Comparing fishery-independent and fishery-dependent data for analysis of the distributions of Oregon shelf groundfishes

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Abstract

We investigate whether fishery-dependent time series can be used to fill in spatial and temporal data gaps where scientific, fishery-independent data are not available. Limitations in sampling coverage combined with a historical focus on continental slope-dwelling groundfish resulted in a gap in understanding Oregon's nearshore groundfish fishery. Although fisheries-independent surveys have been conducted across most of the fishery's depth range, the data are limited by years and seasons surveyed, as well as the absence of data for areas shallower than 55 meters water depth. Fishery-dependent data are available for those shallow waters and for a broader temporal range. However, these data are self-reported and the coverage was determined by where fishers choose to fish. To investigate the potential for future combined uses for these data sources, we analyzed spatial and temporal changes in catch rates, as well as gaps in fishery (logbook) and scientific (NOAA survey) data, for six flatfishes. We found that more heavily targeted species that live in deeper water, like Dover sole and petrale sole, had more spatial scientific sampling coverage compared to less frequently targeted species that live in shallow water, such as starry flounder and sand sole. Overlap between datasets was variable in space and time but consistently higher near large ports. We identified the winter season, and the pre-2003 time-period as having the highest potential to benefit from complementary use of fishery-dependent data. Prior to 2003, the survey design was variable and there was greater spatial and temporal coverage of logbook data compared to post-2003. Integration of these data sets may be useful for future research given their differences in spatial and temporal range. This work provides a new perspective on the value of using fishery-dependent data to understand the spatial distribution of species in habitats that are under sampled in scientific surveys.

Key words: fishery-independent, fishery-dependent, groundfish, trawl, local index of collocation

1 Introduction

Fishery-independent and fishery-dependent data are the two primary sources of information used by fishery scientists for assessing population distributions over time and space. Both have their advantages and disadvantages depending on the methods applied, but their combined use is valuable for the management of many fisheries. For multiple regions, mapping of species distributions are reliable only when using fishery-independent data, as locations are not necessarily recorded correctly or at all by fishery-dependent sources, and because fishery-dependent data are a function of fishery behavior (Hilborn & Walters, 1992). In areas where fishers consistently document location data, visualization or mapping is more difficult due to inherent biases present in fishery-dependent data, whereas there is standardization and scientific sampling design built into fishery-independent data (Hilborn & Walters, 1992; Maunder & Punt, 2004). There can also be issues with fishery-independent surveys. These challenges largely stem from a lack of time and funding, which can restrict the spatial and temporal extent of sampling, but inadequate survey design or coverage can also be an issue (Hilborn & Walters, 1992). Region and fishery specific research is needed to determine whether it is possible or necessary to combine fishery-independent and -dependent data to improve species distribution analyses and design future surveys.

Preferential collection of fishery-dependent data, meaning that there is no sampling design used to determine where sampling occurs, results in sampling biases, as fishers target areas they believe they will find their target species (or avoid non-target species) and during times of the year that are either optimal or when fishing is allowed. Therefore, both spatial and temporal biases are potential issues for fishery-dependent data. When using data collected opportunistically for species distributions or developing an index, it is necessary to account for preferential sampling when developing the models in order to avoid overestimates of abundance (Pennino et al., 2019) or inaccurate management plans (Grüss et al., 2019). For example, this can be accomplished by using joint (Conn et al., 2017) or marked point process (Pennino et al., 2019) models to reduce bias when predicting species spatial distributions, or through spatiotemporal modeling frameworks when standardizing catch-per-unit-effort data (CPUE) (Ducharme-Barth et al., 2022; Grüss et al., 2019). Applying methods that minimize biases present in fishery-dependent data may allow the use of this type of opportunistic data for answering a greater range of questions.

Recent studies examine the differences between fishery-independent and fishery-dependent spatial information and show that it may be possible to use fishery-dependent datasets to visualize or predict species distributions. For example, fishery observer and survey data in the western Mediterranean Sea display similar distribution patterns of elasmobranch bycatch species despite differences in temporal and spatial coverage of the datasets (Pennino et al., 2016). However, the authors also identify differences in predictive ability of each data type for temporal and spatial presence and absence. Earlier studies indicate that the combination of various sources of fishery-independent and -dependent data can provide a more complete picture of population distributions (Pecquerie et al., 2004), allow for a better understanding of bycatch-fishery interactions (Lyons et al., 2013; Murray & Orphanides, 2013), and be valuable for stock assessment models (Booth, 2000). Multiple methods allow for to integrating fishery-independent and -dependent data into the same model, allowing for potentially more accurate species distribution models by using complementary data sources (Bourdad et al., 2017; Sant'Ana et al., 2017; Zhu et al., 2018; Pinto et al., 2019; Rufener et al., 2021).

Numerous commercial and recreational fisheries are located in waters off the U.S. West Coast, with Oregon home to the largest portion of the West Coast's groundfish trawl fishery. In 2019, 61 vessels participated in the non-whiting groundfish trawl fishery, generating approximately $18.7 million in ex-vessel value (The Research Group, 2021). This fishery, along with several others, makes up about 8% of Oregon's coastal economy and generates about 9,200 jobs (The Research Group, 2021). Logbook and landing documents from Oregon fishers provide an opportunity for further study given the detailed fishery-dependent data from 1981 to the present. These data include records of set and retrieval locations for fishing gear, catch weight and number of each species caught, and tow duration, amongst other information. Despite the existence of this long time series, these data are infrequently used to analyze population distributions. Additionally, a fishery observer program initiated in 2001 is used to determine the spatial distribution of discards by depth and area. There are also two fishery-independent data sources spanning different time-periods. The Alaska Fisheries Science Center (AFSC) Triennial survey (1977-2004) was superseded by the NOAA West Coast Groundfish Bottom Trawl Survey (WCGBTS, 2003-2021, ongoing). The latter is essential for informing stock assessments in the West Coast groundfish fishery.

Fox and Starr (1996) were the first to investigate both West Coast groundfish fishery-independent and -dependent data. In their study, they compared commercial trawl catch data to the AFSC Triennial survey using Geographic Information System mapping. They found that differing results between the datasets included lack of spatial overlap in certain regions and a discrepancy in Dover sole (*Microstomus pacificus*) biomass, likely a result of gear differences, but that overall, the standardized CPUE data could supplement survey data to study fish distribution and abundance (Fox & Starr, 1996). Later work used logbooks and commercial landings data to investigate patterns of fishing effort, as well as visualize spatial and temporal extent of fisheries (Macomber, 2000; Hannah, 2003; Bellman et al., 2005; Bellman & Heppell, 2007). Sampson (2011) found that while there are issues with accuracy in the logbooks, information from tows on the continental shelf are typically consistent with landings data and bathymetric maps, but are less accurate on the continental slope.

Here, we focus on flatfishes in the Oregon nearshore commercial bottom trawl fishing grounds, defined as water depths of less than or equal to 200 meters off the coast of Oregon and Washington states. This area largely covers the continental shelf in the northern California Current. The shelf inshore of approximately 55 meters depth is understudied compared to the slope and remaining portion of the shelf (Howard et al., 2021). Recently there has been renewed interest in nearshore commercial trawling, which declined following the collapse of the U.S. West Coast groundfish fishery in 2000 (Sjostrom et al, 2021). These nearshore fishing grounds are habitat for many flatfishes, including those most heavily targeted by the groundfish fishery such as petrale sole (*Eopsetta jordani*) and Dover sole, and they are the dominant group fished by Oregon nearshore bottom trawlers (Sjostrom, 2019). Many of these species use the shelf either for their entire lives or to complete their life cycles (Pedersen, 1975; Jacobson & Hunter, 1993; Abookire & Bailey, 2007; Toole et al., 2011; Krygier & Pearcy, 1986; Richmond, 1983). Additionally, flatfishes display different behavior near trawl gear compared to rockfishes (*Sebastes* spp.) and roundfishes, so using only flatfish species for analyses allows for a better comparison between species (Ryer, 2008). Historically, flatfishes are also more consistently identified to species in the logbook data compared to rockfishes.

