Comparison of fishery and survey length distributions of Alaskan Pacific cod (*Gadus macrocephalus*): is there a mismatch?

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# Abstract

Scientific surveys provide the foundation for sound, effective management of fishery resources. Both survey and fishery data are integral to observing fish population trends, however, bias in sampling gear and operating hours may confound shifts in species distributions that likely occur over time and space. Pacific cod *Gadus macrocephalus* is a large-bodied gadid with a range that extends across the entire North Pacific Ocean. Pacific cod supports a large commercial fishery where multiple gear types are used to annually harvest fish in the Aleutian Islands, and Eastern Bering Sea, the focus areas for this study. Pacific cod undergo seasonal migrations during the winter months (January – April) when adult cod form large, dense aggregations in specific areas throughout the Eastern Bering Sea and Aleutian Islands. In the summer months Pacific cod are widely distributed across their range, presumably to feed. These seasonal shifts can complicate management models when incorporating fishery and survey data types. In this study we examined the overlap in time and space of Pacific cod length frequencies measured in the bottom-trawl fishery and the scientific survey, where a discrepancy in Pacific cod size distributions have been consistently observed for many years. When standardizing observations of adult, mature fish in time and space, there was no observed difference in the size distribution of Pacific cod between the bottom-trawl fishery and the survey in the Eastern Bering Sea. However, the size discrepancy remained when examining Pacific cod in the bottom-trawl fishery and survey in the Aleutian Islands. Population-dynamic models can account for these differences in the survey and fishery selectivity, as long as models are informed by sufficient data. Because the bottom-trawl fishery for Pacific cod primarily targets spawning aggregations in the winter months, care should be taken in management as they are considered among the most vulnerable fisheries.

# Keywords

Pacific cod, Gadus macrocephalus, fishery length distributions, survey length distributions

# 1.0 Introduction

Scientific surveys provide the foundation of effective management of commercial fish stocks (Kimura and Somerton, 2006; Walker et al., 2017). In the federal marine waters of Alaska, abundance and size structure of most groundfish species are measured primarily through National Marine Fisheries Service (NMFS) annual or biennial bottom-trawl surveys. These standardized surveys assume accurate sampling of multiple species distributions; however, the surveys primarily occur during summertime months (e.g., May, June, July, and August) and may or may not accurately capture seasonally shifting distributions of fish species. Several examples of shifting fish distributions include poleward shifts due to a warming climate, diel vertical migration to seek optimum conditions for feeding, digestion, and avoiding predation, and ontogenetic shifts in distribution as fish mature and biological needs change (Stevenson and Lauth, 2018; Barbeaux and Hollowed, 2018; Spies et al., 2019; Campana et al., 2020).

The Pacific cod *Gadus macrocephalus*, is an example of a fish species that undergoes a seasonal shifting distribution. It is a large marine gadid with a range that extends across the entire North Pacific (Shimada and Kimura, 1994). Recent studies have supported their migratory behavior, based on mark-recapture and satellite telemetry tagged Pacific cod, where changes in the both the spatial (e.g., northward) and temporal (e.g., seasonal) distribution patterns of Pacific cod in the Aleutian Islands and Eastern Bering Sea have been documented (Bryan et al., In Review; Rand et al., 2014). In winter (January - April), adult Pacific cod are known to form dense spawning aggregations at specific locations throughout their range (Neidetcher et al., 2014; Shimada and Kimura, 1994). Multiple genetics studies indicate that Pacific cod home to their natal spawning areas each winter (Drinan et al., 2018; Spies et al., 2019).  Shortly after spawning, Pacific cod disperse widely across the Eastern Bering Sea during the summer and fall months, presumably to feed (Shimada and Kimura, 1994; Rand et al., 2014). These shifts in the distribution of Pacific cod can complicate survey and fishery estimates of size compositions based on temporally mismatched samples. For example, NMFS bottom trawl surveys (hereafter termed “NMFS survey”) take place in the summer across the extent of the Eastern Bering Sea where Pacific cod are counted, weighed, and measured. The Pacific cod bottom-trawl fishery (hereafter termed "bottom-trawl fishery”) actively targets Pacific cod aggregations in the preceding winter months, mostly focused on small spatial areas near the shelf and shelf break and within the vicinity of Unimak Pass (Neidetcher et al., 2014). The concentration of the spawning aggregations likely makes winter the most efficient time for bottom-trawl fishers to harvest Pacific cod. For example, the Eastern Bering Sea bottom-trawl fishery’s highest catch-per-unit-effort of Pacific cod occurs during spawning season (Thompson et al., 2020).

