SOUTH SLOUGH RESERVE

A 30-year look into the fish assemblage of the South Slough estuary: Trends of declining productivity and biodiversity in an Oregon estuarine reserve

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Sorting a seine haul at Valino Island site in 2018

Introduction

Estuaries provide critical habitat to many marine, anadromous, and resident estuarine fishes with their dynamic and complex environments supporting larval, juvenile, and adult life stages including serving as spawning grounds (Bottom et al. 1988; Hughes et al., 2014; Schwartzkopf and Heppell, 2020). The transitional nature of an estuary between ocean and land leaves it sensitive to anthropogenic pressures such as human development and climate change (Ilarri et al. 2022; Merrifield et al., 2011; Lefcheck et al., 2017). With many estuarine fish assemblage studies spanning just one or two years, our understanding of how estuarine fish communities respond to continued anthropogenic pressures is unclear (Heppell et al., unpublished; Jackson & Jones, 2009; James, et al., 2008).

It is estimated that along California, Oregon, and Washington's coastlines, human modifications have resulted in an 85% loss of historically vegetated tidal wetlands (Brophy et al., 2019). The continuation of human development along these shorelines further adds to issues of habitat fragmentation, introduction of invasive species, and pollutants (Merrifield et al., 2011; Stachowicz et al., 2002). In Yaquina Bay, Oregon a 27-year comparative study linked shoreline development throughout the second half of the 20th century to a 91% decline of abundance in the estuary's macroinvertebrate and fish community (Heppell et.al, unpublished). With limited long-term studies of fish assemblages, it is unclear to what extent human development is impacting estuarine fish communities at a larger scale. Further, climate change is leading to increasingly frequent extreme marine weather events, such as the 2014-2016 warm water event in the north Pacific Ocean known as 'The Blob' (Khangaonkar et al., 2021). Persistently warmer water temperatures have been linked to a reduction in biodiversity and a higher proportional abundance of invasive species (Ilarri et al., 2020, Stachowicz et al., 2002). A source of this estuarine biodiversity loss may be linked to eelgrass declines, an estuarine foundational species that has been found to decline in abundance in years following warmer waters (Lefcheck et al., 2017; O'Darby-Anderson, unpublished; Plaisted et al., 2022).

The South Slough estuary, located on Oregon's southern coast, has remained largely free from human development and industry since 1974 when a considerable portion of its watershed was designated as a National Estuarine Research Reserve (NERR) (Rumrill, 2007). Today, about 7,000 ac of the 19,600 ac South Slough watershed is under NERR management with most of the lower estuary zoned as county and private land (Rumrill, 2007). South Slough, the sheltered southernmost arm of Coos estuary, covers a full gradient range of marine to fresh water (Rumrill, 2007). It's intertidal fish habitat includes salt marshes, sandbars, mudflats, algal beds, eelgrass meadows, and tidal forests (Rumrill, 2007). South Slough's channels and subtidal environments encompass soft and hard bottom strata as well as subtidal plant habitat (Rumrill, 2007). In 1987, a comprehensive seining study was conducted across South Slough with seining efforts taken at both high and low tides during the estuary's most productive months (April to October) (Bottom et al., 1988). Seining from sites ranging from the lower to upper estuary accounted for more than 30,000 individual fish from 33 species (Bottom et al., 1988). The vast majority of sampled fish were classified as anadromous species, using the Slough for spawning grounds (Bottom et al., 1988). Notably, standing crop and production of fishes was highest among subtidal eelgrass beds in the upper regions of nursery grounds (Bottom et al., 1988). Subtidal channels, which were seined at low tide, had higher catch rates than their high tide counterparts which usually occurred over mud or sand (Bottom et al., 1988). In addition, productivity rates of South Slough's fish assemblage were found to be similar to nearby estuaries of that time (Bottom et al., 1988).

