorea sp.
0
<=1
1-3
3-7
7-10
B
Hormiphora cucumis
0
<=0.1
0.1-0.4
0.4-0.8
0.8-1.4
C
Corolla sp.
0
<=0.1
0.1-0.4
0.4-0.8
0.8-1.4
D
C. melanaster
0
<=1
1-3
3-7
7-11

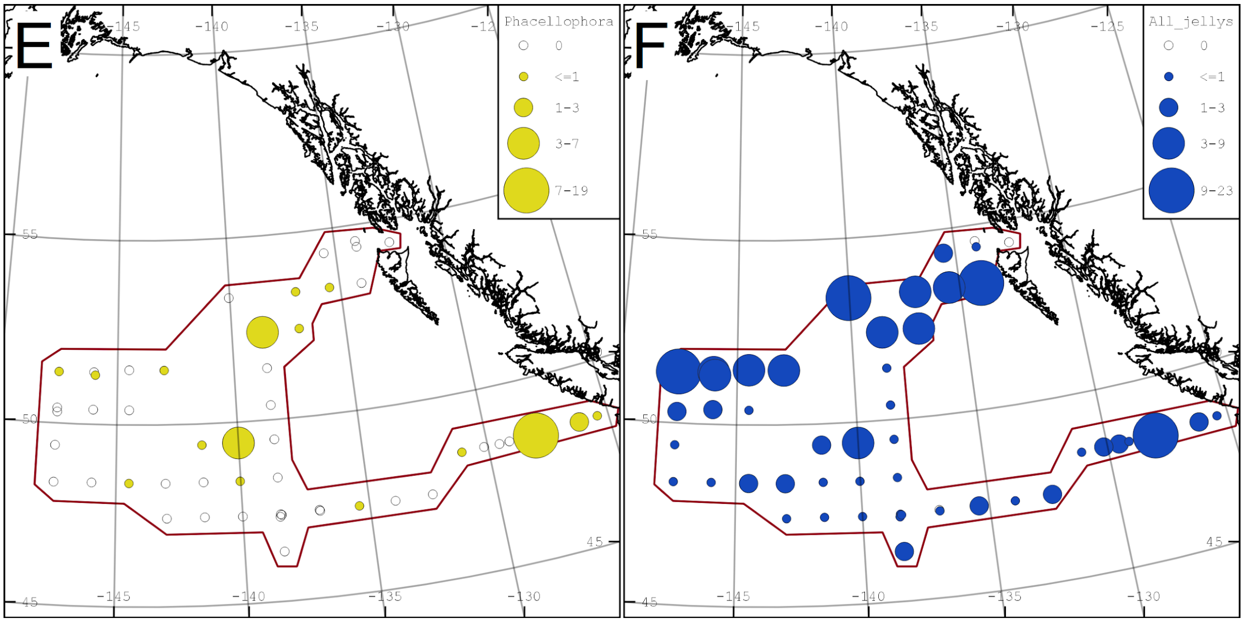


Figure 16. Gelatinous micronekton catches (kg): (A) *Aequorea* spp.; (B) *Hormiphora cucumis*; (C) *Corolla calceola*; (D) *Chrysaora melanaster*; (E) *Phacellophora camtschatica*; (F) all jelly species; during March–April 2020 in the Gulf of Alaska

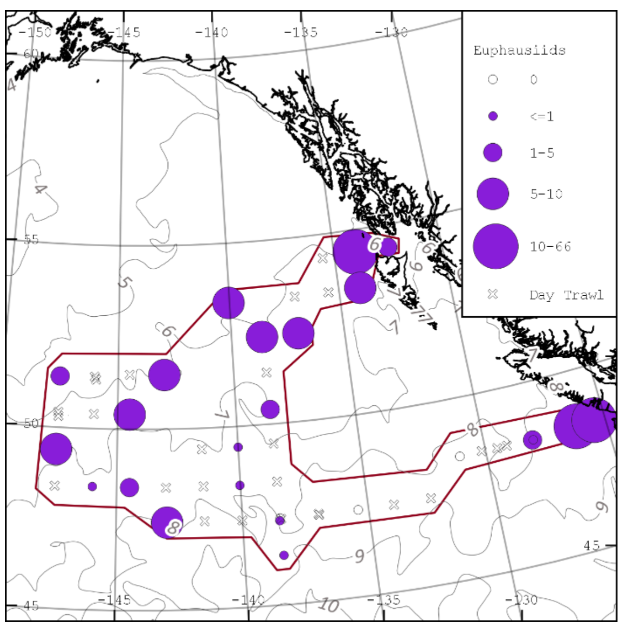


Figure 17. Euphausiid catches (kg): catches consisted mostly of Thysanoessa spinifera and Euphausia pacifica during March–April 2020 in the Gulf of Alaska

Oceanographic conditions

The 2020 survey was conducted in the southern transitional zone of the Sub-Arctic Current (Figure 18A). Surface current flow was predominantly south-eastwards (Figure 18D) while the geostrophic flow (0–250 m) was westward (Figure 22). Weak, jet-like currents were evident in the northern part of the survey area, while at least two anti-cyclonic Haida eddies were visible west of Haida Gwaii (Figure 18D).

A strong south-east to north-west gradient was observed in surface ocean properties off the continental shelf, temperature decreasing and salinity and oxygen increasing (Figure 19). This temperature gradient was evident in the mixed layer in the north-south section (Figure 20). Mixed layer depth (MLD; not shown here) was calculated as the depth at which surface sigma-t was 0.125 > than surface. Off the shelf, MLD ranged between ~ 80–130 m, while on the shelf MLD ranged between 26–60 m. The mixed layer depth was largely driven by salinity (Figure 20). Surface water on the continental shelf was fresher than the offshore region, and freshest east of Haida Gwaii in Dixon Entrance. The depth of the 2.5 $ml.l^{-1}$ oxygen horizon (concentrations below this level may affect salmon and other micronekton physiological performance) decreased from ~ 300m in the south to ~ 200 m in the north and was lowest west of Dixon Entrance (< 175 m) (Figure 21). Overall, the distribution of sea surface properties in 2020 was similar to those observed in 2019. Satellite based SST anomalies (1993–2015 mean) indicated that GoA waters were warmer than long-term average in both years (Figure 18B, C).