With the possibility of increased fishing activity in the nearshore (Sjostrom et al. 2021), increasing our understanding of species distributions in this region will contribute to sustainable management efforts. Therefore, this research assesses the possibility of using the fishery-independent and -dependent data to add to existing knowledge of species distributions and habitat. Integrating data sets into the same model is potentially more useful when the data cover different temporal and spatial ranges, possibly providing a more complete picture of the distribution of a species' biomass. Because the fishery-independent and -dependent data used in this study exhibits those characteristics, it may be useful to combine these data sets in future research. Based on the previous research conducted using logbook and landings data, as well as the limitations of the survey data sets, our first objective was to determine areas of overlap and areas of complementary coverage between fishery-independent and -dependent data. Here, we ascertain whether integrated use of both data types has the potential to improve the characterization of habitats utilized by flatfish species present along the slope and shelf areas. Our second objective was to elucidate which species may be better represented by the complementary use of both types of data. Finally, we determine the potential for use of fishery-dependent data in species distribution models for species poorly represented by available fishery-independent data.

2 Material and methods

2.1 Fishery-dependent data

Logbook and landings data were obtained from the Oregon Department of Fish and Wildlife (ODFW). Logbook records included information for catch rates of individual species, tow duration, average depth of tow, offload port, gear type, and location of each tow. Catch rates for each species were recorded as the original hail weight and an adjusted weight. Hail weight is the original weight recorded by the vessel captain. For adjusted weight, ODFW applied five classifications for each trip or tow to make any appropriate corrections to the hail weight to obtain these values. These corrections were made using the fish ticket pounds, which are a record of catch documented at the port of landing, and depended on errors identified in the data. For example, this may have included adding information to a logbook record for a species without a hail weight but that was recorded on the fish ticket. Because hail weights were not recorded in early years, the adjusted weights were used for our analyses. The logbook CPUE was calculated as kilograms per hour (kg/hr) using the recorded tow duration and catch weight.

To prepare the data for analysis, we limited the logbook records to areas fished by Oregon commercial fishers, between 42 and 47°N (Figure 1), consistent with Sjostrom et al. (2021). Only tows completed using the three most common nearshore groundfish gear types were retained: unspecified bottom trawl, sole net, and selective flatfish trawl (Sjostrom et al. 2021). Tows with missing critical data, such as set latitude or longitude, were removed and locations recorded using the less accurate Loran A and Loran C navigation systems were not used. Tows appearing on landmasses were also removed. Sampson (2011) determined that depth and location consistency was high for catches at depths less than 200 meters, indicating relatively high accuracy for the shelf region, and illustrated that there exist few incentives to misreport data. However, due to numerous previously identified inaccuracies with depth reporting in the logbooks, and the variability in technological capabilities over time, it was deemed best to replace the logbook depth values rather than remove inaccurate records (Sampson, 2011; Sjostrom, 2019). A locally estimated scatterplot smoothing curve (LOESS), a type of nonparametric regression, was used to replace all logbook depth measurements based on recorded position (longitude and latitude). Bathymetric data for the LOESS curve was obtained from the NOAA ETOPO1 global relief model (Amante & Eakins, 2009). The final model (adj. $r^2 = 0.99$), which used a 2nd degree polynomial and 0.01 span, was then used to predict depths for the recorded locations of each logbook tow. Tows with model depths greater than 200 meters or shallower than 10 meters were removed, providing a dataset with 85,143 hauls. Landing and logbook records were joined using individual tow catch ID numbers and the landed weights from the fish tickets were used to calculate total landings over time.

2.2 Fishery-independent data

Both the triennial (1977 – 2004) and WCGBTS annual (2003 – 2018) survey data sets were available for these analyses. For the triennial survey, Alaskan class trawl vessels equipped with a Poly Nor’Eastern trawl were used to sample transects running perpendicular to the coast. Sampling depth, transect spacing, and timing of the survey were variable, but tow duration was consistent at 30 minutes (Dark & Wilkins, 1994; Keller et al., 2017). Until 1995, sampling occurred from July to September or October; after 1995, sampling began in June and ended in October. The annual survey began in 2003 and uses West Coast class vessels equipped with an Aberdeen trawl, towed for 15 minutes at each station. Stations are selected using a stratified random sampling of cells placed along the U.S. West Coast shelf and slope (Keller et al., 2017). The first pass for the survey occurs from May to August and the second pass occurs from August to October. Both the triennial and annual surveys cover the region trawled by the Oregon commercial groundfish fishery, but the sampling density is greater for the annual survey. Survey data were obtained from the NWFSC/FRAM Data Warehouse (url: https://www.nwfsc.noaa.gov/data/) as a dataset containing characteristics from each tow and a dataset containing information on species composition. Tow ID numbers were used to match tows to the species composition data. Only data collected at 200 meters depth or shallower was retained, with the shallowest depth at approximately 55 meters. Using the logbook records, the survey data was restricted to waters consistently fished by Oregon commercial fishers, between 42 and 47°N. Because complete logbook data was only available between 1981 and 2017, the survey data used below were limited to this period as well, leaving 4,343 tows for the analyses. The survey CPUE was recorded as kilograms per hectare (kg/ha). To avoid overlap of the triennial and annual survey data and ensure there were similar sets of years within the two data sets per period, the 2004 data for the triennial survey was removed.

2.3 Species selection and visualization

Six species of flatfish were chosen for analysis: petrale sole, Dover sole, sand sole (*Psettichthys melanostictus*), starry flounder (*Platichthys stellatus*), English sole (*Parophrys vetulus*) and Pacific sanddab (*Citharichthys sordidus*). Petrale sole and Dover sole are the flatfishes most consistently caught by both the survey and commercial fishery, with distributions known to span much of the shelf. Starry flounder and sand sole are two shallow-water species not commonly caught by the surveys or fishery, while English sole and Pacific sanddab are mid-shelf species with some commercial importance (Table 1). Pacific sanddab catch rates were not separated out from speckled sanddab (*Citharichthys stigmaeus*) in logbook records, but speckled sanddab, a similar but smaller species, are assumed to be infrequently encountered by commercial trawl vessels (He et al., 2013). Therefore, the unspecified sanddab grouping was used to assess catch rate of Pacific sanddab.

Table 1: Species below were selected for analyses. Values represent the number of hauls that contained each species.

Species	Survey	Logbook
Dover sole	3,925	53,460
petrale sole	3,422	56,207
English sole	3,135	54,618
Pacific sanddab	2,678	20,681
sand sole	174	20,608
starry flounder	62	19,315

Fishery-independent and -dependent maps and plots for each species were first compared visually before gridding for confidentiality purposes to determine if differences or similarities were present in spatial distribution over time. Dover sole and petrale sole are known to seasonally migrate on and off the shelf, making them useful for investigating seasonal differences in distribution not observed by the NOAA trawl data, which do not capture winter distributions (Ketchen & Forrester, 1966; Pedersen, 1975; Jacobson & Hunter, 1993; Abookire & Bailey, 2007). Therefore, for these species, separate visualizations of the fishery-dependent data were created for months with and without NOAA survey samples.

For the spatial visualizations, we gridded maps of species catch and overall fishing effort for four periods (1981 – 1989, 1990 – 2001, 2002 – 2009, 2010 – 2017) using both survey and logbook data, hereafter referred to as the 1980s, 1990s, 2000s, and 2010s respectively. The logbook data were limited to the period of during survey data collections (May to October) to allow for comparison with the NOAA trawl data. We constructed maps with a grid covering 42° to 47°N latitude and 125° to 123.9°W longitude composed of cells with dimensions of 20 north-south intervals (approximately 27.8 kilometers) and 15 east-west intervals (approximately 5.8 kilometers), to allow for fishing location confidentiality. To investigate effort distribution, maps of overall fishing effort, measured as average number of tows per year and location, were created for each period. For individual species maps we used scaled catch rates to allow for comparison of species distributions between data sets. First, survey and logbook CPUE was transformed using an ln(x+1) transformation and each grid cell represented the mean transformed CPUE in that area during the period depicted. Other data transformations were examined but did not affect our conclusions. CPUE was used rather than total catch because tows conducted by fishers can be of varying length, which typically leads to larger catches for longer tows. Mean survey and logbook CPUE for each grid cell was calculated as follows, with N representing number of tows:

$$CPUE_{avg,lat,lon} = \sum \frac{ln(CPUE_{lat,lon}+1)}{N_{lat,lon}} \quad (1)$$

Then, for comparison between datasets, the logbook data was restricted to the months the survey operates and the resulting mean survey and logbook CPUE values were scaled from 0 to 1.