Using data from a 2015-2018 South Slough NERR program that replicated historical seining efforts throughout the Coos estuary, including South Slough's 1987 study, we identified all directly comparable seines for a 30-year comparison of the fish assemblage in South Slough. The development of this spatial and temporal fish assemblage database will increase our understanding of how the South Slough estuary is responding to ongoing pressures, namely climate change, and work to identify habitat services in need of management.

Methods

Sites and sampling methods conducted in 2016 and 2017 were based on the previous sampling conducted in 1987 (Bottom et al. 1987). Beach seine nets were set by boat from shore at high and/or low tide at 4 sites in the South Slough Estuary (Table 1). The seine net size used in 2016 and 2017 was the same as that used in 1987 (38m long, 2.3m deep, mesh size 1cm in wings and 0.6cm in bag). Immediately after capture, fish were placed in a bucket of cold estuarine water, using a bubbler to maintain oxygen levels in the water. Fish were identified, measured, weighed and placed in a recovery bucket and released once 20-30 fish had been processed. The first 30 fish of each species were measured and weighed; additional fish of that species were counted and released. In 2016 and 2017 water quality variables were taken during each sampling event using a YSI handheld sonde (DO, pH, conductivity, salinity, water temperature). Historical data collected from seines in 1987 (Bottom 1987 et al.) were entered into our database from the original records, acquired in 2018 from Dan Bottom. More seine samples were collected in South Slough from 2015-2018 than we use in the following analyses, but we only include the data from the directly comparable seines in this report to reduce bias due to seasonal fluctuation of estuarine fish communities (McLusky & Elliott, 2004).

Table 1. Site descriptions				
Site	Tides sampled	Latitude	Longitude	Description
Valino Island (VI)	H, L	43.31	-124.321	Mid estuary: Sandbars, eelgrass, emergent wetlands.
Younker Point (YP)	H, L	43.323	-124.323	Low estuary: Mudflats, sandbars, rooted algae.
Winchester North (WN)	H	43.297	-123.319	Upper estuary: Mudflats, eelgrass, emergent wetlands.
Sengstacken (S)	H	43.297	-124.311	Upper estuary: Mudflats, eelgrass, emergent wetlands.

For most comparisons we use the catch (number or biomass) per seine (catch per unit effort, CPUE) to remove the effect of differing number of seines collected. We calculated the monthly and annual CPUE by calculating the average of the individual seine CPUE's for that period. Total fish biomass per seine (wet weight) was determined by first calculating the biomass of each species in each seine. For abundant species we measured 30 randomly selected individuals from each seine. Biomass of each species was calculated by multiplying the average biomass of each species in the seine by the number of each species in the seine. Biomass for each species was then summed to estimate the total fish biomass per seine (biomass CPUE).

Results

Data from 414 seining efforts across South Slough resulted in 88 directly comparable seines from three years of sampling: 1987, 2016, and 2017. These 88 seines were taken between late April to early October of each year and accounted for 20,985 individual fish represented by 30 species (Table 2). In 1987, 25 species were identified in South Slough, whereas in 2016 and 2017 species richness was lower with 19 species identified each year (Table 3).

Table 2. Description of fish community sampling (based on directly comparable data only):			
	1987	2016	2017
Number sites	4 (S,WN,VI,YP)	4 (S,WN,VI,YP)	4 (S,WN,VI,YP)
# Seines (total)	24	29	35
Months	4,6,7,10	5,6,7,8,9,10	5,6,7,8,9,10
Tides	H, L (WN and S = High only)	H, L (WN and S = High only)	H, L (WN and S = High only)
# Fish species	25	19	19
Fish abundance	9,987	6,614	4,384
Estimated biomass (g)	182,171	85,607	15,395

Trends in abundance

Annual catch per unit effort (CPUE) for each of the sites shows strong variability in abundance between years, with 1987 having the highest abundance and each following year having a smaller CPUE than the previous (Figure 1). Declines in annual abundance was most notable at Sengstacken where it’s 2017 CPUE was 81.4% lower than 1987 (Figure 1). This shift of abundance over the 30-year study was followed by Winchester North, Valino Island, and Younker Point which saw a total 81.1%, 70.5%, and 56.3% reduction in abundance, respectively (Figure 1). Sites further up the estuary declined more than sites lower in the estuary (see map, Appendix 1). Cumulative annual abundance from all sites divided by number of annual seining efforts accounts for a total 69.9% reduction of abundance in the fish assemblage of South Slough from 1987 to 2017.