Considering the mean sea surface temperature for the entire region (45–60N, 125–155W), 2020 surface waters were 0.33 °C cooler than in 2019. The biggest difference in surface waters temperature occurred in the northern GoA (52–60N), where in 2020 it was 0.82 °C cooler than 2019, while in southern GoA (45–52N) surface waters in 2020 were 0.06 °C warmer than in 2019 (Figure 18B, C). In both years, shelf and near shelf waters were cooler than the 1993–2015 mean, but 2020 was generally cooler than 2019.

Surface chlorophyll concentrations were patchy and were the highest near the shelf and in the south-central to western part of the survey where they reached ~1.1–1.9 $\mu g\ L^{-1}$ in surface waters < 10 m during leg 1 (Stations 3, 4, 7, 10) (Figure 19). Chlorophyll-a biomass integrated over the top 100 m of the water column showed a clearer north to south difference, with values being ~ 2-fold higher south of 50^{o} N, and generally high throughout the southern survey area (Figure 21). The north to south CTD section showed that chlorophyll-a biomass was elevated throughout the mixed layer except at stations 4 and AJ where the surface 15–30 m were depleted (Figure 20). Both surface and integrated chlorophyll-a values reached double the maximum level measured in 2019. This difference between surveys was likely at least in part due to the difference in voyage timing, with the 2020 survey occurring ~ 4 weeks later than the 2019 survey and thus being later into the spring productive season. It is worth noting that chlorophyll concentrations recorded at some of the southern stations listed above exceeded values recorded in Spring or Summer at the off-shelf stations on Line P measured between 2009 and 2018 (Boldt et al. 2019). The high chlorophyll concentrations measured by *in situ* fluorometer in 2020 need to be verified against pigment samples, however, they suggest that the 2020 spring period may have been unusually productive in the southern GoA. Interestingly, there were clear differences in oceanographic conditions at Station 3 between when it was first sampled on 15 March and when it was sampled again on 3 April. The mixed layer was ~ 0.5^{o}C warmer on 3 April (Figures 23 and 24) and chlorophyll concentrations had decreased to <0.4 $\mu g\ L^{-1}$. This change may have been due to one or a combination of warming and change in water mass, potentially influenced by frontal movement. The fact that high densities of salmon were sampled on the first sampling of Station 3 but were absent on the second sampling indicates that salmon may have been associated with the cooler and more productive water mass sampled on 15 March.

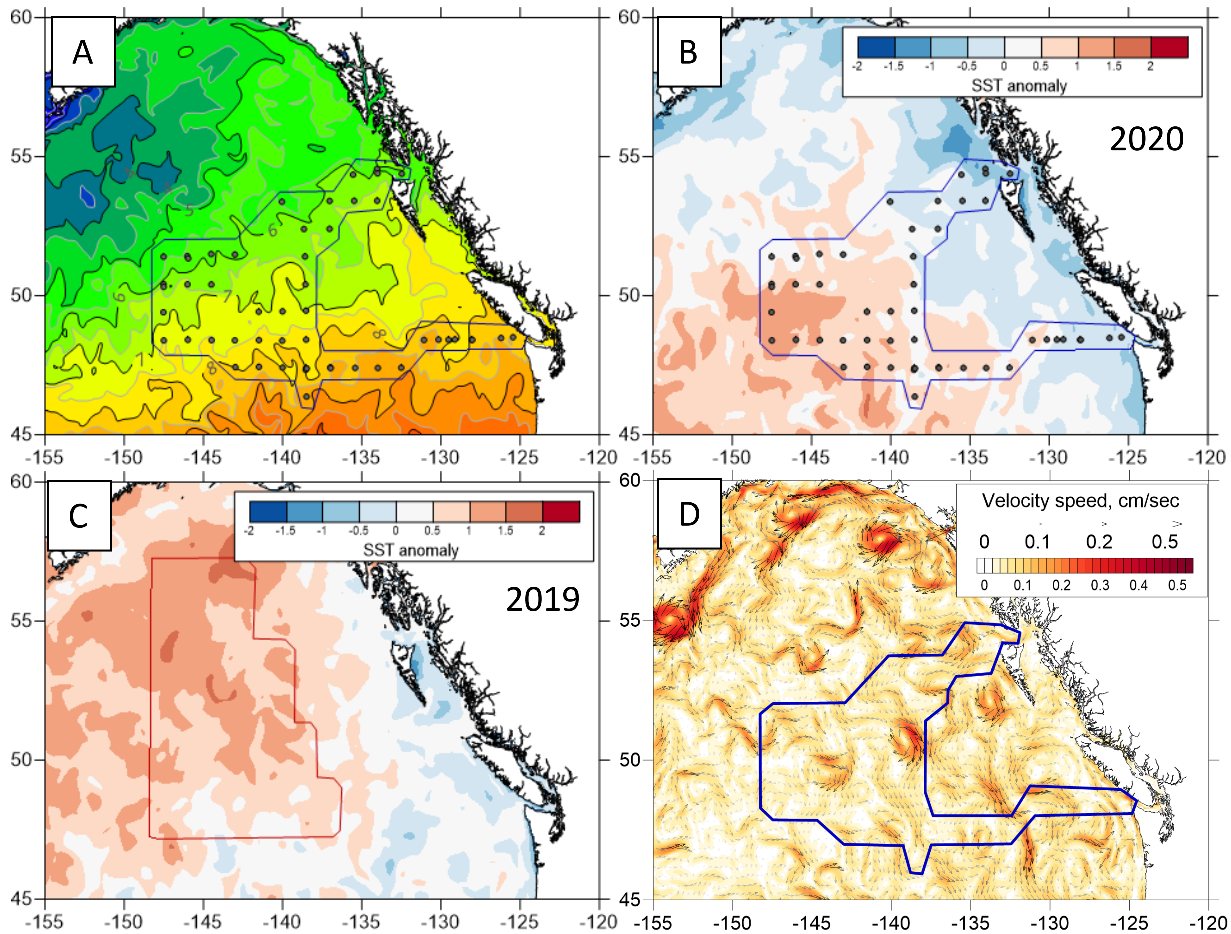


Figure 18. Satellite based SST (A), SST anomaly compared to 1993–2015 mean in 2020 (B) and 2019 (C) and current velocity (D) in the study area; data: marine.copernicus.eu