Survey and fishery disparities in time have created a persistent mismatch between the length distributions of Pacific cod from the (winter) bottom-trawl fishery on aggregations of spawning adults, and the (summer) NMFS surveys that sample the entire feeding population (Thompson, 2018; Spies et al., 2020). This disparity exists across gear types, including longline and pots that target Pacific cod. The NMFS survey, on average, records smaller Pacific cod than those observed in all fishery gear types that target Pacific cod. This has direct implications within the Pacific cod stock assessment models when evaluating selectivity parameters related to the NMFS survey and the fishery. Stock assessment models use survey data to provide reference points for setting fishery quotas. In the Eastern Bering Sea Pacific cod stock assessment model, fishery selectivity-at-length is modeled as asymptotic, where fish less than 40 cm are not captured by the fishery, and nearly full selectivity by 69 cm (mid-year) (Thompson et al., 2020). Alternatively, a dome-shaped selectivity pattern has been considered using the NMFS survey data which implies that larger Pacific cod are not entirely available to the NMFS survey gear, but this is somewhat controversial (Weinberg et al. 2016).

It is still unknown whether the NMFS survey and bottom-trawl fishery produce representative samples of Pacific cod lengths, or if they are instead capturing different segments of the population due to differences in gear or spatiotemporal availability. In this study, we address this question by examining the mismatch in length distributions between the Pacific cod bottom-trawl fishery and NMFS survey with respect to time and space. To control for gear type, we focused solely on the bottom-trawl fishery, because the effects of capturing fish using baited gear (e.g., longline and pots) on the length distribution of the catch is complex and unknown for Pacific cod (Stoner and Ottmar, 2004). We hypothesized in this study that the NMFS survey and bottom-trawl fishery length distribution mismatch for Pacific cod can be explained by a lack of spatial and temporal overlap between fish that are available to the NMFS survey in the summer and the bottom-trawl fishery which primarily occurs in the winter. To test this hypothesis, we used length data from the NMFS survey and bottom-trawl fishery in which Pacific cod were measured from the catch that spatiotemporally overlapped to determine if the Pacific cod length distribution mismatch persists. We hypothesized that if a mismatch in distributions remains when examining this overlap in time and space, then large gear disparities between the NMFS survey and bottom-trawl fishery might contribute to the length distribution mismatch or that the NMFS survey may in fact be missing portions of the Pacific cod populations during the summer months due to Pacific cod availability differences between the NMFS survey and the commercial fishery.

# 2.0 Materials and Methods

To assure the most adequate overlap in time and space, Pacific cod lengths from the Aleutian Islands and Eastern Bering Sea bottom-trawl fishery and NMFS survey were used in these analyses (Figure 1). All Pacific cod raw length measurements from the bottom-trawl fishery used in this study were obtained from the North Pacific Fisheries Monitoring and Analysis division (NMFS Observer Program), which monitors groundfish activities in the federal fisheries off the coast of Alaska (AFSC, 2018). Specifically, the length frequencies were from bottom-trawl fishing vessels, which had full NMFS observer coverage and were either actively targeting Pacific cod or Pacific cod was the dominant catch in the haul as observed by the fishery observer (i.e., bycatch). All Pacific cod length measurements from the NMFS survey were obtained from the NMFS standardized bottom-trawl surveys and were randomly collected from each haul that captured Pacific cod, generally operating between the hours of 0700 and 1900 (Lauth et al., 2019).