Monthly CPUE of fish from all directly comparable years shows a common trend of the fish abundance in South Slough with low rates in the spring that increase to a peak in summer, then steadily decline as seining efforts continue into the fall (Figure 2). Monthly CPUE from October 2016 broke this trend with a sharp increase between September’s average of 9.8 fish per seine to the average 224 fish per seine observed in October, forming a second annual peak (Figure 2).

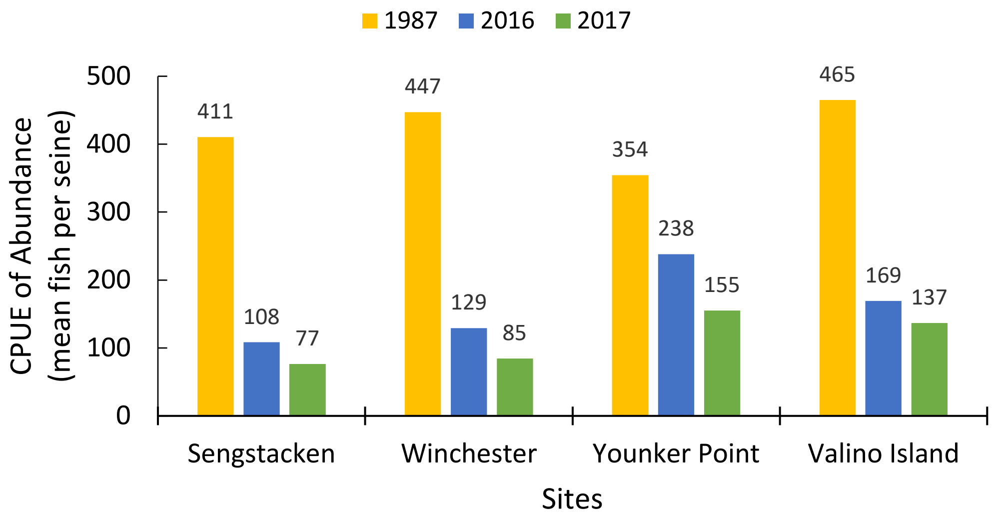

Figure 1. Annual mean number of fish caught per seine (CPUE) across four sites seined from April to October in the South Slough estuary in 1987, 2016, and 2017.

