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ORIGINAL PAPER

Non-random fishery data can validate research survey observations of Pacific cod (*Gadus macrocephalus*) size in the Bering Sea

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Abstract

Research surveys provide the foundation for sound, effective management of fishery resources and are integral to observing fish population trends. However, bias in sampling gear and operating hours may confound observed shifts in species distributions over space and time. Within North Pacific waters off Alaska, Pacific cod (*Gadus macrocephalus*) support a large, commercial fishery and is an example of a species that experiences spatial and temporal shifts. Seasonal migratory shifts are difficult to incorporate into stock assessment models and are further complicated if research surveys do not effectively sample the underlying size distributions. In the Bering Sea, differences in median fish size between the winter Pacific cod bottom-trawl fishery (directed) and the summer research survey have been observed since the onset of the surveys in the 1980s (66 and 41 cm, respectively). Because of this, it has been suggested that large Pacific cod may not be available to the summer research survey for varying reasons. In this study, we compared standardized observations of mature Pacific cod length distributions from a summer multi-species fishery with the National Marine Fisheries Service summer research survey from 2009 to 2018 in the Bering Sea. Controlling for spatiotemporal effects, there was no difference detected in Pacific cod length distributions between the fishery and survey, suggesting that the survey accurately captures the entire size distribution of Pacific cod in the summer. Although standardized research surveys are considered to be representative samples of the entire population, using non-random fishery observations, where the fishery and survey spatiotemporally overlap, can validate survey observations and inform selectivity relationships in stock assessment models.

Keywords Bering Sea · Pacific cod · *Gadus macrocephalus* · Fishery length distributions · Survey length distributions · Size selectivity

Introduction

Fisheries managers use commercial catch data and indices of abundance based on fisheries-independent research surveys to build a foundation for effective management of commercial fish stocks (Kimura and Somerton 2006; Walker et al. 2017). In the federally managed marine waters off the Alaskan coast, abundance and size measurements of most groundfish species are obtained from the National Marine Fisheries Service (NMFS) annual or biennial bottom-trawl surveys (hereafter "NMFS survey"). These standardized NMFS surveys simultaneously sample the distributions of multiple species; however, survey sampling occurs only during daylight hours in the late spring and summer months (i.e., May–August). This limited temporal sampling does not capture either seasonal or diel patterns of fish distributions, nor does it provide information on whether some fraction of

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a given fish population is unavailable to the research survey due to temporal movements.

The restricted temporal sampling opportunities of the current NMFS survey design are of particular concern for Pacific cod (*Gadus macrocephalus)*, a large marine gadid found throughout the North Pacific Ocean and adjacent seas from Japan to the Bering Sea and as far south as California, at bottom depths of 10–500 m (Shimada and Kimura 1994). There has been a persistent mismatch between the length distributions of a winter Pacific cod bottom-trawl fishery (i.e., January–April) and the NMFS survey in the summer (Table 1, median 66 and 41 cm, respectively). The winter bottom-trawl fishery targets aggregated spawning adult Pacific cod, and the NMFS survey in the summer is assumed to sample the entire feeding population (> age 1) (Thompson et al. 2021). However, because these size distributions are considerably different, it has been suggested that the NMFS survey "misses" the larger, adult Pacific cod targeted by the fishery in the winter. If large adult Pacific cod are not adequately sampled by and/or are unavailable to the survey gear, there are direct implications for stock assessment models when evaluating parameters related to catchability and selectivity in the NMFS survey.

Understanding how this research can contribute to improvements in stock assessment modeling requires clarification of the concepts involved. Catchability as a term in fishery stock assessments is defined as the product of abundance and efficiency (Cadrin et al. 2016). Catchability inherently involves some knowledge of both gear efficiency (i.e., the probability of capturing fish that are contacted by fishing gear) and fish availability, which is often dependent on fish life history (i.e., seasonal, and diel migrations, spatial distribution of age classes, etc.) (Arreguín-Sánchez 1996; Kimura and Somerton 2006; Cadrin et al. 2016). Selectivity refers to relative probability of capture of a demographic group and the proportion of that group that is available and vulnerable to the fishery (Maunder et al. 2014; Cadrin et al. 2016). The selectivity curve assigned to various fishery-independent data (e.g., research surveys) and fishery-dependent data are highly dependent on gear types and target species and can greatly impact stock biomass estimates (Cadrin et al. 2016).