To examine differences in depth distribution across time and data types, contour plots of density using two-dimensional kernel density estimation with an axis aligned bivariate Gaussian kernel evaluated on a square grid were created using the ggplot2 stat_density_2d function (Wickham, 2016). Only points of presence for each species were used and plots were divided into the same four periods as above.

2.4 Quantitative comparison

To quantitatively assess the level of overlap between the CPUE of the fishery-independent and -dependent data, we calculated the local index of collocation (LIC). The LIC is a correlation coefficient that is not sensitive to zero-inflation and assesses the overlap of data across two sources over the same spatial bounds (Bez & Rivoirard, 2000; Pianka, 1973). The LIC has previously been used to determine overlap with respect to population abundance (Kotwicki & Lauth, 2013; Petrik et al., 2015; Carroll et al., 2019), predator-prey interactions (Trenkel et al., 2005; Carroll et al., 2019), and fishing effort (Bez et al., 2011; Pointin et al., 2019). Values range between 0 and 1, with lower values indicating less “collocation” (correlation of CPUE) between the two datasets. The total LIC for a given period and the entire region can be calculated as follows (Pianka, 1973; Petigas et al., 2017; Carroll et al., 2019):

$$LIC_{total,t} = \frac{\sum_i^n (D_{lat,lon,t,i} * I_{lat,lon,t,i})}{\sqrt{\sum_i^n D_{lat,lon,t,i}^2 \sum_i^n I_{lat,lon,t,i}^2}} \quad (2)$$

In the above equation for total LIC for a given period, *D* represents the fishery-dependent untransformed logbook CPUE data, *I* represents the fishery-independent untransformed survey

CPUE data, and *t* represents the period. Measures of uncertainty in the overall LIC were also calculated. This was done by determining overall LIC for each year within a period and calculating the mean and standard deviation (Table S1). To look at spatially explicit overlap, we modified Equation 2 to use CPUE in each grid cell for a given species. This gives the contribution of overlap per cell to the total overlap across the study region, providing a spatially explicit value (Carroll et al., 2019):

$$LIC_{lat,lon,t} = \frac{D_{lat,lon,t} * I_{lat,lon,t}}{\sqrt{\sum_i^n D_{lat,lon,t,i}^2 \sum_i^n I_{lat,lon,t,i}^2}} \tag{3}$$

Only logbook data are available in areas shallower than 55 meters water depth, so for comparison purposes the fishery-independent mean survey CPUE value for those unsampled grid cells was artificially set to 0, as there was no survey data but logbook data were available. As seen in Equation 3, this results in an LIC of 0, or no overlap, for areas shallower than 55 meters water depth. This allowed us to illustrate the lack of survey data in shallow areas. All analyses and data processing were completed using R statistical software (v. 4.0.4, R Core Team, 2021).

3 Results

3.1 Fishing effort and catch

A linear regression of ln(x+1) transformed logbook CPUE against vessel length showed little to no relationship between length and catch rate, which indicated that CPUE does not significantly change with vessel length. Overall fishing and sampling effort was distributed differently in space for the fishery-independent and -dependent data, as well as when comparing the triennial and annual surveys (Figure 2). Fishing effort in general on the inner shelf decreased over time. More effort shifted offshore and northward toward Astoria, Oregon over time and there was a decrease in effort across the entire region. Fishing effort in the most recent years (2010-2017) appears to have decreased substantially, with most effort located off the coast near northern Oregon and southern Washington. The survey sampling effort is more evenly distributed, though there was higher average effort and patchy distribution during the triennial survey periods (1981-1989 and 1990-2001). In the most recent two periods (2002-2009 and 2010-2017), sampling effort can be seen in the visualizations to be far more evenly distributed across the shelf, which was expected with the change from transects to stratified random sample design.

3.2 Spatiotemporal visualization of catch

Geographic differences in spatial distribution of catch rates during the survey period were evident between the survey and logbook data types. Maps of average survey and logbook catch rates per year for the two commonly caught species, petrale sole and Dover sole, showed similar patterns of spatial distribution over time within each data type (Figures 3, S1). The highest average logbook catch rate of petrale sole was centered along the 100-meter isobath throughout much of the shelf during the summer, whereas average survey catch values were similar throughout the study area (Figure 3). Dover sole logbook and survey catch rates were highest near the outer edge of the shelf, and in the most recent period, catch rate was highest north of 45°N (Figure S1). For the inshore shallow-water species, the logbook data indicate that nonzero catch occurred almost entirely within areas shallower than 100 meters water depth. Sand sole logbook catch rates were consistent across the four periods throughout this depth range (Figures 4). Starry flounder logbook catch rates were highest near Astoria, Oregon and decreased southward (Figure S2). Both species were sporadically captured by the survey, and the primary location of tows containing either species were near Newport, Oregon at shallow depths. Survey tows containing Pacific sanddab and English sole were more common across the study area than tows containing the inshore species (Figures 5, S3). Pacific sanddab average survey and logbook catch rates were highest off the shelf near Charleston, Oregon and Newport, though this patch of higher catch rates appeared to shift south over time in visualizations of the logbook data (Figure 5). There were also more tows containing Pacific sanddab north of Astoria. English sole logbook catch rates were highest in the southern region and on the wide section of the shelf near Newport (Figure 5).

Depth contour plots and maps revealed the discrepancy in the coverage of spatial sampling between the survey and commercial data. All species commonly caught by the survey (petrale sole, Dover sole, English sole, and Pacific sanddab) had catch rates distributed evenly throughout much of the sampling area (Figures 6, S4-S6). Patches of high presence were visible in areas on the shelf between approximately 44° and 46°N. Petrale sole, Dover sole, and English sole, were present in samples throughout all depths and latitudes sampled by the survey and included in this study but were caught in precise patches by the commercial fishery (Figures 6, S4-S5). Pacific sanddabs were caught consistently across latitudes by the survey but had a clear maximum depth limit at about 100 meters (Figure S6). Recorded logbook catch rates for the infrequently caught shallow-water species, starry flounder and sand sole, occurred almost exclusively inshore of the 70-meter isobath (Figures S7-S8). High catch rate areas for English sole and Pacific sanddab in the logbook data also occurred in shallow water, but substantial catch rates did extend farther offshore than for the shallow-water species (Figures S5-S6). Dover sole and petrale sole were found on the shallow portion of the shelf, inshore of 55 meters, but most catch rates were in deeper water (Figures 6, S4). In recent years, the shallow water distribution of these species has been found entirely near Astoria. The 55-meter depth limitation for the survey is clearly visible in the survey contour plots for these two species as well as English sole and Pacific sanddab. With the logbooks, there is obvious movement northward of overall fishing effort.

3.3 Seasonal Variation

The seasonal variation maps for Dover sole indicated a difference between population distribution during the “winter” (November – April) and “summer” (May – October). During the summer, the mapped Dover sole mean logbook catch values for each period were higher when compared to the winter (Figures 7). Most nonzero values for Dover sole mean logbook catch rates were found on the outer shelf during the winter whereas there were shallower catches during the summer. Maps for petrale sole generally showed similar patterns of mean logbook catch rates for each period when comparing the winter and summer (Figure S9). However, mean logbook catch rate values for petrale sole were lower on the inner shelf north of 45°N in the winter and there were higher values on the outer shelf during winters in the 1980s and 1990s. Contour plots for both species showed that there were more catches in deeper water during the winter compared to the summer (Figures 5, S4, S10-S11).

3.4 LIC

Maps of LIC indicated highly variable levels of overlap between fishery-independent and -dependent data, depending on the species. Dover sole had the highest and most consistent degree of total overlap per period, followed by Pacific sanddab and petrale sole except for in the 1980s, when LIC for petrale sole was much lower (Table 2). English sole had an intermediate amount of total overlap, and the total LIC values for sand sole and starry flounder were low in each period.