## **2.1 Length Measurement Summary**

To test our hypothesis that the observed length distribution mismatch between the bottom-trawl fishery and NMFS is due to lack of seasonal overlap, we examined only those length measurements that spatially and temporally overlapped in the summer months (May – August) within the Aleutian Islands and Eastern Bering Sea. Because there few Pacific cod length measurements in the summer months from the bottom-trawl fishery, we tested at a coarse spatial level – Aleutians Islands-wide and Eastern Bering Sea-wide. We displayed the length distribution from the bottom-trawl fishery in the winter months only to contrast with those observed in the summer months, in effect illustrating the mismatch in length distributions. The Pacific cod winter length measurements from the bottom-trawl fishery were not used in subsequent analyses.

The bottom-trawl fishery conducts fishing operations 24h around the clock thus we examined median length measurements of Pacific cod at 1h intervals during the summer months to determine if the size of fish captured at each hour over a 24h period varied significantly. We noted no significant differences in measured Pacific cod lengths by time of day, however, to maintain the same temporal overlap, only lengths that were measured to coincide with the NMFS survey operating hours from 0700 – 1900 were included in the analysis.

The length measurements from male, female, and unsexed Pacific cod were combined in these analyses within the respective bottom-trawl fishery and NMFS survey datasets.

The NMFS survey net has much smaller mesh sizes (3.1 cm mesh codend liner, Stauffer, 2004) and is designed to capture the breadth of Pacific cod sizes, whereas the bottom-trawl fishery gear has larger mesh sizes and therefore will avoid, in general, capturing small fish. To standardize the observations, the mature portion of the Pacific cod length distribution from the NFMS survey was estimated in order to make comparisons between the NMFS survey and the bottom-trawl fishery. To do this, we used length-based 50% maturity curves that were obtained from Spies et al., (2020) for the Aleutian Islands and from Stark (2007) for the Eastern Bering Sea and noted those fish as "mature" to test our hypothesis. The maturity estimates reach asymptotes, where almost all fish are considered mature, at approximately 86 cm in the Aleutian Islands (≥ 98%) and 88 cm (≥ 98%) in the Eastern Bering Sea. We multiplied the total number of measured Pacific cod lengths per cm and percent mature starting at 21 cm through the range of measured fish sizes.

To account for the vast differences between the NMFS survey gear and the bottom-trawl fishery gear, we only used Pacific cod length measurements greater than ≥ 45 cm based on the on the fact that fishery gear only begins to catch fish at lengths greater than 44 cm (mid-year); catch rates for fish in the 40-45 cm range are minimal (Thompson et al., 2020). This allowed a more formal comparison between the bottom-trawl fishery and NMFS survey length measurements of Pacific cod during the summer months.

We used the Mann-Whitney test to compare the bottom-trawl length frequency distributions of Pacific cod to the NMFS survey length frequency distribution of Pacific cod. The total number of Pacific cod length measurements examined from the bottom-trawl fishery and the NMFS survey in the Aleutian Islands and Eastern Bering Sea are summarized in Table 1.

## **2.2 Aleutian Islands (1991 – 2018)**

### **2.2.1 Bottom-Trawl Fishery Data**

Pacific cod length distributions from the bottom-trawl fishery in the Aleutian Islands were examined between the years 1991 – 2018 during the summer months only (May – August), to coincide with the NMFS survey. All raw measured lengths are shown as the proportion per cm bin. Because bottom-trawl data was very limited in the summer months, the area of analysis spans the entire Aleutian Islands management area. Additionally, it should be noted that there are very few length measurements from the bottom-trawl fishery in the Aleutian Islands in the summer months (<200) during the 2010 – 2018 time-period (which roughly coincides with the time period examined in the Eastern Bering Sea) due to fishery management changes (i.e., closures) and shifts in fishing behavior; therefore, we included a longer time series (1991 – 2018). All bottom-trawl fishery length measurements were aggregated to the Aleutian Islands NMFS survey grid, which measures 5 km x 5 km for each grid cell, using ESRI ArcGIS 10.8, in order to display the median length of Pacific cod. Aggregating fishery data over several years and grid cells ensured vessel and haul confidentiality. The total number of measured lengths is summarized in Table 1.