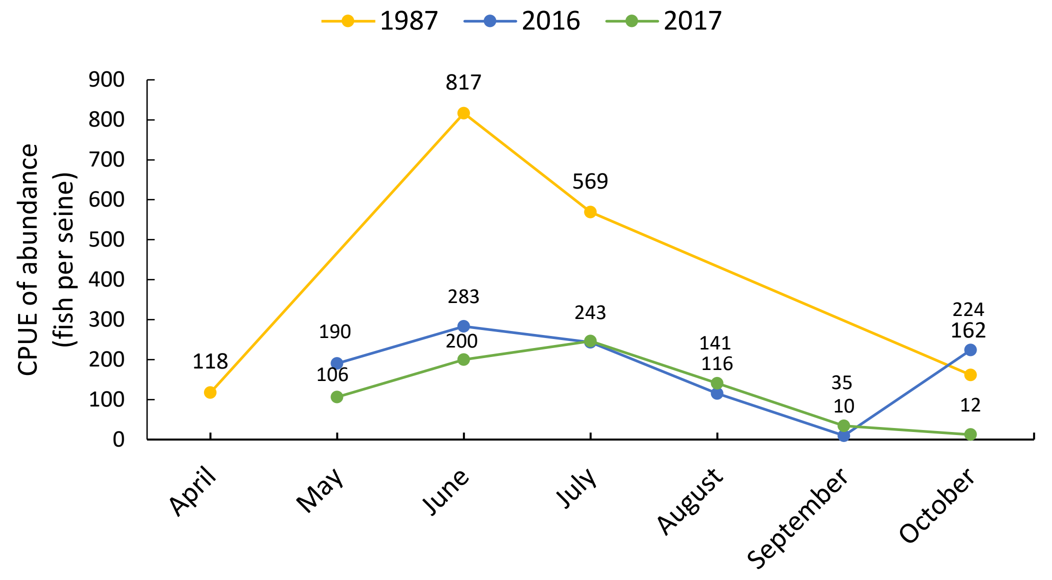

Figure 2. Comparison of fish abundance (number, mean monthly CPUE) collected from April to October in seines at four locations in the South Slough estuary during 1987, 2016, and 2017.

With a large decline in the total abundance of the fish community from 1987 to 2017 we examined the change in abundance of individual fish species to determine which species are responsible for this pattern. Of the 25 fish species sampled in 1987, 19 of them had declined in abundance by 2017. Notably shiner perch, the most abundant fish of 1987, saw a 99% decline over the 30-year study period with an initial mean abundance of 303.9 individuals in 1987 dropping to just 3.2 per seine in 2017 (Table 3). In addition, 8 of the original 25 species were absent in 2016 surveys and 10 were absent in 2017 surveys (Table 3).

Among the six species that had an overall increase of abundance from 1987 to 2017 are chinook salmon, coho salmon, and steelhead. These three species, as well as chum salmon are part of an ongoing Oregon Department of Fish and Wildlife (ODFW) rearing program that began in 2003 and includes statewide hatchery sites, rearing ponds, and adult trapping facilities (Chilton, 2017; Chilton, 2018). Adipose fin clips, used to identify hatchery fish, were not comprehensively noted across these sampled species therefore the influence of ODFW hatchery programs on observed abundance rates is unclear. Among other increasing trends, five fish species were detected in 2016 and 2017 surveys that had not been found in 1987 surveys (Table 3).

Table 3. Annual CPUE by species. CPUE was determined by annual total abundance of each species divided by the total number of seining efforts. Absolute change was determined by 2017's CPUE minus 1987 CPUE. Pink cells indicate an overall decline in abundance, blue cells indicate an overall increase, and white cells indicate species that weren't found in 1987 seines but observed in 2016 and/or 2017.

Common Name	1987	2016	2017	Absolute Change
American shad	0.208	0.241	0.143	-0.065
Bay goby	-	0.069	0.114	0.114
Bay pipefish	0.208	0.138	0.057	-0.151
Buffalo sculpin	-	-	0.057	0.057
Cabezon	-	-	0.029	0.029
Chinook salmon	0.375	2.414	2.914	2.539
Chum salmon	0.042	-	-	-0.042
Coastal cutthroat trout	-	0.103	0.143	0.143
Coho salmon	0.042	0.207	0.086	0.044
English sole	5.792	41.586	14.371	8.580
Green sturgeon	0.042	0.069	-	-0.042
Kelp greenling	0.208	-	-	-0.208
Lingcod	0.083	-	-	-0.083
Northern anchovy	0.333	25.414	17.429	17.095
Pacific herring	15.500	15.759	49.343	33.843
Pacific sand lance	0.042	-	-	-0.042
Pacific sardine	-	3.276	-	0.000
Pacific staghorn sculpin	30.667	22.586	25.771	-4.895
Penpoint gunnel	0.042	-	-	-0.042
Pile perch	2.292	0.069	-	-2.292
Saddleback gunnel	2.125	0.000	-	-2.125
Shiner perch	303.917	14.655	3.171	-300.745
Speckled sanddab	0.208	0.345	0.029	-0.180
Starry flounder	0.708	0.759	0.343	-0.365
Steelhead	0.042	-	0.086	0.044
Striped seaperch	0.417	-	-	-0.417
Surfsmelt	4.750	4.690	2.143	-2.607
Topsmelt	25.208	40.448	8.829	-16.380
Walleye surfperch	8.458	-	-	-8.458
White seaperch	14.417	0.379	0.143	-14.274