Maps for each species provided a more detailed image of where collocation occurred (Figures 8, S12-S14). Petrale sole and Dover sole both had spatial overlap between data sources on much of the shelf between the 55- and 200-meter isobaths (Figures 8, S12). The highest spatially explicit LIC values for Dover sole were located near the 200-meter isobath, whereas high values for petrale sole were more evenly dispersed throughout the 55- to 200-meter depth range. Pacific sanddab had some of the highest total LIC values of all the species, though the spatially explicit values were largely centered around the mid-latitude area of the shelf similarly to sand sole and starry flounder (Figures 8, S13). English sole had more variable spatial overlap than Pacific sanddab and the average total LIC values for each period were lower than those for Pacific sanddab (Figure S14).

Table 2: Overall LIC values calculated for each period for each species. Lower values indicate less overlap between the fishery-independent and -dependent data.

Species	1980s	1990s	2000s	2010s
starry flounder	0.09	0.01	0.12	0.02
petrale sole	0.14	0.46	0.75	0.57
sand sole	0.18	0.19	0.29	0.02
English sole	0.37	0.29	0.50	0.37
Pacific sanddab	0.53	0.59	0.50	0.67
Dover sole	0.67	0.76	0.78	0.53

4 Discussion

With new opportunity to revitalize the nearshore fishery, it is crucial for managers to understand the current and past ecology of Oregon's continental shelf. Should species like starry flounder and sand sole become increasingly targeted or caught as bycatch, spatiotemporal data from logbooks could allow for better future assessment and a more complete historical baseline dataset. English sole and Pacific sanddab are perhaps more likely than the other species to gain market interest in Oregon, given their previous importance as part of the nearshore fishery (He et al., 2013; Cope et al., 2015). In the case of Pacific sanddab, the species has had a moderate resurgence in popularity in California. While over 90% of the petrale sole quota is caught each year, this is not true for Dover sole because sablefish is a co-occurring choke species, and there is limited market interest unless sablefish quota increases. Despite this, there are current efforts to increase Dover sole quota utilization, particularly for the northern region, so the Oregon nearshore may experience more fishing activity as a result (SaMTAAC, 2019). Additionally, there are ongoing attempts to increase consumption of Oregon seafood through industry-driven groups like Positively Groundfish and Oregon Sea Grant's Eat Oregon Seafood initiative. Utilizing fishery-independent and -dependent data can assist in this endeavor, providing more context for potential bycatch interactions and changes in community composition due to distributional shifts over time. This is not only useful for groundfishes with directed fisheries, but also for those caught less frequently.

Lack of survey data (see Table 1) has made it difficult to determine whether there have been spatial shifts within starry flounder and sand sole populations, which could be partially remedied by the use of logbook data. While starry flounder and sand sole are not among the most heavily targeted flatfishes, commercial trawl vessels consistently land them, albeit in smaller amounts than other species (Pearson & McNally, 2005; Ralston, 2005). Both species are considered data-limited by the PFMC, and there is uncertainty about the status of either species (PFMC, 2018). There is not presently a dedicated fishery for starry flounder and sand sole, though they were once more frequently pursued as part of a nearshore mixed flatfish fishery (Alverson et al., 1964; PFMC, 2018). There was very little overlap between fishery dependent and independent data for starry flounder and sand sole catch rates (Table 2), but logbook data indicate both species are present throughout the inshore portion of the shelf (Figures 4, S2). Therefore, logbook data may prove useful for future research on the changes in distribution of starry flounder and sand sole.

Data comparison and visualization of petrale sole, Dover sole, English sole, and Pacific sanddab presented very different results from the shallow-water species, in particular, the deeper water species petrale sole and Dover sole. Petrale sole was the only flatfish species previously categorized as overfished by the PFMC and for which nearly all quota was caught each year (Haltuch & Hicks, 2009; PFMC, 2018; Wetzel, 2019). The petrale sole shelf population distribution off Oregon and Washington exhibits decreases in areas that now regularly experience hypoxia but increases off the coast of southern Oregon and on the outer shelf off the coast of northern Oregon and Washington (Howard et al., 2021). There has been an overall increase in presence of Dover sole, especially on the northern shelf (Howard et al., 2021). These changes may explain the increase in mean logbook catch rate per year of Dover sole on the shelf near Astoria seen in the most recent period and the increase in logbook catch rates for petrale sole off the southern Oregon Coast since the 1990s (Figures 3, S1). Although there is not consistent catch of either species in the shallowest portion of the shelf, the depth distribution plots show that the shallow portion of both populations were missed by the NOAA surveys, especially near Astoria (Figures 6, S4). Thus, increased sampling inshore of the 55-meter isobath could provide new information on the distributions of these species and should be considered as an addition to the current sampling protocols for the WCGBTS. This was especially necessary for detecting any population expansion shoreward, which may be occurring for both species given their increase in presence on the shelf and recent higher logbook catch rates inshore (Figures 3, S1). This increase is expected for petrale sole as their population increased in recent periods from low numbers in the 1990s (Haltuch et al., 2013; Wetzel, 2019). Habitat compression, which has the potential to reduce habitat availability and change predator-prey interactions, is also possible due to factors such as hypoxia (Stramma et al., 2010; Stramma et al., 2012). Some species may shift to more oxygenated areas while other hypoxia tolerant species, like Dover sole, may remain.

For Dover sole and petrale sole, there is also information missed by the survey due to the timing of sampling. While most fishing occurs during the summer months, fishing happens outside of those months and the winter community composition is different due to seasonal migrations. Therefore, for species like petrale sole, both winter and summer fishery-dependent data have been investigated during the stock assessment process and these data may also be useful for determining change in the distributions of the winter spawning aggregations targeted by fishers. In addition, the winter petrale sole fishery-dependent CPUE indices have been considered more consistent due to fewer changes in spatial management during that time of year (Haltuch et al., 2011; Haltuch et al., 2013). However, this study was limited to the shelf, which explains the minor differences between seasons for petrale sole, as the spawning aggregations occur in deeper water (Haltuch & Hicks, 2009). Future work could investigate inclusion of winter fishery-dependent data in research on seasonally migratory species like petrale sole and Dover sole.

The final two species, Pacific sanddab and English sole, portrayed a middle ground between the other four species. Survey data indicated both species are predominantly found on the inner shelf, but this did not necessarily hold true for the logbooks. The narrow latitudinal band of Pacific sanddab commercial catch rates with patches of high catch rates suggests specific geographic areas where either Pacific sanddab are targeted or retained, or where there are high-density clusters (Figure 5). Recent research found a similar distributional pattern for juvenile Pacific sanddab, indicating that these patches in the logbook data are likely groups of juveniles in nursery grounds (Tolimieri et al. 2020). High English sole commercial catch rates were variable and may be associated with either ports or proximity to the estuaries where English sole live as juveniles (Krygier & Pearcy, 1986; Gunderson et al., 1990). Despite the similar inner shelf spatial distributions for English sole and Pacific sanddab, overlap metrics were surprisingly different. The differing amounts of survey and logbook dataset overlap for Pacific sanddab and English sole, as well as Dover and petrale sole, was unexpected. It was clear that a high total LIC for a given species does not necessarily indicate that there would also be an even distribution of spatially explicit LIC values. For example, in the case of Pacific sanddab and Dover sole there were isolated locations with high spatially explicit LIC values while the petrale sole and English sole spatially explicit LIC values were more evenly distributed throughout the study region (Figures 8, S12-S14). This showed that total overlap does not necessarily correspond to how heavily the species is targeted, as in high LIC does not indicate a heavily fished species, and that fishery-dependent data may be valuable for filling in spatial gaps not just for shallow water populations, but also for species like Dover sole and Pacific sanddab. Evaluation of the utility of combining these data sources for spatiotemporal analyses should therefore be determined on an individual species basis. Species with low spatially explicit or total LIC values, shallow distributions, or seasonal variability would be potential candidates for future work as long as they are reliably identified to species within logbook records. Additionally, this research only examined logbook data from the Oregon fleet and only catches that occurred on the shelf. The flatfishes in this study are distributed throughout the California Current System and are found both on and off the shelf, which necessitates further investigation into additional data sources and locations that are beyond the scope of this project.