An asymptotic selectivity curve assumes a probability of capture up until a certain size (or age) is reached and then all fish are assumed to be available to the gear, whereas a dome-shaped selectivity curve assumes that availability increases to a certain age, after which probability of capture is reduced for larger/older fish (Cadrin et al. 2016). Both asymptotic and dome-shaped selectivity parameters have been applied to the eastern Bering SeaNMFS survey lengths in the Pacific cod stock assessment (Thompson 2018, Thompson et al. 2021). In 2013, Weinberg et al. (2016) conducted a study that specifically examined the use of a dome-shaped selectivity parameter for the NMFS survey. Their study concluded that the size of Pacific cod captured by the NMFS survey net did not increase with higher vessel towing speed nor did fish escape above the net; therefore, their results did not support the use of a dome-shaped selectivity curve based on gear sampling efficiency (Weinberg et al. 2016). We build on the results of the Weinberg et al. (2016) study by examining the size range of Pacific cod available to the NMFS survey during the summer months.

In this study, we proposed that comparisons of the length distributions from the NMFS survey and a fishery that occurred in the same space (Bering Sea) and seasonal time-period (summer) would lead to a better understanding of differences in selectivity and therefore catchability. We

Table 1 Summary statistics for the length distributions used in the study from the National Marine Fisheries Service annual research survey (NMFS survey) and multi-species bottom trawl fishery (MSBT fishery) during May–August, from 2009 to 2018

Metric	MSBT fishery (summer)	NMFS survey (summer)	Pacific cod directed fishery (winter)
Number of raw lengths	19,092	145,442	–
Mean length all fish (cm)	53.7	42	–
Median length all fish (cm)	53	41	–
Number mature fish (*n*)	7637	35,685	133,868
Percent immature fish (%)	60	74	–
Percent mature fish (%)	40	26	69
Mean length mature fish (cm)	60.4	59.5	69
Standard error mature fish (cm)	0.11	0.05	0.02
Median length mature fish (cm)	60	59	69
Max length mature fish (cm)	107	110	115

Shown for comparison to the summer data are the winter Pacific cod fishery lengths. The fishery (MSBT and winter Pacific cod lengths) were obtained from the Alaska Fisheries Science Center North Pacific Observer Program for the years 2009–2018. The bottom-trawl gear used in the MSBT fishery (summer) and winter Pacific cod fishery can be highly variable; therefore, there are no available data to summarize fishery gear metrics (i.e., net size, spread) in this study hypothesized that we would observe the same size distributions between the NMFS survey and the fishery because previous studies have detected no evidence that NMFS survey-gear efficiency decreased with increasing Pacific cod size (Weinberg et al. 2016) and that Pacific cod are widely dispersed in the summer months (Shimada and Kimura 1994; Rand et al.). To test this hypothesis, we examined Pacific cod length data from the NMFS survey and from a multi-species bottom-trawl fishery (hereafter termed "MSBT fishery"). The summer MSBT fishery primarily targets flatfish species; however, Pacific cod are captured as an incidental species (Spies et al. 2020). To control for seasonal and diurnal movements of Pacific cod, we restricted the MSBT fishery data to include only fish captured during summer months, corresponding with the timing of NMFS surveys. To control for gear type, we focused solely on the MSBT fishery trawl gear, because the effects of capturing fish using baited gear (e.g., longline and pots) on the length distribution of the catch are complex and unknown for Pacific cod (Stoner and Ottmar 2004). To control for gear selectivity, we only considered mature Pacific cod for this analysis to account for the inherent differences between NMFS survey and MSBT fishery bottom-trawl nets. In general, survey nets are constructed with small mesh sizes in order to retain the full size spectrum of Pacific cod (i.e., juveniles to adults) and fishery nets with larger mesh sizes generally select for larger size classes. We discuss results in terms of implications for understanding differences between the winter Pacific cod fishery and the summer NMFS survey for stock assessment.

Materials and methods

We examined NMFS survey and MSBT fishery length measurements that spatially and temporally overlapped in the summer months (May–August) within the Bering Sea between the years 2009–2018 (Fig. 1). The NMFS survey begins in May in the southern portion of the Bering Sea and works northward until early August. The NMFS survey generally operates between the hours of 0700 and 1900 (Lauth et al. 2019), and the MSBT fishery operates over a 24-h time period. We compared the means (*t*-test) for fish captured at all times of the day with fish captured during daylight hours (0700–1900) to determine whether time of day affected the size of fish captured by the MSBT fishery. We pooled all length measurements regardless of sex, as males and females have been shown to grow at the same rate (Thompson et al. 2021). For comparison purposes, we included basic metrics for the winter Pacific cod fishery (i.e., Pacific cod are targeted for harvest). To be clear, the winter Pacific cod fishery is a directed fishery targeting Pacific cod, whereas the MSBT fishery in the summer incidentally captures Pacific cod while targeting other species. The winter Pacific cod fishery data shown were obtained from the Alaska Fisheries Science Center's Fisheries Monitoring and Analysis Division, the North Pacific observer program (Alaska Fisheries Science Center 2022).