Trends in Biomass

Annual mean biomass declined 90.4% from 1987 to 2017 (Table 4). When looking at how these annual mean biomass estimates were distributed across months, trends that match monthly abundance rates are observed (Figure 3), with monthly mean biomass continually increasing toward a summer peak then declining as seining efforts approach the fall.

Table 4. Total biomass (g) and biomass per seine of all fish species sampled in the South Slough estuary in 1987, 2016, and 2017 using directly comparable seines (same locations, tides, and time-period). Mean biomass was calculated, by dividing the total estimated biomass by the number of seines from that year.

Year	Number of Seines	Estimated Biomass (g)	Mean Biomass (g / # of seines)
1987	24	182,170.72	7,590.45
2016	29	85,607.74	2,951.99
2017	35	25,394.49	725.56

Monthly mean biomass from 2016 differed from this trend, remaining relatively consistent from May to July with a strong decline of seined biomass in September followed by a sharp upward spike in October (Figure 3). Notably, a single seining survey supplied October 2016's data. This seine was comprised of 224 fish from just two species: 22 staghorn sculpin and 202 topsmelt. The large number of topsmelt suggests that the observed spikes in both biomass and abundance in October 2016 was the result of netting a school of topsmelt during a single seine event (OCS, 2016).

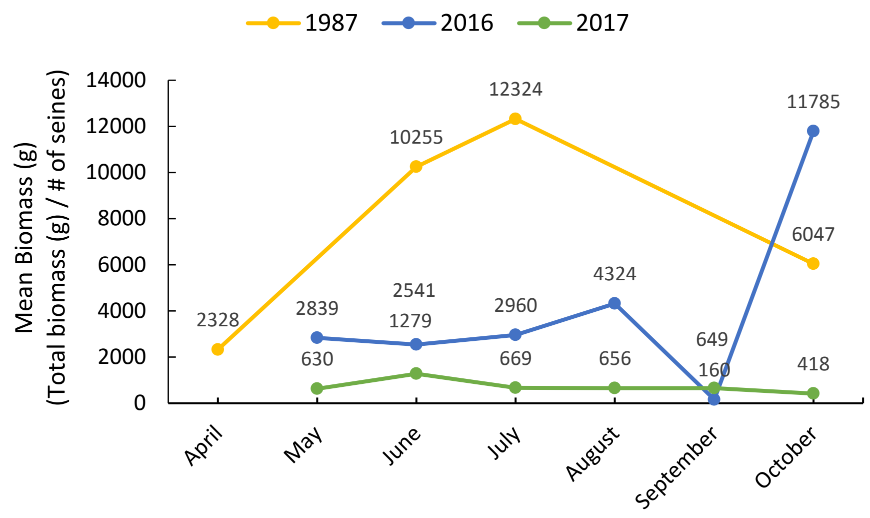

Figure 3. Monthly mean biomass (g) per seine of fish sampled from April to October at four sites in the South Slough estuary in 1987, 2016, and 2017.

Community Structure

Species accumulation curves are a way of determining whether the sampling effort is adequate to make inferences on the species richness of the community. If curves approach a plateau, it means that most of the species in the community have been sampled. Species accumulation curves for 1987 and 2016 continually increased throughout all seining efforts, although the number of new species added with each seine decreased, indicating few new species were recorded as the number of seines increased (Figure 4). The curve for 2017 seines appeared to be reaching a plateau more rapidly than those of the previous years, indicating that few new species would be sampled even if sampling effort was increased.