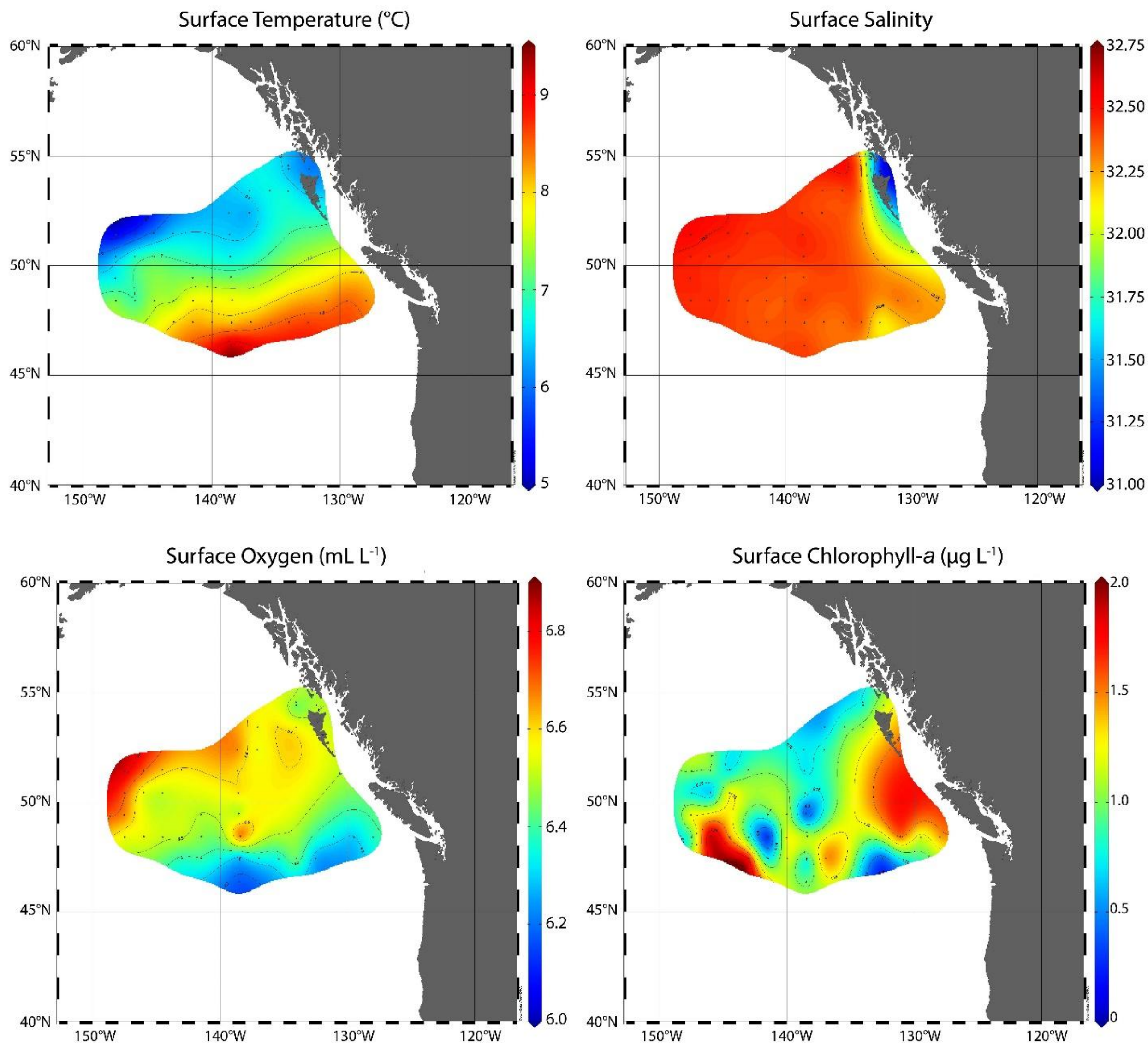


Figure 19. Water conditions within study area, March–April 2020

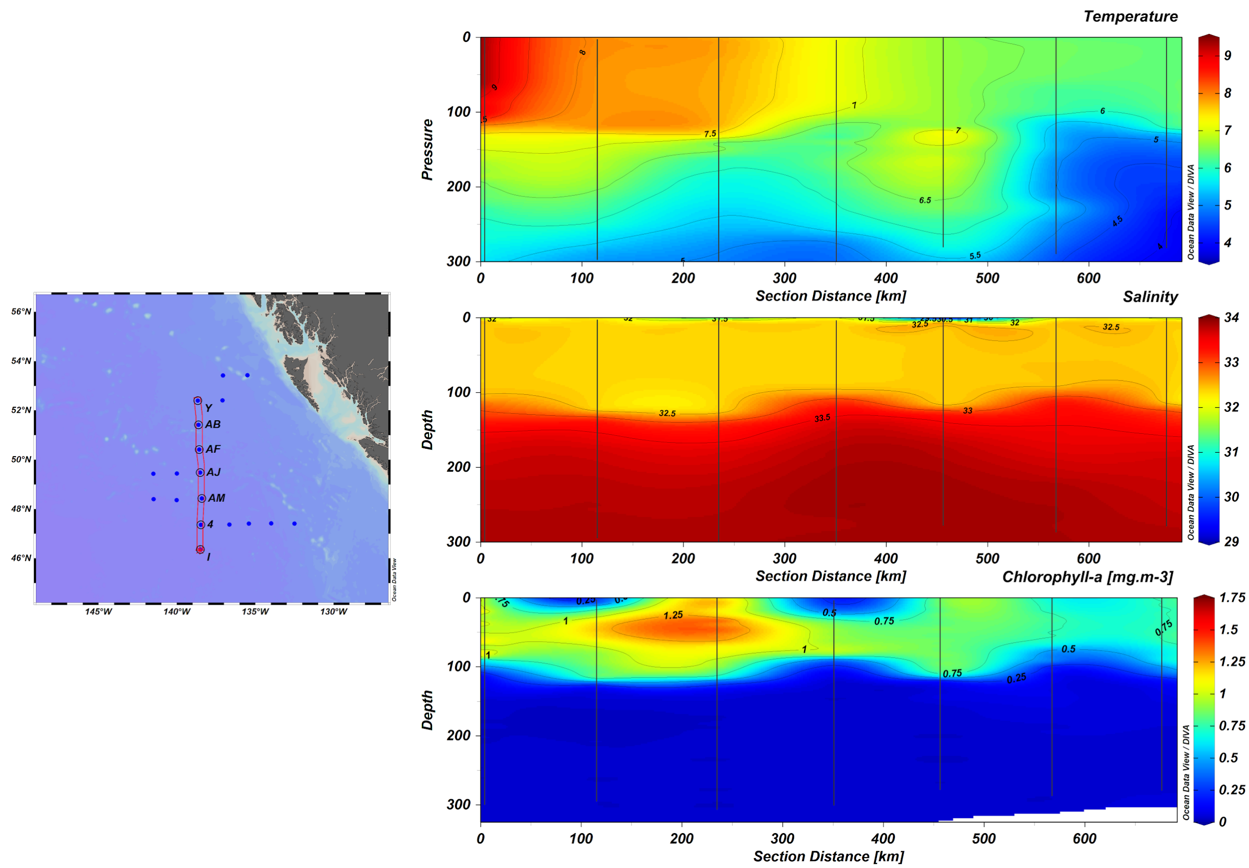


Figure 20. South (right) to north (left) section of temperature, salinity, and chlorophyll-a biomass from stations sampled between 28 March and 3 April 2020

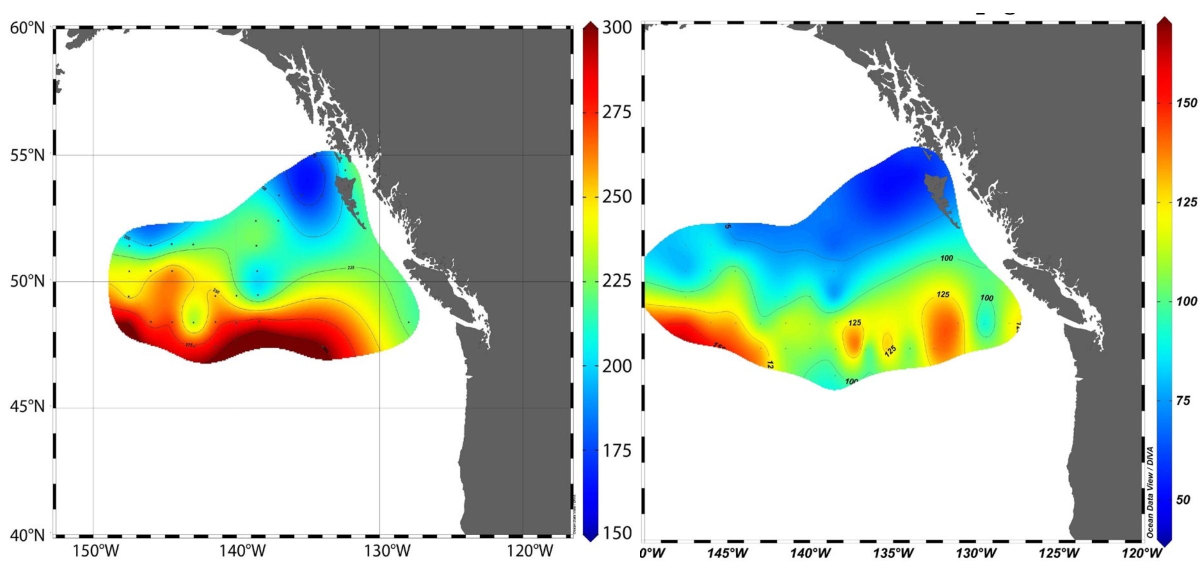