Fishery-independent and -dependent data have been shown to be complementary when mapping fish distributions in other regions (Pecquerie et al., 2004; Stallings, 2009; Murray & Orphanides, 2013; Lyons et al., 2013) and this is the case for the 1980s and 1990s and for starry flounder, sand sole, Pacific sanddab, and English sole in particular. The logbooks provide a large quantity of self-reported data, while the survey data sets are smaller but implement random sampling and have more uniform spatial coverage. Visualization of the fishery-independent and -dependent effort associated with the Oregon nearshore trawl fishing grounds illuminated clear spatiotemporal disparities between the datasets. This lack of agreement happens for several reasons. First, the NOAA surveys do not sample inshore of the 55-meter isobath and there were fewer survey years in the 1980s and 1990s, when the surveys were triennial, than in the 2000s and 2010s. Secondly, even though the fishery annually targets the inshore, total fishing effort during the 2000s and 2010s declined and became concentrated to the north. This leaves a noticeable gap in fishery-dependent data in the south and shoreward of 55 meters in the recent periods. In addition, comparing species distributions from the two surveys requires caution, given the different survey designs. The triennial surveys sampled different depth and latitudinal ranges throughout its duration that differ from those used consistently during the annual surveys that began in 2003.

Northerly movement of fishing effort in recent periods, toward Astoria and Newport, took place because the northern region is where most of the fleet is homeported and where factories that process non-whiting groundfish are located (Warlick et al., 2018). This concentration of effort around larger ports or those with processing plants illustrates one reason why the NOAA surveys can provide more spatially consistent and statistically useful data. Although in general there is more fishing near ports, in the 1980s and 1990s these ‘biases’ toward specific ports were less evident. Numerous processing facilities were available to fishers at most ports prior to the intensified regulation and management that followed the fishery’s collapse in 2000 (Hanna, 2000; Warlick et al., 2018). Management and policy changes in the early 2000s led to consolidation and a federal buyback of vessels, resulting in only five major processing facilities for non-whiting groundfish. Therefore, the period most suitable for potential use of fishery-dependent data to fill in fishery-independent gaps for flatfish is likely during the 1980s and 1990s. For spatial analyses, this likely requires use of preferential sampling models to account for vessels targeting or retaining flatfish (Diggle et al., 2010; Pennino et al., 2016). Caution should be taken when using logbook data for the 1980s and 1990s because the technology available to record fishing locations was less accurate, compliance was variable, and bycatch was not recorded (Sampson, 2011; Sjostrom, 2019). The WCGBTS annual shelf/slope survey that began during 2003 instituted a grid-based stratified random sampling with better spatial coverage (Figure 2), a greater depth range, and a consistent period each year. Logbook data from the 2000s and 2010s show the fishery concentrated in the north so fishery-dependent data may be redundant with the WCGBTS for shelf flatfish, such as petrale sole and Dover sole. Additionally, this study focuses only on the shelf portion of the petrale sole and Dover sole range off the Oregon and Washington coasts, so the WCGBTS is better suited for use in stock assessments as their populations extend onto the slope, into Canadian waters, and off the California coast.

Fishery-dependent data collected by the Oregon nearshore trawl fleet has potential applications for investigating the distributions of groundfishes that are spatially under sampled by scientific surveys or for species that migrate seasonally. This is crucial for thoroughly understanding habitat use of coastal species throughout the year in light of increased use of nearshore waters. The shelf waters off the Oregon Coast are shared by a number of industries beyond the groundfish trawl fleet, including other commercial fisheries, telecommunications, tourism, and wind and wave energy. This shared use of marine resources is not unique to Oregon, so this research highlights the potential benefits of incorporating additional data sources to better inform future management decisions in areas beyond Oregon where fish habitat is also used by other stakeholders. To effectively utilize fishery-dependent data in these contexts, additional research should focus both on developing appropriate methods for use of opportunistic data to study distributions of under sampled species as well as exploration of methods that can integrate both data types for investigation of seasonally migratory species. These possible directions of future research and the increased incorporation of fishery-dependent data in spatiotemporal analyses have the potential to provide more accurate predictions of species distributions and therefore lead to better informed management decisions.

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Declaration of interests

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.

CRediT authorship contribution statement

Rebecca Howard: Methodology, Formal analysis, Visualization, Writing – Original draft preparation, Writing – reviewing and editing. **Lorenzo Ciannelli**: Conceptualization, Methodology, Supervision, Funding acquisition, Writing – reviewing and editing. **Waldo Wakefield**: Conceptualization, Supervision, Writing – reviewing and editing. **Melissa Haltuch**: Methodology, Writing – reviewing and editing.

Figure Captions

Figure 1: Map of the study region off the coasts of Washington (WA) and Oregon (OR), along with relevant ports. Contour lines represent the 50-meter and 200-meter isobaths.

Figure 2: The top four panels depict fishing effort by Oregon commercial fishing vessels. The bottom four panels depict survey sampling effort over the same period. Each grid cell represents average fishing effort per year for each period.

Figure 3: The panels above depict the spatial distribution of catch rates for petrale sole over four periods. The top four panels depict data from logbooks and the bottom four panels depict data from the NOAA surveys. Grid cells indicate scaled catch in each area.

Figure 4: Same as Figure 3, but for sand sole.

Figure 5: Same as Figure 3, but for Pacific sanddab.

Figure 6: Contour maps depicting depth distribution of petrale sole for the logbooks (upper four panels) and for the survey (lower four panels).

Figure 7: The panels above depict the spatial distribution of Dover sole for two different times of the year using logbook data. The bottom four panels depict data from the portion of the year not sampled by the survey, which ranges from October to mid-May. The top four panels depict tows conducted during the same months the survey samples. Grid cells indicate average catch in each area.

Figure 8: The four panels for each species depict average LIC in each grid cell for each period. Darker colors indicate collocation while lighter colors indicate higher LIC. Unfilled grid cells (light blue) indicate areas without both fishery-independent and -dependent data. The contour lines delineate the 200- and 55-meter isobaths. Due to confidentiality reasons, the grid cell size is large enough to cross over the 55-meter isobath, leading to the appearance of grid cells with non-zero LIC in this area.

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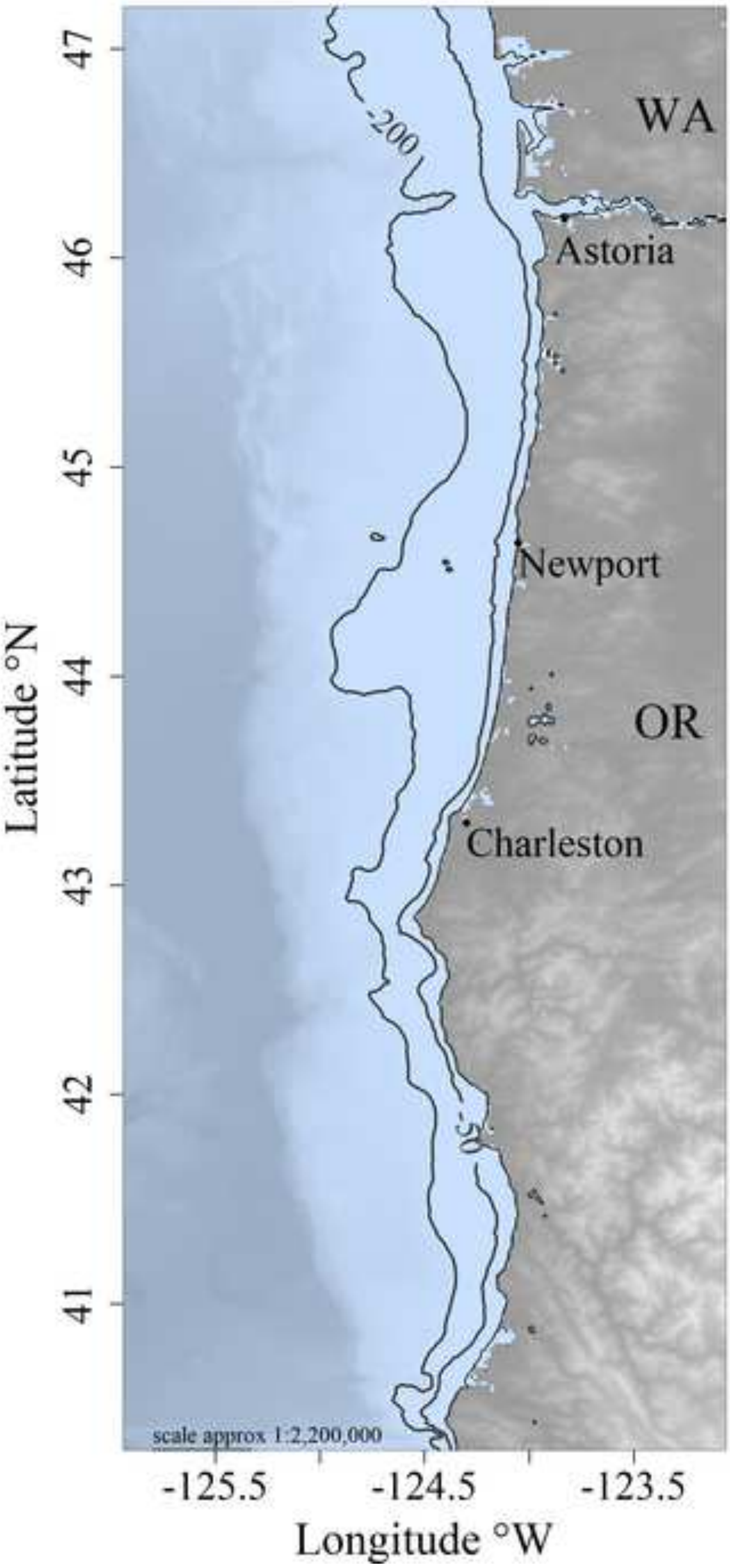
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Longitude °W