Rank-abundance curves are a way to visualize the structure of a biological community. The length of the line indicates the species richness of the community and the slope of the line indicates the evenness (or equitability) among species in the community (Figure 5). We observed 6 fewer species in 2016 and 2017 when compared with 1987. Although the species accumulation curves indicate a possibility that not all species were sampled, the curves for 2016 and 2017 showed that fewer species were being added with increased effort than in 1987 (Figure 5). This suggests that the fish species richness in South Slough was lower in 2016 and 2017 when compared with the fish community in 1987. It is interesting that the change represented not just the absence of certain species in 2016 and 2017 when compared with 1987, but also an exchange of species with some species found in 2016 and 2017 that were absent from 1987 surveys.

Species evenness did not appear to change much over time (Figure 5). The fish community equitability was similar to that seen for many biological communities with a few abundant species, many common species, and a few rare species. It is interesting that the 1987 surveys sampled more rare species than the 2016 and 2017 surveys, even though more seines were taken in each of the more recent sample years, 2016 and 2017.

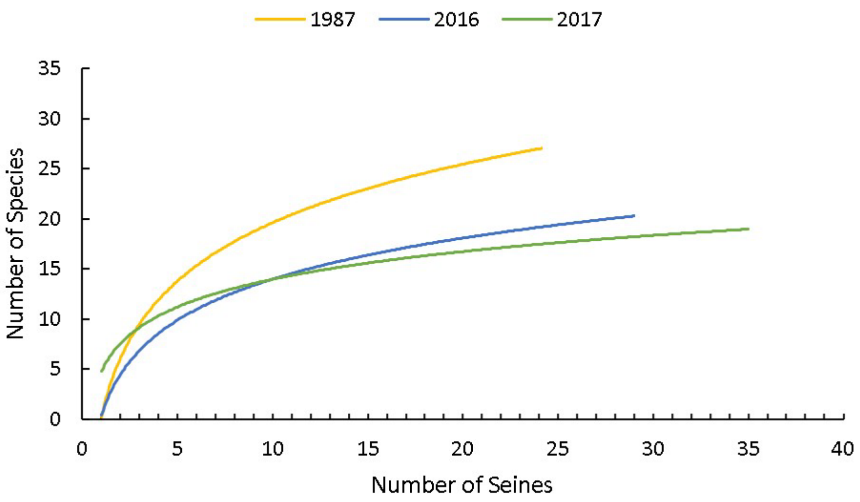

Figure 4. Annual species accumulation curves were used to assess sampling adequacy for completeness of species diversity readings.

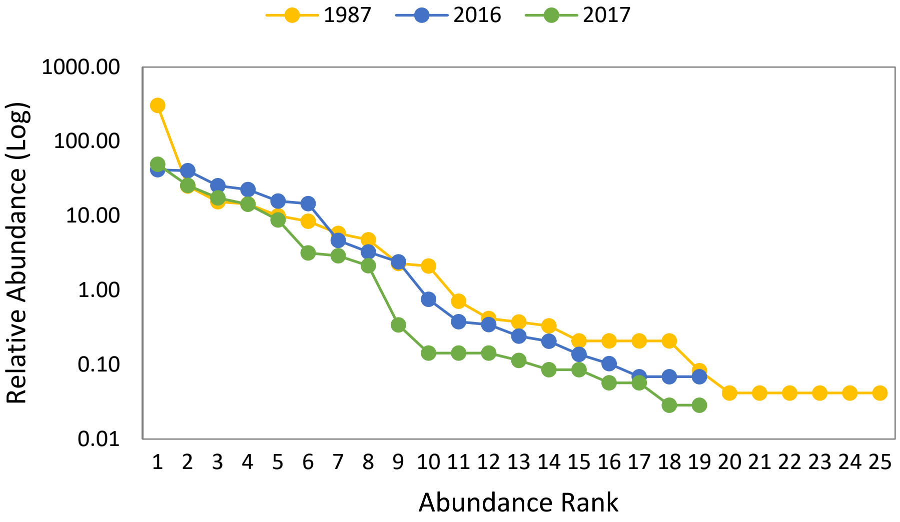

Figure 5. Rank abundance curves of fish sampled from each 1987, 2016, and 2017.