### **2.2.2 NMFS Survey Data**

Pacific cod length distributions from the NMFS survey in the Aleutian Islands were examined between the years 1991 – 2018 during summer months (May – August) when the survey occurs. All raw measured lengths are shown as the proportion per cm bin. The Aleutian Islands NMFS survey takes place biennially; however, there was no survey in 1993 and the next survey occurred in 1994; there was also no survey in 2012. The NMFS survey uses a Poly Nor’Eastern trawl net (Stauffer 2004). The NMFS survey is an index survey based on a stratified-random design of previously successful stations. Stations are allocated among measured strata and a grid of 5 km x 5 km cells is overlain over the survey area and stations are targeted to fit within the preselected grid of the station (Figure 1). Stations within grids are surveyed in habitat that is trawlable to the NMFS survey gear. All NMFS survey length measurements were aggregated to the 5 km x 5 km NMFS survey grid. The total number of measured lengths is summarized in Table 1.

## **2.3 Eastern Bering Sea (2009 – 2018)**

### **2.3.1 Bottom-Trawl Fishery Data**

Pacific cod length distributions from the bottom-trawl fishery in the Eastern Bering Sea were examined between the years 2009 – 2018 during the summer months only (May – August), to coincide with the NMFS survey. All raw length measurements are shown as the proportion per cm bin. All bottom-trawl fishery length measurements were aggregated to the Eastern Bering Sea NMFS survey grid, which measures 20 nmi x 20 nmi for each grid cell, using ESRI ArcGIS 10.8, in order to display the median length of Pacific cod. Aggregating fishery data over several years and grid cells ensured vessel and haul confidentiality. The total number of length measurements is summarized in Table 1. In the case of the Eastern Bering Sea, Pacific cod length measurements from the bottom-trawl fishery were spatially limited in the summer months to certain portions of the Eastern Bering Sea shelf. Therefore, NMFS survey length measurements were confined to areas where the bottom-trawl fishery locations overlapped with NMFS survey (Figure 1).This eliminated less than 5% of the Pacific cod length measurements from the bottom-trawl fishery in the summer from the NMFS survey extent (i.e. those hauls that occurred outside the Eastern Bering Sea NMFS survey grid cells) (Figure 1).

### **2.3.2 NMFS Survey Data**

Pacific cod length distributions from the NMFS survey in the Eastern Bering Sea were examined between the years 2009 – 2018 during summer months (May – August) when the survey occurred. All raw length measurements are shown as the proportion per one centimeter bin. The Eastern Bering Sea NMFS survey takes place on an annual basis and conducts a single tow within each 20 nmi x 20 nmi grid cell, across the entire Eastern Bering Sea shelf and shelf break from 13 m to approximately 300 m, with occasional gear depths recorded up to 420 m off the shelf break (Figure 1). All NMFS survey length measurements were aggregated to the 20 nmi x 20 nmi grid NMFS survey grid (Table 1).

# 3.0 Results

Pacific cod length summary statistics for the bottom-trawl fishery and NMFS survey Pacific cod length measurements are summarized in Table 2.