Figure2.jpeg

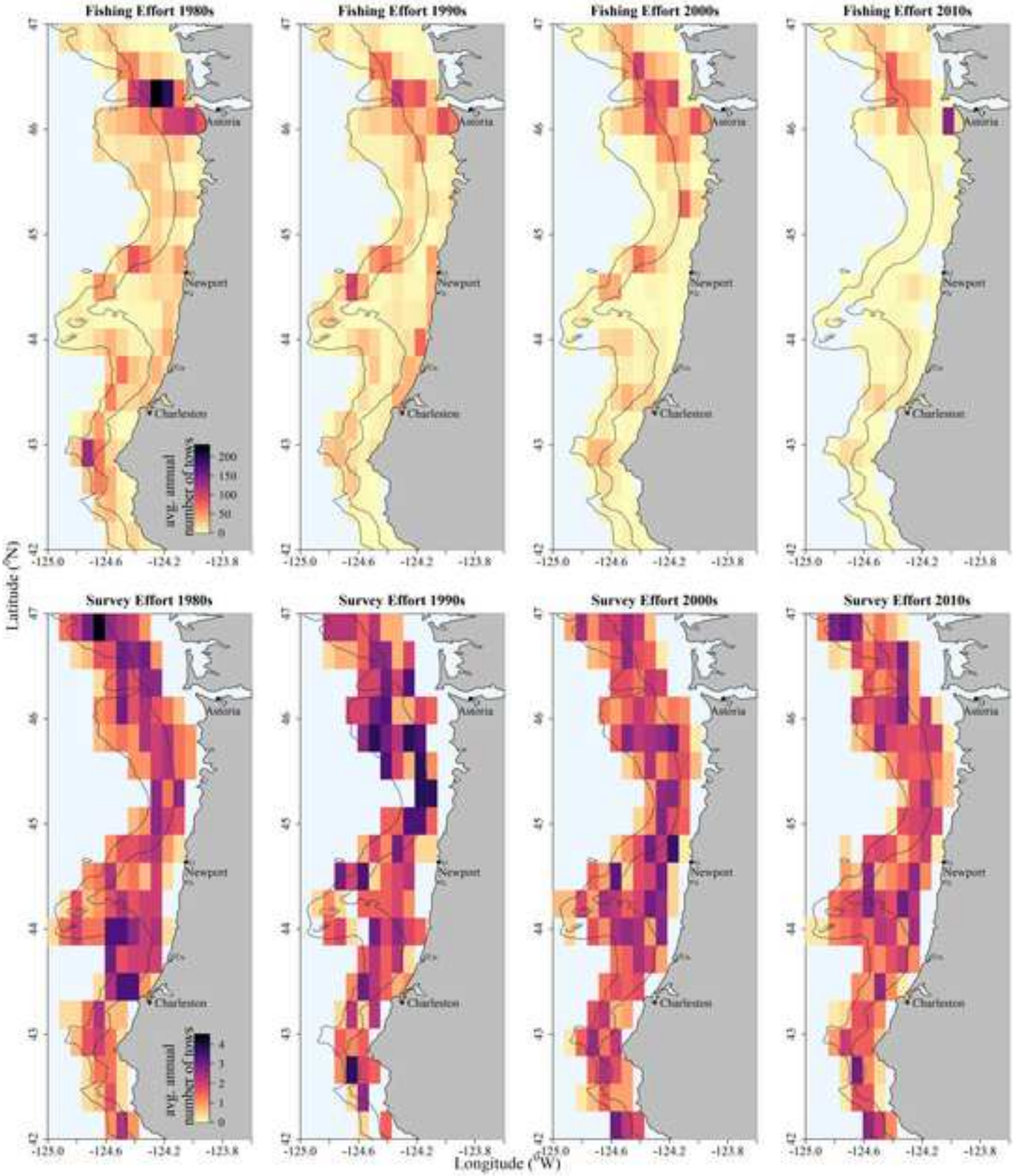

Figure 3

Figure3.jpeg

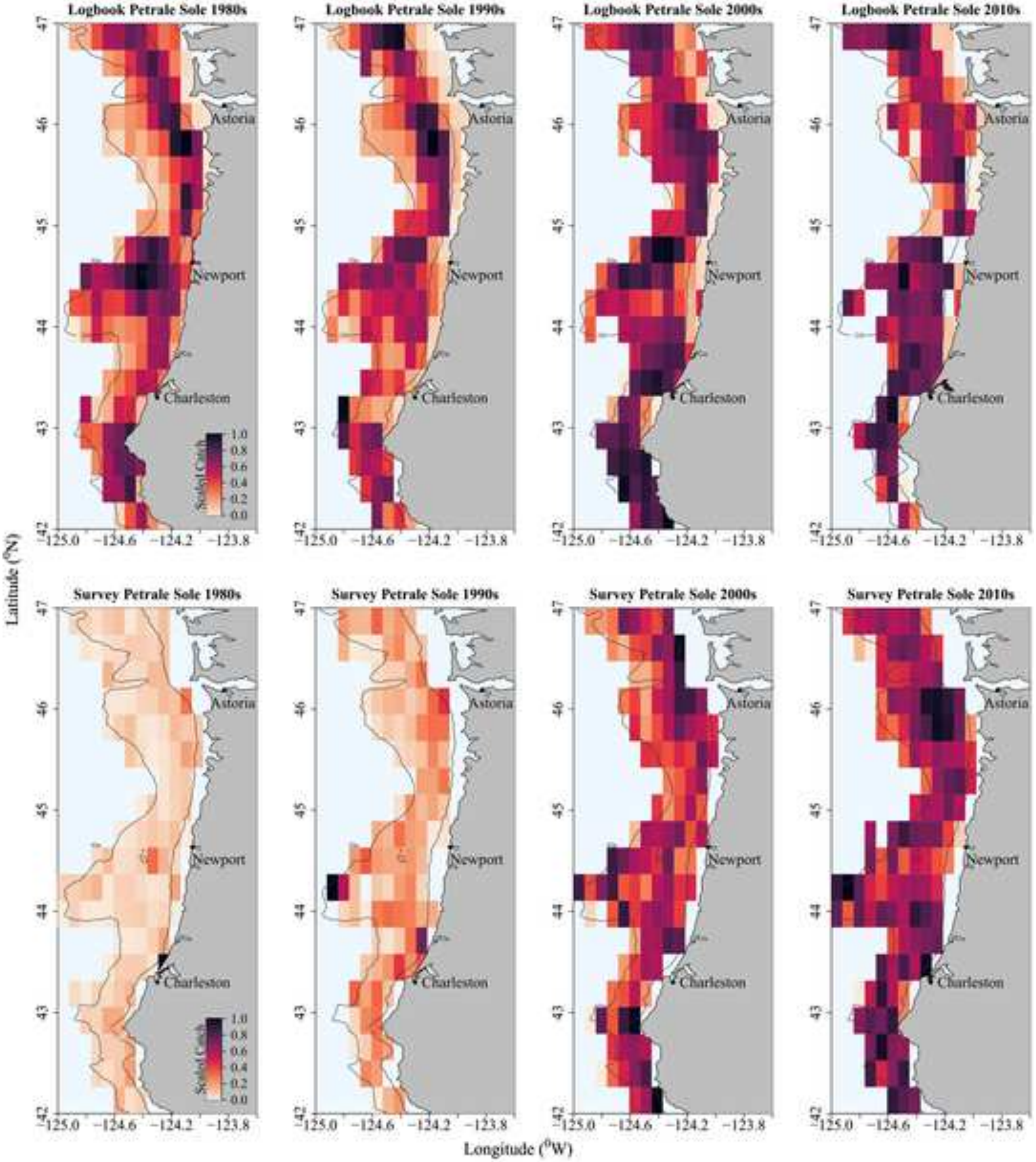

Figure 4

Figure4.jpeg

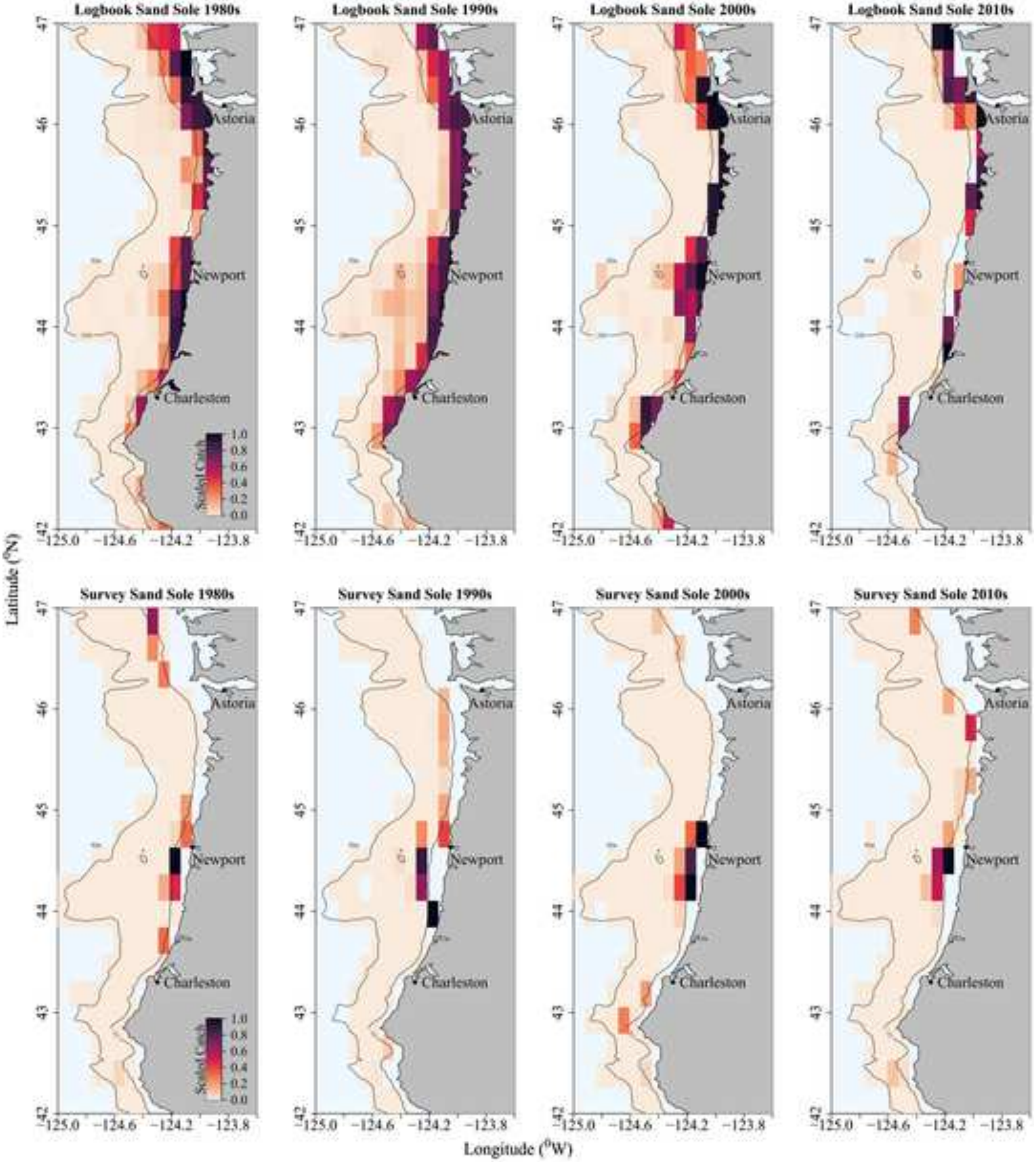