Multi-Species Bottom-Trawl (MSBT) Fishery Data (May–August)

All Pacific cod lengths from the MSBT fishery were obtained from the Alaska Fisheries Science Center's Fisheries Monitoring and Analysis Division, the North Pacific observer program which monitors groundfish activities in the federal fisheries off the coast of Alaska (Alaska Fisheries Science Center 2022). Pacific cod lengths were measured by onboard fishery observers to the nearest cm (fork length) as they occurred in their random sampling scheme that varies by haul (Alaska Fisheries Science Center 2022). Length measurements were collected on all MSBT fishery vessels with full NMFS observer coverage; in general, Pacific cod were only measured when they were estimated to be in sufficient quantities in an observer sample (Alaska Fisheries Science Center 2022) (Table 1). Pacific cod length measurements from the MSBT fishery were spatially limited in the summer months to certain portions of the Bering Sea shelf. Therefore, NMFS survey length measurements were restricted to areas where the MSBT fishery locations occurred either in the same grid cell or those cells directly adjoining with the NMFS survey to accommodate trawl paths by the fishery that included multiple grid cells (Fig. 1).This eliminated less than 5% of the Pacific cod length measurements from the summer MSBT fishery. Starting in 2019, Pacific cod net excluder's were implemented in summer trawl fisheries to reduce incidental take of Pacific cod, particularly in the flatfish fisheries. Our study includes years through 2018, so excluder use did not impact the Pacific cod length distributions. The bottom-trawl gear used in the MSBT fishery can be highly variable, as can fishing practices and behaviors; therefore, we did not try to summarize fishery gear metrics (i.e., net size, spread).

National Marine Fishery Service (NMFS) Survey Data (May–August)

All Pacific cod length measurements from the NMFS survey were taken from the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering Division's Groundfish Assessment Programs annual bottom-trawl survey (NMFS survey). The NMFS survey in the eastern Bering Sea uses a standardized 83–112 Eastern otter trawl with a stretched net body of 10.2 cm and codend liner with 3.2 cm mesh (for specifications and protocols, see Stauffer 2004). The NMFS survey is conducted annually where a