## **3.1 Aleutian Islands (1991 – 2018)**

Approximately 83% of the Pacific cod captured in the bottom-trawl fishery during the summer months were considered mature, whereas 87% of fish captured during the winter fishery (January – April) were mature (Table 1). During the summer months, 53% of Pacific cod from the NMFS survey were considered mature (Table 1).  The median length of mature fish ≥ 45 cm for the bottom-trawl fishery, May – August, was 76 cm and 68 cm for the NMFS survey (Table 1, grey rows). The average median lengths for all Pacific cod lengths by NMFS survey grid cell, May – August, are shown in Figure 2a-d. For the bottom-trawl fishery, measured Pacific cod lengths were sparse in the western Aleutian Islands (Figure 2a), and likely occurred as bycatch in other fisheries. The median of all measured Pacific cod lengths for the NMFS survey illustrated broad coverage of both the east and western Aleutian Islands; Pacific cod with a median length between 86 and 104 cm occurred in the western Aleutian Islands (Figure 2c-d).

Pacific cod length distributions for the Aleutian Islands (Figure 3a-c) show different modes for the bottom-trawl fishery (summer), NMFS survey, and winter bottom-trawl fishery(Table 2). When examining only the mature Pacific cod in the bottom-trawl fishery and NMFS survey in the summer months, the fish were greater length in the bottom trawl fishery than in the NMFS survey (Figure 3b). The Mann-Whitney test on the length distributions for mature fish ≥ 45 cm during the summer months confirmed this observation and revealed a significant difference in the median length between the NMFS survey and the bottom-trawl fishery (Figure 3b and Table 2; W=64423783, *p*-value < 0.001). The winter bottom-trawl fishery “All Lengths” and “Mature” fish are very similar and illustrate that the winter fishery primarily targets larger, mature fish (Figure 3c).

## **3.2 Eastern Bering Sea (2009 – 2018)**

There was no difference noted in the median length and standard deviation of Pacific cod length measurements by hour (24h) from those fish captured in the bottom-trawl fishery (Figure 4, n=19,092). Approximately 55% of the Pacific cod caught in the bottom-trawl fishery during the summer months were considered mature, whereas 69% of fish captured during the winter fishery (January – April) were mature (Table 1). During the summer months, 23% of the Pacific cod captured in the NMFS survey were mature (Table 1). The median length of mature  ≥ 45 cm fish for the bottom-trawl fishery during May – August was 61 cm; the median length of mature ≥ 45 cm fish for the NMFS survey was 60 cm (Table 1, grey rows). The average median lengths for all Pacific cod lengths by NMFS survey grid cell during May – August show that median sizes 16 - 50 cm fish are almost entirely located on the inner to middle Eastern Bering Sea shelf as designated by the green and blue grid cells  (Figure 5b). The bottom-trawl fishery observed the smallest fish (32 - 50 cm median size) within the same region as the NMFS survey (Figure 5a). Figure 5b also illustrates the shift from small Pacific cod on the Eastern Bering Sea shelf and large Pacific cod (Figure 5b, orange and brown grid cells) located along the shelf break.

Pacific cod length distributions for the Eastern Bering Sea are shown in Figure 6a-c. The modes for the bottom-trawl fishery (summer), NMFS survey, and winter bottom-trawl survey, all differ (Table 2; Figure 6a). When only examining the bottom-trawl fishery and NMFS survey in the summer months (Figure 6b), the modes were well aligned (Figure 6b). The Mann-Whitney test on the length distributions for mature fish ≥ 45 cm during the summer months revealed no difference in the medians between the NMFS survey and the bottom-trawl fishery (Figure 6b and Table 2; W=118173419, p-value=0.23). Similar to what was observed in the Aleutian Islands, the winter bottom-trawl fishery in the Eastern Bering Sea primarily targets fish of mature size, which are likely pre-spawning or actively spawning (Figure 6c).