Figure 21. Depth of the 2.5 mL/L oxygen level (left) and Chlorophyll a biomass (mg.m-2) integrated between 0–100 m (right) within study area, March–April 2020

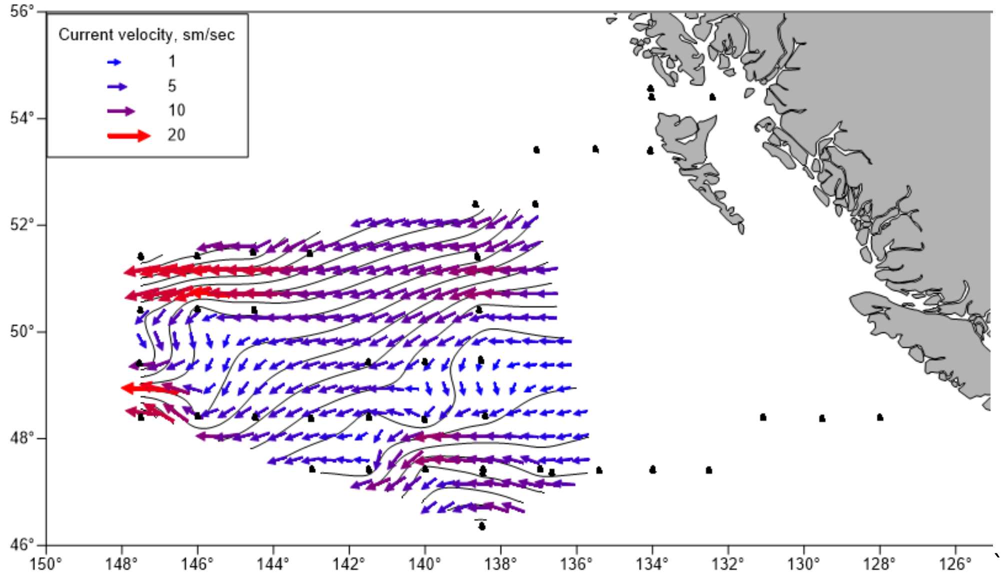


Figure 22. Geostrophic currents (0–250 m) during March–April 2020 in the Gulf of Alaska (map created by Anna Kurnosova, TINRO)