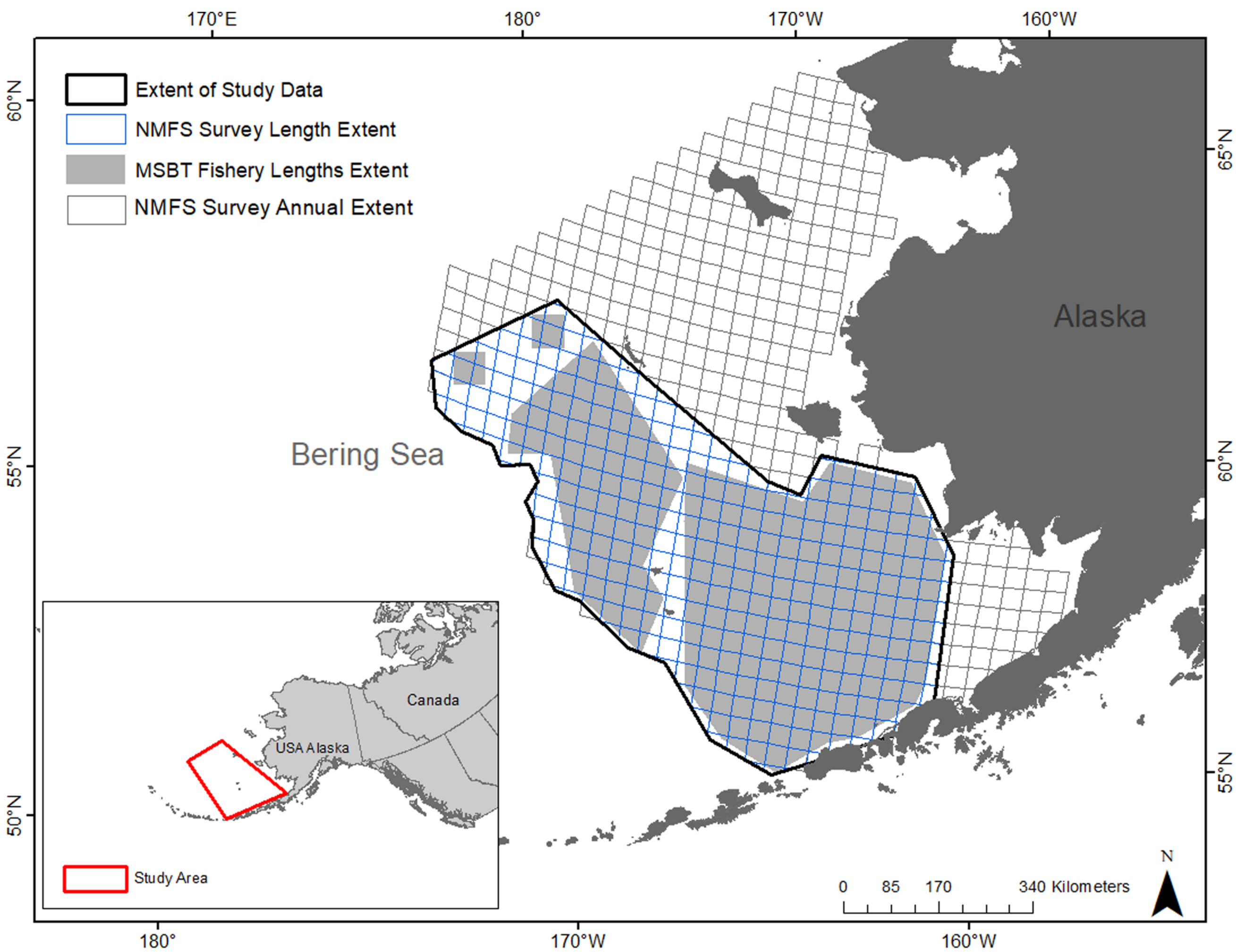

Fig. 1 Study region for Pacific cod (*Gadus macrocephalus*) length distributions from 2009 to 2018 in the Bering Sea. The black line represents the study area's extent. The grey lined grid cells represents the National Marine Fisheries Service survey's annual extent (NMFS survey), and the blue lined grid cells represent the NMFS survey grid cells used in this study. The dark grey shading represents the multi-species bottom trawl fishery (MSBT fishery) extent. Due to fishing location confidentiality, measurements for the MSBT fishery used in this study were aggregated to the grey shaded areas

single tow is sampled within each 37.04 km × 37.04 km grid cell, across the entire eastern Bering Sea shelf and shelf break from 13 m to approximately 300 m depths, with occasional gear depths recorded up to 420 m off the shelf break (Fig. 1). In general, all Pacific cod captured in the tows are measured onboard the survey vessel to the nearest mm (fork length) and were converted to cm for comparison with the MSBT fishery lengths. In instances where the number of Pacific cod is > 200 fish, approximately 150 fish are randomly selected to be measured. The NMFS survey is the only research survey that samples Pacific cod in the summer.

Statistical analyses

The NMFS survey net is designed to capture the extent of Pacific cod sizes (Stauffer 2004). In contrast, the MSBT fishery gear typically has a range of larger mesh sizes and is designed to avoid capturing small fish. To coarsely standardize these observations and control for selectivity, only the mature portion of the Pacific cod length distributions from MSBT fishery and NMFS survey were used for comparison, for the combined years 2009–2018. Adult, mature fish comprise the segment of the population where discrepancies are observed between the fishery and the survey (Thompson 2018, Thompson et al. 2021). We subsampled raw Pacific cod length measurements from each respective length distribution using length-based 50% maturity curves that were obtained for the Bering Sea (Stark 2007). The maturity estimates reach asymptotes, where all Pacific cod are considered mature at approximately 88 cm. The mature portion of each length distribution were estimated by multiplying the total number of measured Pacific cod lengths per cm and corresponding percent mature estimate starting at 21 cm through the upper range of measured fish sizes for the MSBT fishery and NMFS survey. The NMFS survey data used in the analysis is available as Online Resource 1 (ESM. 1); see Data Availability for limitation regarding the MSBT fishery data.

We examined the empirical cumulative distributions (eCDF) for the MSBT fishery and NMFS survey length distributions. Because the eCDFs appeared similar, we used a Kolmogorov–Smirnov (KS) test to determine whether the mature Pacific cod length distributions between the MSBT fishery and NMFS survey were significantly different (Massey 1951). The KS test is a non-parametric, distribution-free test that determines whether the greatest difference between the respective cumulative distributions is significant (Zar 1999). Based on results of the KS test, the visual similarity between the density estimates by year, and box plots, we further examined the maximum difference between the two eCDFs which was calculated from the KS test, or observed D statistic. Because the data included in these analyses consisted of large and unbalanced sample sizes, this would likely infer a high degree of statistical power and possibly rejecting the null hypothesis when it is true, or Type I error (Gordon and Klebanov 2010). The unbalanced sample sizes in this study were greatly magnified when we attempted analyses at a finer scale (i.e., by year, grid cell, etc.); thus, we pooled all years and grid cells. In addition, we were acutely aware that small differences can accumulate over large samples sizes and be statistically significant but may not be ecologically significant (McBride et al. 1993; Halsey 2019). In other words, if there were a statistical significance between a pair of medians at 59 and 60 cm, this would be ecologically insignificant to a fish, as the life history characteristics (i.e., feeding, maturity) are almost identical.