# **4.0 Discussion**

Pacific cod population distributions in Alaskan waters vary seasonally, based on tagging studies and patterns observed in the bottom-trawl fishery and NMFS survey catch data (Shimada and Kimura, et al., 1994; Bryan et al., In review). Pacific cod seasonal movements complicate population-dynamic models which rely on data collected by the fishery and NMFS survey. These data are used to inform model parameters such as selectivity, which is a function of gear and the size of fish that can be retained by the gear. In the case of Pacific cod, the selectivity parameter is highly dependent on the seasonal availability of fish to multiple gear types. In the Eastern Bering Sea, given the same time and space, the bottom-trawl fishery and NMFS survey observed the same size distributions of Pacific cod when accounting for Pacific cod maturity and removing small fish from the analysis which the bottom-trawl fishery trawls were designed to avoid, however, this was not the result in the Aleutian Islands. Because our study could align those differences in size distributions between the bottom-trawl fishery and NMFS survey when accounting for spatiotemporal overlap in the Eastern Bering Sea, our results adds to the existing body of evidence that the NMFS survey likely represents the summer distribution of Pacific cod. In addition, the NMFS survey is designed to sample across the range of fish sizes, and we did not observe an upper size range of Pacific cod in the bottom-trawl fishery that wasn't observed in the NMFS survey, in both the Aleutian Islands and Eastern Bering Sea. Our observations do indicate the fact that the NMFS survey is catching immature fish at a much higher rate than the bottom-trawl fishery. When equalizing space, and time, and eliminating small fish from the analysis which the bottom-trawl fishery trawls are designed to avoid, it appears that there is little or no NMFS gear selectivity for mature Pacific cod ≥ 45 cm. Gear selectivity differences do occur on the small end of the size spectrum for Pacific cod (i.e., the bottom-trawl fishery cannot capture Pacific cod less than 40 cm).

The bottom-trawl fishery and NMFS survey Pacific cod length distributions in the Aleutian Islands remain significantly different and the bottom-trawl fishery captures larger Pacific cod regardless of the fact that only mature fish, ≥ 45 cm, are considered. We speculate several spatial and temporal reasons for this result. When examining the NMFS survey effort across the Aleutian Islands, the number of grid cells that the NMFS survey has visited is comprehensive, which includes sampling of areas the bottom-trawl fishery may not fish (i.e., no large cod) and those size classes that are not observed in the bottom-trawl fishery data (i.e., small cod) (Figure 2a-c). Bottom-trawl fishery length measurements for Pacific cod in the Aleutian Islands during the summer months were sparse. Those patterns in the length distribution mismatch between the bottom-trawl fishery and NMFS survey noted in the Pacific cod stock assessment are likely exacerbated by little to no temporal overlap in data across the Aleutian Islands (Spies et al., 2020). This lack of data in the summer months likely reflects bottom-trawl fishing behavior that primarily targets spawning aggregations in the preceding winter months when the fishery targets large, spawning Pacific cod. Reconciling these length distribution mismatches observed in the Aleutian Islands may not be feasible.

The Aleutian Islands are rugose and the bottom-trawl fishery can likely target fishing locations that the NMFS survey may never be able to sample (i.e. rugosity can vary widely within a single grid cell). The observed mismatch in the length distributions can also be due to the wide disparity in bottom fishing gear types used in the Aleutian Islands compared to the Eastern Bering Sea, which is flat with almost no occurrence of untrawlable habitat. In the Eastern Bering Sea, it is assumed that most of shelf and shelf break is available to both the bottom-trawl fishery and the NMFS survey; however, this cannot be assumed for the Aleutians Islands. Examining the Eastern Bering Sea Pacific cod length distributions, and comparing these to the Aleutian Island length distributions could be viewed as a control for the hypothesis that untrawlable grounds and bottom-trawl fishing vs. NMFS survey gear differences are a factor in the observed size range discrepancy in Pacific cod length distributions in the Aleutian Islands.