Figure5.jpeg

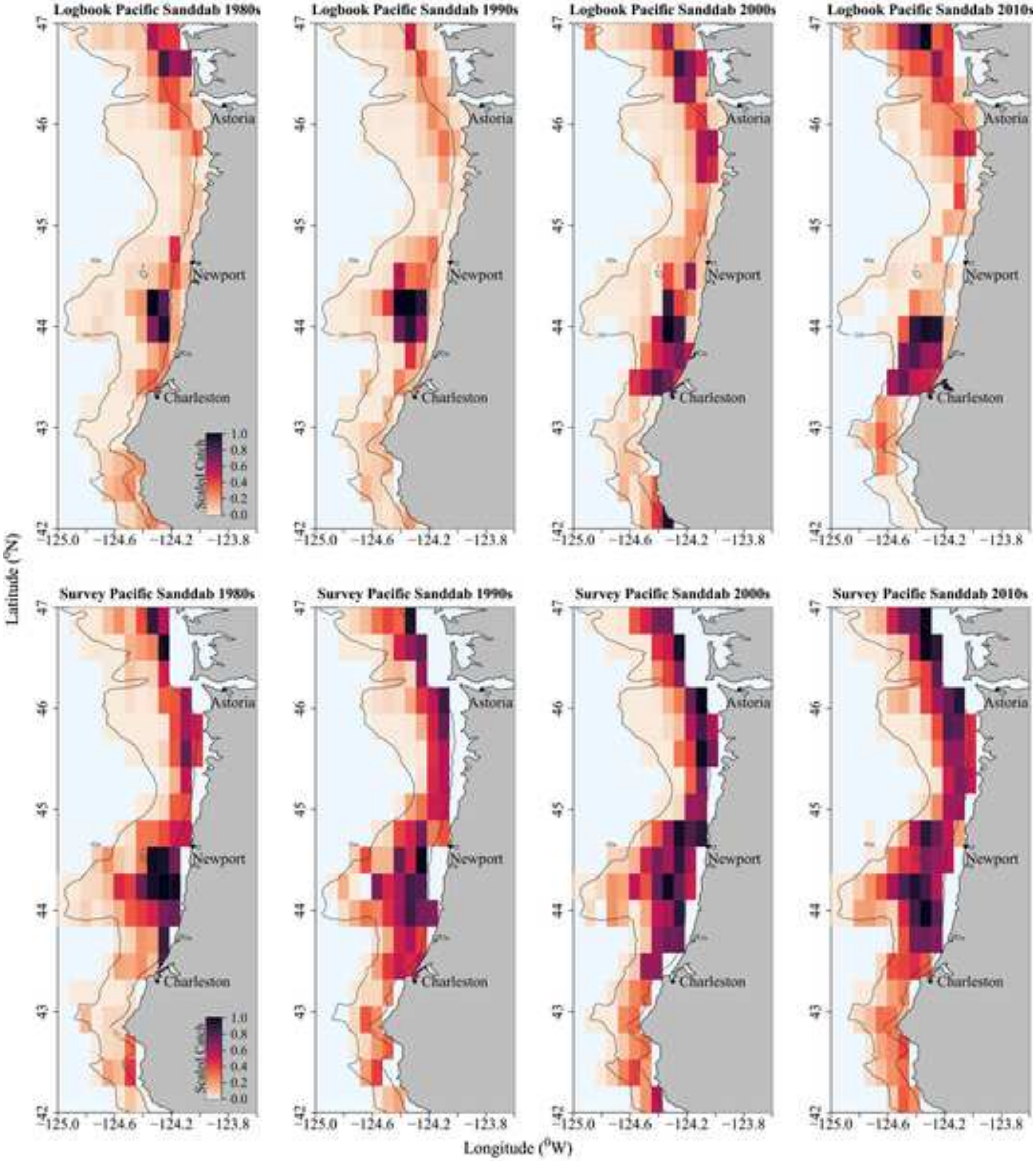

Figure 6

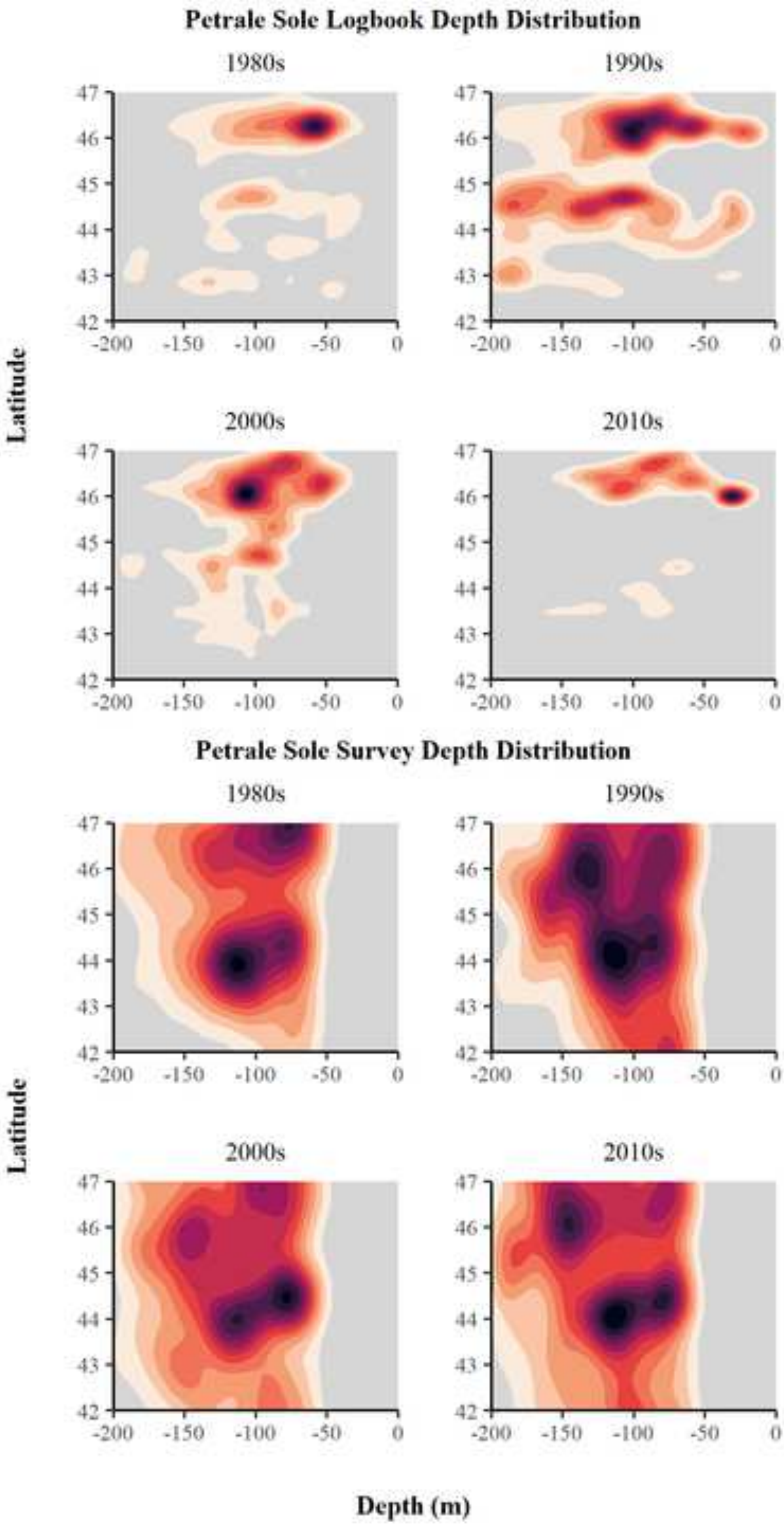
Petrale Sole Logbook Depth Distribution
1980s
1990s
2000s
2010s