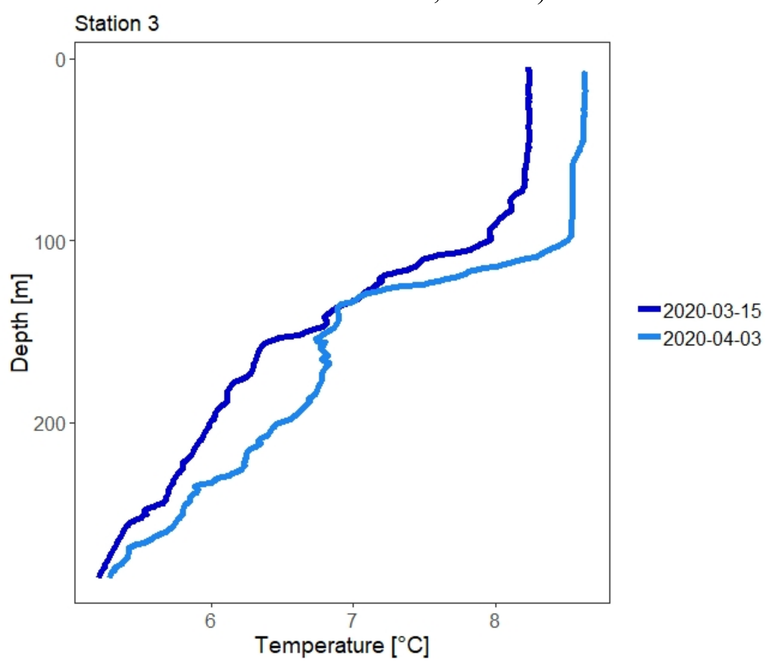


Figure 23. Differences in vertical temperature profile at the station 3 (the highest salmon catch on March 15 and no catch on April 3)

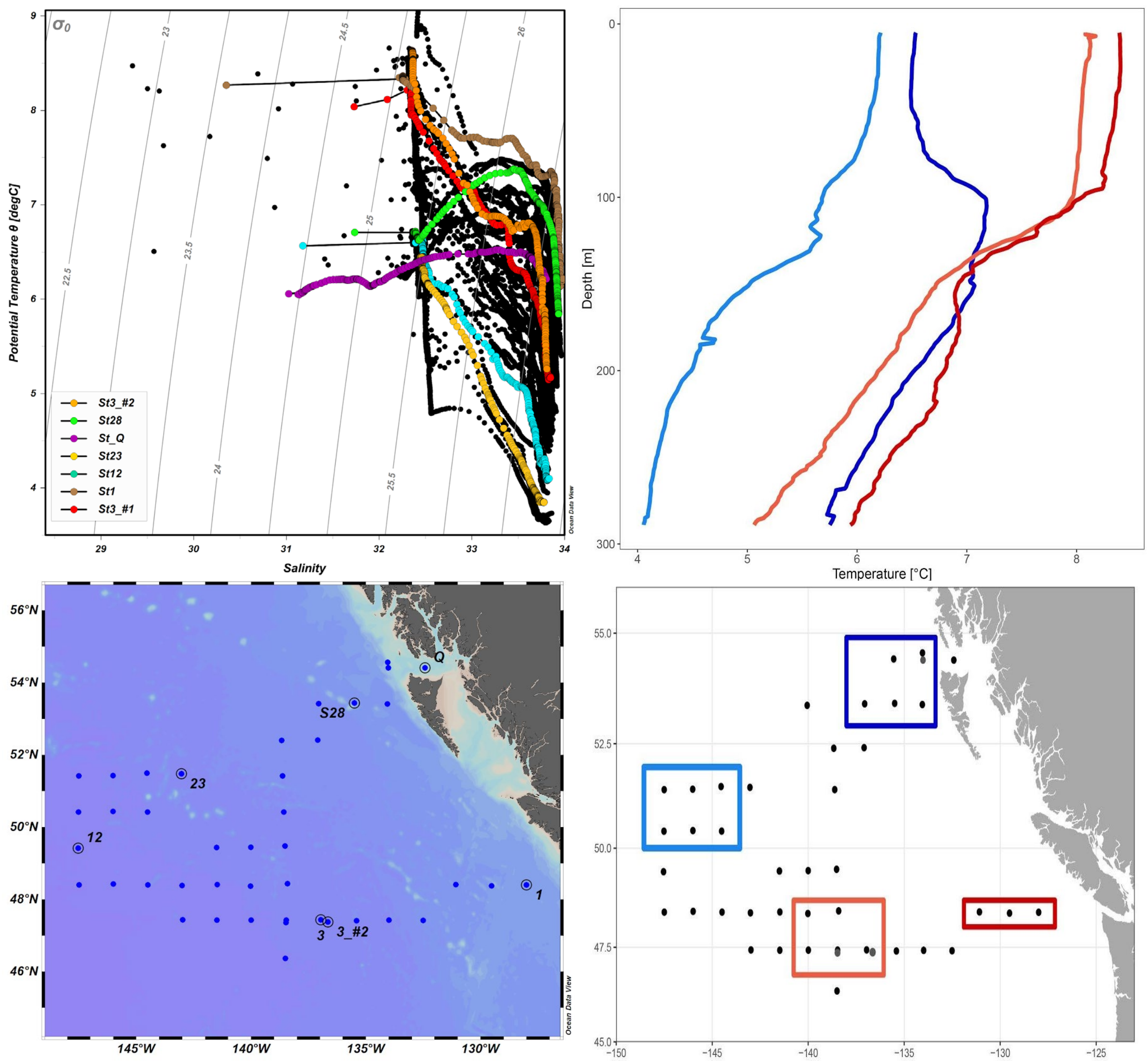


Figure 24. TS plot of all stations with density contours (left) and averaged vertical temperature profiles indicating different water masses (right) within study area, March–April 2020

Summary

This document provides preliminary findings of the GoA winter (March–April) 2020 expedition. This survey was a continuation of the first scientific effort started in 2019. It furthered international collaboration on an unprecedented scale with contributions from Russia, the United States, and Canada. The 2020 expedition was able to capture more salmon than the 2019 expedition, despite covering a reduced sample grid due to logistical limitations. Overall, a more heterogeneous distribution of salmon was observed for many species, reflected in high patchiness of salmon catch. Two-thirds of salmon individuals were captured in just two highly productive sets in the south central survey area, characterised by the highest phytoplankton biomass and warmest sea surface temperatures for the survey. The same locations failed to produce any catch when sampled two weeks later. A warmer mixed layer and lower phytoplankton biomass suggested that different water masses were sampled. In contrast to 2019, the 2020 expedition surveyed several stations on the continental shelf and slope. These stations were characterized by a predominance of first winter fish, including Sockeye salmon, Chum salmon and Chinook salmon. The northern GoA was not sampled which may explain the larger proportion of smaller and younger Sockeye salmon in 2020. Indeed, during the 2019 survey the maturing Sockeye salmon was caught in the northern GoA. Interestingly, pink salmon catches were significantly higher in 2020, despite them being composed by the even year Pink salmon stock. Overall, the 2020 expedition has made an important contribution of data furthered a unique collection of the GoA high seas ecosystem components, including Pacific salmonids. It will advance our knowledge on a poorly understood open ocean phase of Pacific salmon in the GoA during winter-spring. The survey also highlighted the value of a research program that builds upon the joint international expertise from across the North Pacific, and bodes well for further research in 2021.