The indirect comparison we make in this study between bottom-trawl fishing gear and the NMFS survey gear regarding Pacific cod does not directly account for the differences in gear types, however, it warrants further discussion. The efficiency of standardized trawl survey nets has been an area of debate and study since fisheries have been managed (REFS). Trawl survey nets may capture a different size composition of a given species than exists in the true population. This can happen because of gear efficiency (e.g., how well the water column is sampled) and species availability to the survey gear, which varies both across, and within species (Kimura and Somerton, 2006; Walker et al., 2017). Moreover, all sampled species must be available to the gear within the same time and space as the survey operates, and we know this is not true, but can potentially be quantified or measured for a given species (REF). Weinberg et al. (2016) conducted a field study that specifically addressed the NMFS survey selectivity of Pacific cod. The study concluded that the size of Pacific cod captured by the NMFS survey net did not increase, with an increase in either vessel towing speed (e.g., outswimming the net) or acoustic backscatter (e.g., escape above the net) (Weinberg et al., 2016).

As we note with Pacific cod, a species’ availability to the survey gear is important to measure, because marine fish species undergo shifting distributions that can both vary in time and space and can occur on multiple levels (Rouyer et al., 2011; Engelhard et al., 2014). One example is the potential for vertical migrations where fish may not be at or near the bottom and therefore not available to the NMFS survey gear. As related to Pacific cod, when we examined bottom-trawl fishery data by the time of day captured during the summer months, we observed the median size of Pacific cod was consistent regardless of time of capture. If large Pacific cod were known to migrate into the water column during daylight hours to feed (i.e., not available to the NMFS survey gear), we should observed a drop in the median size of capture in the bottom-trawl fishery data during daylight hours. A study by Nichol et al. (2007), using archival tagged fish, estimated that between 47-91% (Eastern Bering sea and Aleutian Islands NMFS trawl gear, respectively) of Pacific cod were available to the NMFS survey net during daytime hours. Although these tagged Pacific cod showed an affinity to the bottom (<10 m) during daylight hours, we can't say definitively that Pacific cod of any size do not exhibit some daytime vertical migrations into the water column. The NMFS survey headrope heights measure 2.5 m in the Eastern Bering Sea (Nichol et al., 2007), and we can assume that unless a fish is hard on bottom, that some portions of the population will avoid capture by the NMFS survey; whether those portions of the Pacific cod population are significantly larger, remains to be examined.

## 4.1 Management Implications

Seasonal migrations of Pacific cod will always confound the temporal aspect of comparing Pacific size distributions for both the Eastern Bering Sea and Aleutian Islands. However, addressing size disparities using simple metrics (e.g., examining data in the same time and space), can help inform fishery management models. Population-dynamic models can account for these differences in the NMFS survey and fishery selectivity, as long as models are informed by sufficient data. Because the bottom-trawl fishery for Pacific cod primarily targets spawning aggregations in the winter months, care should be taken in management as they are considered among the most vulnerable fisheries (Hilborn et al. 2003; Tobin et al. 2013).

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# 7.0 Tables

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Type | Study Area | Type | Year Range | Season | *n* | Mean | Max | Min | Mode | Median |
| Fishery | Aleutian | All Lengths | 1991 – 2018 | May – August | 7,729 | 76 | 123 | 27 | 75 | 77 |
| Fishery | Aleutian | Mature ≥45 cm | 1991 – 2018 | May – August | 6,602 | 79 | 123 | *NA* | 75 | 79 |
| Fishery | Aleutian | All Lengths | 1991 – 2018 | Jan - April | 178,660 | 81 | 139 | 14 | 82 | 82 |
| Fishery | Aleutian | Mature ≥45 cm | 1991 – 2018 | Jan - April | 155,633 | 84 | 139 | *NA* | 82 | 84 |
| Survey | Aleutian | All Lengths | 1991 – 2018\* | May – August | 71,207 | 59 | 117 | 7 | 57 | 59 |
| Survey | Aleutian | Mature ≥45 cm | 1991 – 2018\* | May – August | 37,404 | 70 | 117 | *NA* | 65 | 68 |
| Fishery | Bering Clip | All Lengths | 2009 – 2018 | May – August | 13,498 | 53.5 | 107 | 8 | 48 | 53 |
| Fishery | Bering Clip | Mature ≥45 cm | 2009 – 2018 | May – August | 7,424 | 61 | 107 | *NA* | 59 | 61 |
| Fishery | Bering Clip | All Lengths | 2009 – 2018 | Jan - April | 194,573 | 66 | 122 | 17 | 67 | 66 |
| Fishery | Bering Clip | Mature ≥45 cm | 2009 – 2018 | Jan - April | 133,363 | 70 | 122 | *NA* | 70 | 69 |
| Survey | Bering Clip | All Lengths | 2009 – 2018 | May – August | 145,442 | 43 | 110 | 4 | 46 | 44 |
| Survey | Bering Clip | Mature ≥45 cm | 2009 – 2018 | May – August | 32,984 | 61 | 110 | *NA* | 60 | 60 |