Based on observed similarities in these distributions, we used a bootstrap method to test for statistical significance when combining summary histograms. This method combined the MSBT fishery and NMFS survey length measurements into a single vector, randomly sampled a set number of length measurements with replacement (f and s), and then a KS test between f and s was initiated. The single vector was sampled for each f and s using the observed fishery/survey data sample sizes of 7639/35,687, respectively, and the process was repeated 10,000 times to produce a simulated D statistic distribution. Like the observed D statistic, the simulated D statistic is a measure of the maximum distance between two randomly sampled eCDFs (f and s). The NMFS survey and MSBT fishery data used in this study's spatial extent were aggregated to a shapefile along with corresponding attributes and was generated in ESRI ArcGIS 10.8. All statistical analyses were completed using R Core Team (2020).

Results

No difference was detected in mean fish length between the MSBT length measurements taken during daylight hours ($M = 60.24$, $N = 5330$) and all lengths measurements ($M = 60.42$, $N = 7637$); $t(11{,}487) = 1.002$, p-value $= 0.31$; therefore, all MSBT lengths were used in subsequent analyses. Boxplots, length frequency histograms, and density plots by year, from 2009 to 2018 for the mature portions of Pacific cod from both the MSBT fishery and NMFS survey are shown in Fig. 2. The results of the eCDFs for the NMFS survey and MSBT fishery are shown in Fig. 3.

We examined a total of 19,092 raw lengths from the summer MSBT fishery data and 145,442 lengths from the summer NMFS survey (Table 1). These were reduced to 7637 mature fish from the MSBT fishery and 35,685 from the NMFS survey. Approximately 40% of the Pacific cod caught in the summer MSBT fishery were considered mature, whereas 26% of the Pacific cod captured in the NMFS survey were mature (Table 1). For reference, in the winter Pacific cod fishery, an estimated 69% of the Pacific cod were mature; the mean and median of mature fish were 69 ± 0.02 cm ($n = 133{,}868$), and the median of all measured fish was 66 cm (Table 1). The mean length of mature Pacific cod for the MSBT fishery in the summer was 60.4 ± 0.11 cm ($n = 7{,}637$) and 59.5 ± 0.05 cm ($n = 35{,}685$) for the NMFS survey (Table 1). We did not observe an upper size range of Pacific cod in the MSBT fishery that was not observed in the NMFS survey, nor was there a large shift in the upper size limits from the MSBT fishery (Table 1; Fig. 2). The maximum length observed in the MSBT fishery was 107 cm, and 110 cm in the NMFS survey (Table 1).

Using the bootstrap method, we detected no significant difference between the combined MSBT fishery and NMFS survey length distributions in 10,000 simulations with observed sample sizes (Fig. 4). The probability of drawing from the combined distribution and being able to determine from which observed distribution the length measurement came from is near zero (< 0.00001).

Discussion

We hypothesized that the use of fishery-dependent observations could inform selectivity in stock assessment models for Pacific cod in the Bering Sea. In particular, we