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Appendix

Table 3. Species composition of trawl catches and abundance estimations.

N	Species	Family	q	Lmin	Lmax	F	NF	Average catch, ind	Average catch, kg	Relative abundance, ind/sq.km	Relative biomass, kg/sq.km	Total biomass, ths. t.	Total abundance, mln. Ind.
							Fish						
1	Oncorhynchus gorbuscha	Salmonidae	0.3	27.5	38.5	4	1	2.78	0.75	5.32	19.7	3.45	12.8
2	Oncorhynchus keta	Salmonidae	0.3	35.8	59.1	13	7	1.71	1.84	14	13	9.06	8.42
			0.3	60.8	70.2	1	0	0.06	0.21	1.77	0.52	1.15	0.34
			0.4	25.4	35.8	3	1	3	0.88	4.72	16.2	3.06	10.5
3	Oncorhynchus kisutch	Salmonidae	0.3	31.5	46.1	9	8	2.37	1.63	12.7	18.5	8.24	12
4	Oncorhynchus mykiss	Salmonidae	0.3	40.1	40.1	1	1	0.02	0.01	0.1	0.17	0.06	0.11
5	Oncorhynchus nerka	Salmonidae	0.3	36	47.8	8	5	0.33	0.2	1.7	2.74	1.1	1.78
			0.4	23.2	34.5	7	5	0.71	0.15	0.94	4.54	0.61	2.95
6	Oncorhynchus tshawytscha	Salmonidae	0.3	31	54.4	2	0	0.16	0.16	1.31	1.36	0.85	0.88
			0.4	23.5	29.4	1	0	0.37	0.09	0.55	2.33	0.36	1.51
7	Clupea pallasii	Clupeidae	0.4	16	21.6	1	0	0.14	0.01	0.06	0.91	0.04	0.58
8	Ammodytes hexapterus	Ammodytidae	0.1	2.3	4.6	1	0	16.3	0	0.07	392	0.04	254
9	Diaphus theta	Myctophidae	0.1	2.3	8.5	15	15	36.1	0.07	1.76	899	1.14	583
10	Stenobrachius leucopsarus	Myctophidae	0.1	0	10.5	20	20	336	0.06	1.52	8475	0.98	5499
11	Symbolophorus californiense	Myctophidae	0.1	9	20.3	8	8	0.67	0.01	0.14	16	0.09	10.4
12	Tarletonbeania crenularis	Myctophidae	0.1	1.9	8.2	21	21	372	0.49	12.1	9256	7.87	6006
13	Lipolagus ochotensis	Bathylagidae	0.1	0	18.1	7	7	4.29	0.02	0.57	102	0.37	66.2
14	Anotopterus nikparini	Anotopteridae	0.3	28.8	41	4	0	0.08	0	0.03	0.65	0.02	0.42
15	Sebastes melanops	Sebastidae	0.5	41.9	52.1	2	0	0.06	0.1	0.52	0.31	0.34	0.2
16	Sebastes sp.	Sebastidae	0.1	0.6	3.8	6	2	146	0.01	0.17	3518	0.11	2283
17	Sebastes sp. 2	Sebastidae	0.1	1.3	2.5	2	0	9	0	0.03	219	0.02	142
18	Trichodon trichodon	Trichodontidae	0.5	29	29	1	0	0.02	0.01	0.03	0.1	0.02	0.07
19	Thalassenchelys coheni	Xenocongridae	0.1	23.5	33.5	6	5	0.37	0.02	0.54	9.23	0.35	5.99
20	Glyptocephalus zachirus	Pleuronectidae	0.1	6	6	1	1	0.02	0	0	0.51	0	0.33
21	Microstomus pacificus	Pleuronectidae	0.1	0	5.8	10	8	1.52	0	0.03	37	0.02	24
22	Pleuronectidae (мол.)	Pleuronectidae	0.1	1.5	2.1	1	0	8.63	0	0.02	219	0.01	142
23	Citharichthys sordidus	Paralichthyidae	0.1	2	3.6	4	3	1.08	0	0	25.9	0	16.8
24	Citharichthys stigmaeus	Paralichthyidae	0.1	0	4.1	7	5	5.9	0	0.04	142	0.02	91.9

N	Species	Family	q	Lmin	Lmax	F	NF	Average catch, ind	Average catch, kg	Relative abundance, ind/sq.km	Relative biomass, kg/sq.km	Total biomass, ths. t.	Total abundance, mln. Ind.
Squids													
25	Onychoteuthis borealijaponica	Onychoteuthidae	0.1	6.1	25	17	15	6.81	0.78	19.3	168	12.5	109
26	Boreoteuthis borealis	Gonatidae	0.1	1.9	13.9	17	17	9.1	0.05	1.32	225	0.85	146
27	Gonatidae sp.	Gonatidae	0.1	1.1	3.9	7	7	1.48	0.01	0.13	37.6	0.09	24.4
28	Okutania anonycha	Gonatidae	0.1	3	8.1	5	4	5.9	0.04	1.01	146	0.66	94.5
29	Doryteuthis opalescens	Loliginidae	0.1	5	9	0	0	7	0.15	3.85	178	2.49	115
30	Dosidicus gigas	Ommastrephidae	0.1	1.5	5.4	1	1	0.12	0	0.01	3.08	0.01	2
31	Japetella diaphana	Bolitaeninae	0.1	3.5	3.5	1	1	0.02	0	0	0.48	0	0.31
32	Chiroteuthis calyx	Chiroteuthidae	0.1	0	0	1	1	0.02	0	0	0.51	0	0.33
33	Abraliopsis felis	Enoploteuthidae	0.1	1.9	5.6	16	15	25.2	0.07	1.76	627	1.14	407
Jellies													
34	Aequorea sp.	Aequoreidae	0.1	0	0	41	17	0	1.21	29.7	0	19.3	0
35	Calycopsis nematophora	Bythotiaridae	0.1	0	3.1	2	2	0.57	0	0.02	14.1	0.02	9.12
36	Corolla calceola	Gastropoda, Cymbuliidae	0.1	0	3	12	7	8.61	0.05	1.18	193	0.76	125
37	Chrysaora melonaster	Pelagiidae	0.1	13	32	5	3	0.69	0.49	12.1	17.1	7.82	11.1
38	Periphylla periphylla	Periphyllidae	0.1	2.5	2.5	1	1	0.02	0	0	0.5	0	0.32
39	Hormiphora cucumis	Pleurobrachiidae	0.1	0	4.5	37	16	19.5	0.16	4.01	466	2.6	302
40	Pterotrachea sp.	Pterotracheidae	0.1	0	5.5	5	3	0.27	0	0.01	6.49	0.01	4.21
41	Salpa aspera	Salpidae	0.1	0	0	2	2	0.02	0.01	0.25	0.5	0.16	0.33
42	Phacellophora camtshchatica	Scyphozoa, Phacellophoridae	0.1	0	53	16	10	0.69	0.73	17.9	16.8	11.6	10.9
43	Aurelia labiata	Ulmaridae	0.1	0	23	11	4	0.29	0.07	1.63	6.93	1.06	4.5
44	Aurelia limbata	Ulmaridae	0.1	22	22	1	0	0.02	0.01	0.27	0.46	0.17	0.3
Crustaceans													
45	Euphausiidae gen. sp.	Eupausiidae	0.1	0	3.5	23	20	682	9.12	229	64990	149	42166
46	Pasiphaea pacifica	Pasiphaeidae	0.1	0	0	1	1	2.96	0	0.05	74.4	0.03	48.2