Table 1 Sample sizes for Pacific cod measured lengths data used in the analysis for the Aleutian Islands ("Aleutian") and Eastern Bering Sea ("Bering Clip"). Bering Clip refers to a reduced area of the NMFS survey sampling grid where the bottom-trawl fishery occurs in the Eastern Bering Sea during the summer within the NMFS survey sampling grid (See Figure 1). "Mature" refers to a subset of "All Lengths" using a regionally appropriate 50% maturity estimate per cm of length. The grey rows coincide with the results of the Pacific cod length distribution Mann-Whitney test (See Table 2).

\*NMFS Survey sampling occurred in 1991, 1994, 1997, and 2000; from 2000 – 2018 it occurred biennially, except no sampling in 2008.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Type | Study Area | Type | Year Range | Season | P-value | W | Distribution |
| Fishery/Survey | Bering Clip | Mature ≥45 cm | 2009 – 2018 | May – August | <0.001 | 70612144 | Different |
| Fishery/Survey | Aleutian | Mature ≥45 cm | 1991 – 2018 | May – August | 0.62 | 121991464 | Same |

Table 2 Results of the Pacific cod length distribution test using Mann-Whitney

# 8.0 Figures

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Figure 1 Study areas for the Pacific cod length distributions in the Aleutian Islands and Eastern Bering Sea.

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C:\Users\kimberly.rand\Work\COD\COD PAPER\figures and tables\AI_Survey_542Median_small.tifC:\Users\kimberly.rand\Work\COD\COD PAPER\figures and tables\AI_Survey_541Median_small.tif

Figure 2a-d. Pacific cod median length measurements (cm) from the bottom-trawl fishery (a, b) and the NMFS survey (c, d) for 1991 – 2018 time-period, summer months only (May – August). The left column (a, c) is the far west Aleutian Islands and the right column (b, d) is the east Aleutian Island s.

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Figure 3a-c. Aleutian Islands Pacific cod length frequency distributions (Percent Total) for the bottom-trawl fishery and the NMFS survey for the 1991 - 2018 time period. "All Lengths" include all measured raw lengths, and "Mature" are subsampled length frequencies from "All Lengths" using a 50% maturity estimate for each one cm length (Spies 2020).

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Figure 4. Median length (sd) measurements (n=19,092) for Pacific cod captured by the bottom-trawl fishery only in the summer months (May – August) for the 2009 – 2018 time period. The grey shaded area coincides with NMFS survey operating hours. Only those lengths measured during the NMFS survey operating times are included in the study analysis.

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Figure 5a-b. Eastern Bering Sea Pacific cod median length measurements (cm) from the bottom-trawl survey (a) and NMFS survey (b) for the 2009 – 2018 time-period; median is aggregated to the NMFS survey grid which measures 20 nmi x 20 nmi per grid cell.

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Figure 6a-c. Eastern Bering Sea Pacific cod length frequency distributions (Percent Total) for the bottom-trawl fishery and the NMFS survey for the 2009 to 2018 time period. "All Lengths" include all measured raw lengths, and "Mature" are subsampled length frequencies from "All Lengths" using a 50% maturity estimate for each one cm length (Stark 2007).