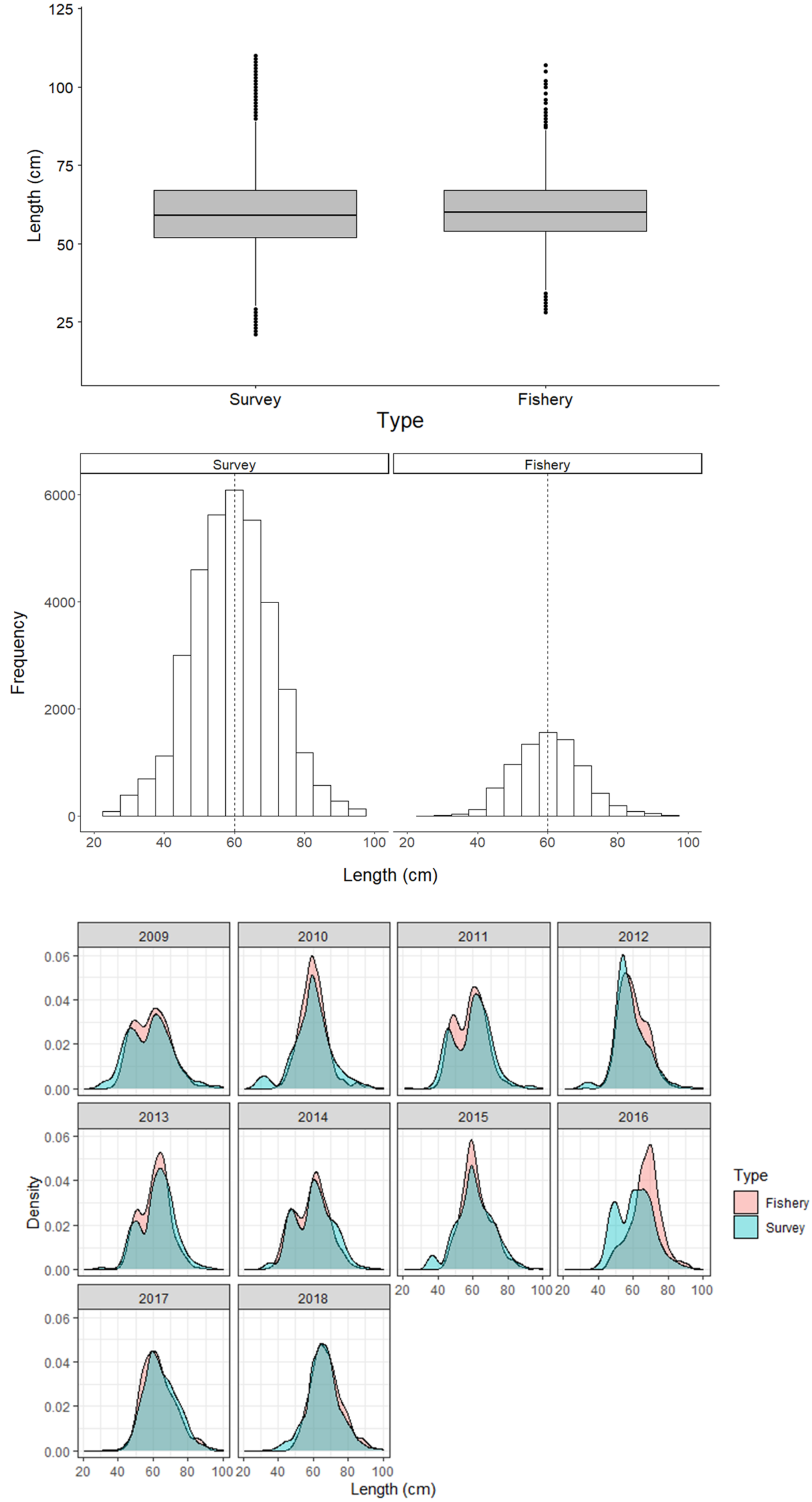

Fig. 2 These data were subsampled mature portions of the Pacific cod (*Gadus macrocephalus*) length (cm) distributions from the National Marine Fisheries Service survey ("Survey") and multi-species bottom trawl fishery ("Fishery") using Stark's (2007) maturity curve. Shown in the top panel is a box plot (top), the middle panel a frequency histogram (middle), and the bottom panel are density plots by year (bottom).The range of years in this study for both the Survey and Fishery is 2009–2018, summer months only (May–August). The dotted line on the frequency histogram is placed at 60 cm for reference

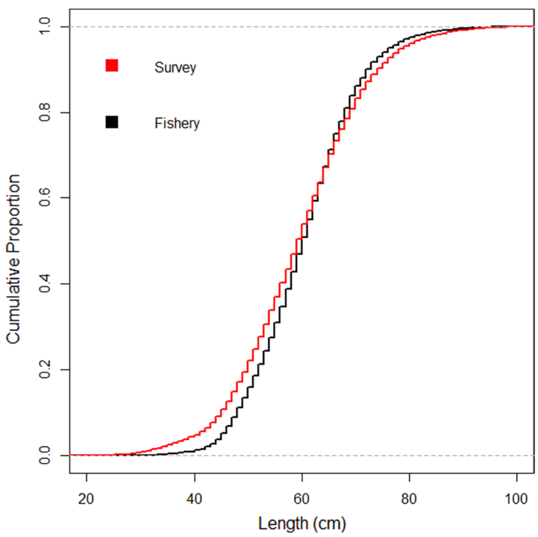

Fig. 3 The empirical cumulative distribution (eCDFs) for the National Marine Fisheries Service ("Survey", red line) and the multi-species bottom trawl fishery ("Fishery", black line) for the subsampled mature portions of the Pacific cod (*Gadus macrocephalus*) length distributions using Stark's (2007) maturity curve. The range of years shown is 2009–2018, summer months only (May–August)