Remark. F—Frequency of occurrence, FN—frequency of occurrence during night-time trawls

Table 4. Technical parameters of trawls and Pacific salmon catches

№	X	Y	Date/time*	Technical parameters						Conditions					Total catch, kg	Salmon catch, ind (kg)				
				AS	HD	VO	HO**	W	Course	Depth, m	SST	Wind	Waves, m	Day/night		Sockeye	Coho	Chum	Pink	Chinook
1	-128.06	48.42	12.03.20 21:20	4.9	14.2	11.8	46.2	275	110	2600	8.5	W 7 m/s	1.8	night	4.312	-	-	-	-	-
2	-129.52	48.42	13.03.20 9:00	5.2	2.0	15.8	44.2	240.3	160	2000	8.7	NE 13 m/s	3	day	1.495	-	-	-	-	-
3	-136.98	47.42	15.03.20 11:13	4.7	0.0	17	46.8	277.7	70	4100	8.5	NE 7 m/s	2	day	109.3	-	-	165 (76.2)	126 (33.1)	-
4	-138.51	47.40	15.03.20 22:19	5	0.0	16	46.7	260.2	60	4150	8.3	N 6 m/s	1	night	82.53	-	96 (67.3)	10 (13.1)	-	-
5	-138.54	47.33	16.03.20 0:30	4.6	28.7	8.7	51.2	384	208	4200	8.3	N 5 m/s	1	night	2.267	-	2 (1.32)	-	-	-
6	-140.00	47.41	16.03.20 9:55	5.3	0.0	18.8	43.7	236.2	191	4200	8.3	N 8 m/s	1	day	0.118	-	-	-	-	-
7	-141.49	47.44	16.03.20 19:08	5.3	0.0	17.7	45.5	254	191	4300	8.4	NE 3 m/s	0.5	day	1.317	-	-	-	2 (1.04)	-
8	-142.98	47.43	17.03.20 4:02	4.7	0.0	18.3	45.2	260	202	4400	8.2	N 3 m/s	0.5	night	8.702	-	-	-	-	-
9	-143.01	48.40	17.03.20 13:39	5.4	0.0	18.2	44.3	242	284	4300	7.7	light	0.5	day	3.267	-	2 (1.57)	-	-	-
10	-144.48	48.40	17.03.20 22:02	5.2	0.0	18	44.8	248.8	260	4400	7.5	calm	0.5	night	11.02	-	-	1 (2.25)	-	-
11	-145.98	48.42	18.03.20 6:52	5.1	0.0	18	44.8	246.5	253	4600	7.1	calm	0.5	night	5.244	-	3 (1.25)	1 (1.49)	-	-
12	-147.50	48.39	18.03.20 15:20	5.1	2.2	17.7	45	261.2	7	4800	7.4	NW 3 m/s	0.5	day	1.601	-	-	1 (0.81)	-	-
13	-147.53	49.41	19.03.20 0:12	4.8	0.0	17.7	45.3	255	101	4600	6.7	NW 12 m/s	1.5	night	12.71	3 (1.67)	2 (0.92)	-	-	-
14	-147.51	50.42	19.03.20 11:21	5.2	3.7	16	44.8	254.7	157	4500	6.5	N 7 m/s	1	day	2.028	-	-	1 (1.39)	-	-
15	-147.51	50.32	19.03.20 13:24	4.8	30.5	8.7	51.5	392.5	8	4500	6.5	N 7 m/s	1.5	day	1.308	-	-	-	-	-
16	-147.52	51.40	18.03.20 23:22	4.9	2.5	19	43.5	243.7	98	3100	5.4	N 10 m/s	1	night	24.62	15 (4.46)	-	1 (1.41)	-	-
17	-146.02	51.42	20.03.20 8:09	4.9	1.7	19.2	43.5	248	156	4200	5.7	NE 9 m/s	1	day	13.09	10 (3.27)	-	3 (2.37)	-	-
18	-145.96	51.34	20.03.20 10:13	4.7	29.2	11.3	50.3	397.8	310	4300	5.7	NE 9 m/s	1	day	7.533	-	-	-	-	-
19	-146.01	50.41	20.03.20 19:03	5.2	5.5	17.8	42.5	240	162	4050	6.9	N 5 m/s	1	day	19.1	-	-	20 (18)	-	-
20	-144.50	50.40	21.03.20 3:56	4.6	4.8	18.2	43.2	248.5	350	4180	7.3	light	0.5	night	11.79	1 (0.46)	6 (3.24)	-	-	-
21	-144.51	51.50	21.03.20 13:03	5.1	5.2	17	43.3	253.2	84	4156	6.1	SW 7 m/s	1	day	4.844	1 (0.69)	-	-	-	-
22	-143.01	51.48	21.03.20 21:19	5	7.8	16	42.5	240	16	4077	6.5	SW 13 m/s	1.5	night	9.245	1 (0.25)	-	-	-	-
23	-140.04	53.38	22.03.20 2:07	5.3	4.0	18.3	41.8	230.7	105	3550	5.9	NW 14 m/s	2.5	night	19.86	-	-	-	-	-
24	-135.55	54.35	24.03.20 8:25	5.5	0.0	20	43.8	244	124	2950	6.6	NW 6 m/s	1.5	day	1.023	-	-	-	-	-
25	-134.04	54.56	24.03.20 16:22	4.7	2.0	18	44.8	260.8	104	226	6.9	WNW 7 m/s	1	day	22.38	14 (2.89)	-	22 (14.1)	7 (2.03)	-
26	-132.47	54.39	26.03.20 5:40	5.7	6.8	21.2	37.7	197.5	279	250	6.1	W 7 m/s	0.5	night	3.987	-	-	-	1 (0.41)	-
27	-134.00	54.40	26.03.20 13:43	5.5	1.7	18.3	38.5	168.3	95	290	6.3	W 3 m/s	0.5	day	36.19	-	-	-	-	-
28	-134.03	53.42	26.03.20 23:03	5.1	0.0	21	42.8	236.7	147	2850	6.8	W 7 m/s	0.5	night	27.57	-	-	1 (1.64)	-	-
29	-135.48	53.41	27.03.20 8:19	5.2	0.7	20.5	44.2	261.8	252	2000	6.8	W 7 m/s	0.5	day	12.46	-	-	4 (6.11)	-	-
30	-137.03	53.41	27.03.20 16:48	5.1	0.0	21	42.3	231.7	113	3300	6.6	W 11 m/s	1	day	7.631	1 (1.45)	-	-	-	-
31	-137.03	52.40	28.03.20 2:36	5.3	0.0	21.2	42.3	231.7	100	4100	6.4	W 10 m/s	1.5	night	12.1	1 (0.77)	1 (0.34)	-	-	-
32	-138.65	52.40	28.03.20 21:28	4.9	0.0	20.2	42.8	229.7	90	3550	6.4	W 12 m/s	2.5	night	16.87	1 (0.22)	-	-	-	-