Petrale Sole Survey Depth Distribution
1980s
1990s
2000s
2010s
Latitude
47
46
45
44
43
42
-200
-150
-100
-50
0
Depth (m)

Figure7.jpeg

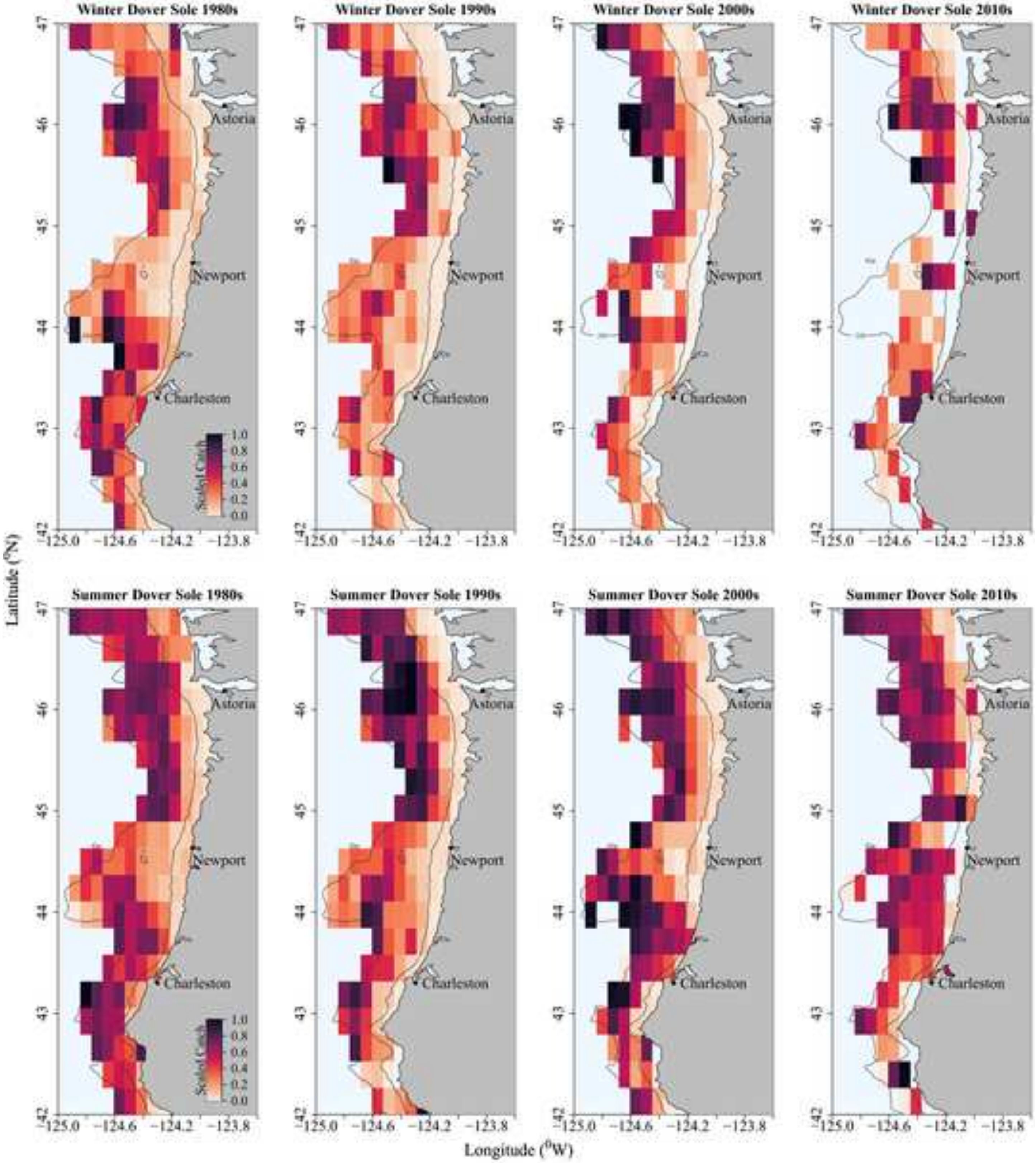

Figure8.jpeg