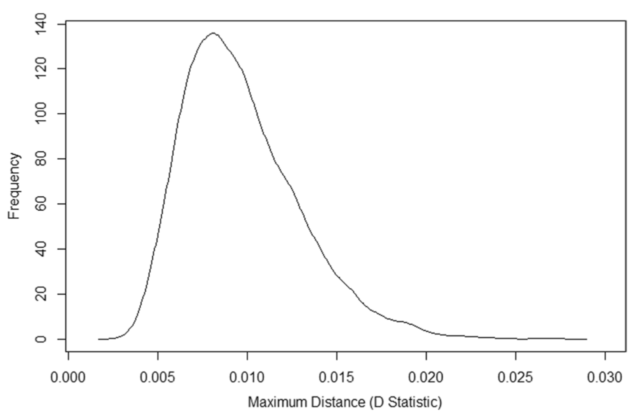

Fig. 4 Kolmogorov–Smirnov maximum distance test statistic (D) from 10,000 simulations of the combined lengths for the National Marine Fisheries Service survey (NMFS survey) and the multi-species bottom-trawl fishery (MSBT fishery) subsampled mature portions of the Pacific cod (*Gadus macrocephalus*) length distributions for the years 2009–2018, summer months only (May–August). The probability of drawing from the combined distribution and being able to determine from which observed distribution the length measurement came from is near zero (< 0.00001)

considered length distributions that overlapped in space and time between the MSBT fishery and the NMFS survey as a tool to inform selectivity because NMFS survey gear is designed to capture the breadth of fish size ranges (Stauffer 2004), whereas fishery gear generally avoids smaller fish. Regardless of these differences in gear efficiency, we detected no difference in the length distributions of mature Pacific cod between the MSBT fishery and NMFS survey, although the NMFS survey captured a higher proportion of immature fish than the MSBT fishery. This evidence supported our hypothesis that the NMFS survey gear does not prevent the probability of capture of larger individuals.

This result demonstrates that the MSBT fishery and NMFS survey are capable of capturing the upper size distributions of Pacific cod in the same time period (summer) and space (Bering Sea). The similarity in lengths observed indicated no difference in availability, a result that is somewhat complicated to confer to catchability, as catchability is the product of availability and gear efficiency. The efficiency of standardized trawl survey nets has been an area of debate and study since fisheries have been managed (Somerton et al. 1999). Trawl survey catches may observe a different size composition of a given species than exists in the true population. This can happen because of gear efficiency (e.g., escapement under the footrope, limited headrope height, etc.) 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 are assumed to be available to the gear during operating hours and within the space the survey operates. Admittedly, this is likely not true for any species, but can potentially be quantified or measured for a given species (Kotwicki and Weinberg 2005).

As we note with Pacific cod, the availability of a species' to survey gear is important to measure as these elements play an important role in estimating a species abundance in research surveys (Kimura and Somerton, 2006). Measuring fish availability is complicated by those species that undergo shifting distributions, which can vary on multiple spatiotemporal 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 any bottom-trawl gear type (fishery or survey). The NMFS survey gear makes seafloor contact and up to ~ 2.5 m in the water column (Stauffer 2004; Nichol et al. 2007). Although archival tagged Pacific cod in the Bering Sea spend 95% of the time within 10 m of the seafloor during all times of the day, there is evidence that Pacific cod do exhibit some daytime vertical migrations into the water column (Nichol et al. 2007, 2013). However, no study has determined a size-dependent affinity for diel migration. It is doubtful that Pacific cod of all sizes are less than 3 m from the seafloor bottom and fully available to any gear type; however, the results of our study highlight the fact that NMFS survey bottom-trawl gear is likely no less efficient than fishery bottom-trawl gear at capturing large Pacific cod in the summer months.