№	X	Y	Date/time*	Technical parameters						Conditions					Total catch, kg	Salmon catch, ind (kg)				
				AS	HD	VO	HO**	W	Course	Depth, m	SST	Wind	Waves, m	Day/ night		Sockeye	Coho	Chum	Pink	Chinook
33	-138.58	51.41	29.03.20 12:20	5	1.5	19.7	43	239.5	98	3600	6.6	W 13 m/s	1.5	day	0.85	-	-	-	-	-
34	-138.56	50.41	31.03.20 5:25	5.1	0.0	20.5	42.5	228.3	110	3600	6.8	NW 10 m/s	2	night	8.407	2 (0.93)	2 (1.72)	-	-	-
35	-138.52	49.46	31.03.20 13:50	4.8	0.0	20.3	43.3	239.8	165	3700	7.3	N 5 m/s	1	day	0.196	-	-	-	-	-
36	-140.00	49.44	31.03.20 22:36	5	0.0	20	43.3	233.8	177	3800	7.3	light	0.5	night	9.125	-	-	1 (0.92)	-	-
37	-141.51	49.43	01.04.20 8:05	5	0.0	19.7	44.5	255	175	3850	7.3	N 2 m/s	0.5	day	1.497	-	-	-	-	-
38	-141.49	48.41	01.04.20 16:26	5	0.0	19.5	45.3	272.3	118	4200	8.1	light	0.5	day	0.662	-	-	-	-	-
39	-140.02	48.38	02.04.20 0:38	4.9	0.7	20.7	43.7	259.2	41	4070	7.8	E 5 m/s	0.5	night	1.603	-	-	-	-	-
40	-138.51	48.42	02.04.20 9:31	5.2	0.0	20.7	43.7	244.7	119	3600	8	E 5 m/s	0.5	day	1.307	-	-	-	-	-
41	-138.48	47.38	02.04.20 18:27	5	0.0	19.7	43.7	240.5	316	4150	8.1	SE 7 m/s	1	day	0.654	-	-	-	-	-
42	-138.49	46.37	03.04.20 5:20	4.8	0.0	19.8	43.2	234.8	35	4250	9.4	N 5 m/s	1.5	night	5.143	-	-	-	-	-
43	-136.96	47.40	03.04.20 16:37	5.2	0.0	20.3	43.3	236.2	278	4100	8.7	E 3 m/s	0.5	day	0.001	-	-	-	-	-
44	-135.42	47.40	04.04.20 2:40	5	0.0	20	43.8	243	102	4000	8.7	NW 5 m/s	0.5	night	5.722	-	-	-	-	-
45	-133.98	47.40	04.04.20 11:06	4.9	0.0	20	43.2	234.7	114	4000	8.8	N 3 m/s	0.5	day	0.366	-	-	-	-	-
46	-132.51	47.41	04.04.20 19:20	4.8	0.0	17.5	46.3	273.7	104	3200	8.8	N 10 m/s	1	day	1.178	-	-	-	-	-
47	-131.07	48.41	05.04.20 6:36	5.1	0.7	20	42.7	233.3	110	2900	8.4	NW 10 m/s	1	night	8.617	1 (0.16)	4 (3.38)	3 (3.65)	-	-
48	-130.15	48.42	05.04.20 12:04	5.1	1.8	19.2	43.5	244.7	117	2000	8.5	N 10 m/s	1	day	1.196	-	-	-	-	-
49	-129.12	48.43	05.04.20 17:22	5.4	0.5	19.7	43.8	248.7	129	2400	8.3	N 8 m/s	0.5	day	0.18	-	-	-	-	-
50	-128.02	48.41	04.04.20 23:10	4.8	0.0	19.2	47.3	303	114	2650	8.8	N 7 m/s	1	night	23.6	-	-	-	-	-
51	-126.20	48.48	06.04.20 7:55	5.6	1.0	21	40.2	206.5	118	465	8.9	NWN 3 m/s	0.5	day	24.85	-	-	-	-	2 (3.42)
52	-125.45	48.51	06.04.20 12:25	4.7	5.7	17.3	45.3	292.7	35	95	9	light	0.5	day	82.52	-	-	-	-	24 (8.6)

Remark: *—Vancouver time; **—estimated parameter (see material and methods); AS—Average speed, nm; HD—Headrope depth, m; VO—Vertical opening, m; HO—Horizontal opening, m; W—Warps, m