The main factor contributing to the observed differences in Pacific cod length distributions between the winter Pacific cod bottom-trawl fishery and the NMFS survey in the summer is due to the seasonal movement of Pacific cod (Shimada and Kimura 1994; Rand et al. 2014; Bryan et al. 2021). North Pacific cod populations undergo seasonal changes in their spatial distribution, which have been documented through mark-recapture and satellite telemetry studies (Shimada and Kimura 1994; Rand et al. 2014; Bryan et al. 2021). In winter (i.e., January-April), mature Pacific cod migrate to specific areas and form dense spawning aggregations within the 100–200 m depth range, mostly on the Bering Sea continental shelf edge and across the Aleutian Islands and Gulf of Alaska (Shimada and Kimura 1994; Neidetcher et al. 2014). Winter spawning aggregations and genetic population structure suggest some degree of spawning site fidelity and/or resident populations of Pacific cod (Drinan et al. 2018; Spies et al. 2019). The winter Pacific cod bottom-trawl fishery targets those large aggregations of mature, spawning fish which is supported by the highest fisheries catch-per-unit-effort (CPUE) occurring in the winter months (Thompson et al. 2021). Shortly after winter spawning, Pacific cod disperse widely across all depths of the Bering Sea and remain dispersed through the fall months, presumably to feed (Shimada and Kimura 1994; Rand et al. 2014). It is during this wide dispersion of Pacific cod across the Bering Sea that the NMFS survey takes place. In spite of what we know from previous studies on seasonal migration, it cannot be ruled out that some portion of large Pacific cod migrate from the Bering Sea to other unsampled and unfished regions during summer months (e.g., Russia waters). Recent NMFS surveys have observed increasing abundances of Pacific cod in the northern Bering Sea and there is some evidence to date that those increases in abundance consists of Pacific cod that are larger than fish observed in the eastern Bering Sea (Stevenson and Lauth 2019). Notably, the NMFS survey was able to observe these large size classes (> 70 cm), which can be accounted for in future management scenarios.

In this study, we used fisheries data as an additional observation of Pacific cod size distributions in the same space and time as the NMFS survey, to gain understanding of fish availability to the NMFS survey. We acknowledge that there are Pacific cod spatiotemporal patterns on a much finer scale than we have shown here (e.g., inter-annual, annual, and grid cell variability). However, examining trends at a coarser level allowed us to address the basic hypothesis that the size distribution of mature Pacific cod observed in the summer is the same regardless of the bottom trawl platform (i.e., fishery or survey). A caveat to using fishery-dependent data is that fish distribution patterns observed in the MSBT fishery may be correlated with seasonal fishing behavior; therefore, the MSBT fishery may not always reflect attributes of the summer distribution of Pacific cod. Over the last decade, incentives to avoid capturing Pacific cod during the MSBT fishery targeting flatfish have increased. As a result, allowable annual catch for Pacific cod in the bottom-trawl fisheries is limited, likely driving fishing activities to areas where Pacific cod incidental take is lower. These areas with lower abundance of Pacific cod may not reflect the size distribution of the entire population (i.e., size stratification) and likely occurs on very small spatial scales (< 10 km). Since our study examined data at a much larger spatial scale, the non-random aspect of fishery size selection at these small spatial scales may be difficult to determine. Thus, it is important to keep in mind that patterns observed in fishery data can be influenced by fishing behavior choices. To eliminate potential biases in fishery-dependent data, a future study could direct commercial fishing tows within a relatively narrow time and space window of the NMFS survey tows. A well-vetted metric would allow for a direct comparison of size classes captured by both the fishery and the survey, accounting for varying trawl gear types (Kotwicki et al. 2017). However, this type of comparative survey is costly and time-consuming, which was the impetus for examining existing fishery-dependent data used in this study.

The lack of statistical difference between the NMFS survey and MSBT fishery length distributions of mature Pacific cod requires a careful reconsideration on the use of a dome-shaped selectivity curve for the NMFS survey in the Alaskan Pacific cod stock assessments. Seasonal migrations of Pacific cod will always confound the temporal aspect of comparing the size distributions of fish from the winter Pacific cod fishery and the summer NMFS survey. Population-dynamic models can account for these differences in the NMFS survey and fishery selectivity, as long as models are informed by sufficient data. This study highlights the utility of using fishery-dependent data as an additional observation, and examining size disparities using simple methods (e.g., examining data in the same time and space), which can help inform fishery management models.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00300-022-03088-3.

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Author contributions KMR conceived and designed the research and wrote the manuscript. SFM, DRB, JKN, IBS contributed expertise on Pacific cod movement and statistical analyses. IBS and SB contributed guidance on management implications and stock assessments for Pacific cod. TL and JG contributed expertise on commercial fishing dynamics, and how that has changed with time. All authors read, edited, and approved the manuscript.

Data availability NMFS survey data used in this study are submitted as Electronic Supplementary Material (ESM 1). The percent mature Pacific cod data were generated from parameters given in Stark (2007). The MSBT fishery data are confidential and therefore not publicly available. However, the MSBT fishery raw measurement length file (i.e., no location information) and the study extent shapefile generated in ArcGIS 10.8 are available from the corresponding author upon request.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The findings and conclusions in the paper are those of the authors and do not necessarily represent the views of the National Marine Fisheries Service.

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