Discussion

We observed declines in the number, biomass, and biodiversity of fish species in the South Slough estuary from 1987 to 2017. Mean abundance declined by 69.9%, mean biomass declined by 90.4%, and species richness declined by 6 species. With a 29-year gap in comparable data from 1987 to 2016, it is unclear at what rates these declines occurred, how much these metrics vary by year, and what factors contributed to reduced productivity. Notably, in our only consecutive years of comparable data, 2016 to 2017, we saw sharper rates of decline for both abundance and biomass than the 30-year average. Without adequate comparable data before and after 2016-17, we cannot identify whether these stronger declines are a direct result of environmental events occurring concurrently, part of a longer trend, or high annual variability.

Comparison with data from Yaquina Bay

South Slough's reduced fish productivity corroborates the loss of abundance and biodiversity observed in Yaquina Bay, OR where fish and macroinvertebrate populations declined by 91% over a 30-year trawling study from 1967 to 2005 (Heppell et al. unpublished). Notably, Yaquina Bay had experienced major alterations to its natural shoreline habitats from both industry and development in the latter half of the last century, linking much of their fish and invertebrate declines to habitat loss (Heppell et al. unpublished). In South Slough, with the exception of logging in the upland forests, the mid and upper reaches of the estuary have been protected from industry since 1974, with just the lower estuary open to development (Rumrill, 2007). This suggests that although human development may be a cause of declining productivity in Oregon's estuaries, it is not the only contributing factor.

Possible influence from the recent eelgrass, Zostera marina, die-off and warm water blob

The sharp reduction in South Slough's fish productivity between 2016 and 2017 coincided with two major environmental events: a warm water blob that persisted along the northeast Pacific Ocean from 2014 to 2016 (Khangaonkar et al., 2021) and an eelgrass die-off beginning in 2016 that saw a 44.8% net loss across South Slough from 2016 and 2019 (O'Darby Anderson, unpublished). Studies of *Z. marina* have found declining productivity of eelgrass beds in years following warm waters, including studies in Coos Bay, Oregon (Lefcheck et al., 2017; Marin Jarrin et al. 2022; Plaisted et al., 2022). This indicates that climate change driven warm water events produce compounded pressures on an estuary, including both direct effects of increased temperature on fish populations and also secondary effects of habitat loss from declining populations of a foundational species (Lefcheck et al., 2017; Plaisted et al., 2022).

Although the life histories of many of estuarine fish remains unclear, we know that the presence of eelgrass meadows in our estuaries supports a more abundant, and more diverse, fish community (Lefcheck et al., 2017; Plaisted et al., 2022; Schwartzkopf et al. 2020). Therefore, species that inhabit eelgrass beds during multiple life stages would likely decline more rapidly in abundance during and after an eelgrass die-off event (Schwartzkopf et al. 2020). Among the fishes that were abundant in 1987 and that have life histories strongly tied to estuarine eelgrass habitat are topsmelt, Pacific herring, shiner perch, and surf smelt (Hughes et al., 2014; Krygier & Pearcy, 1986; OCS, 2016). Three of these four species accounted for some of the largest declines in species abundance observed between 2016 and 2017, suggesting that the eelgrass die-off in South Slough may have contributed to the decline in fish number and biomass observed between 2016 and 2017.

Conclusions

Findings of a strong reduction in the productivity of South Slough's fish assemblage was consistent with other Oregon estuaries (Heppell et al., unpublished). However, direct estuary-based causes for loss of productivity may vary (Heppell et al., unpublished). A lack of seining efforts over time prevents a clear understanding in the rate of decline and possible driving forces behind the changes in South Slough's fish communities. Moving forward, the continuation of a more comprehensive temporal and spatial fish assemblage database through future seining efforts could improve our understanding of the shifts occurring in the fish assemblage of South Slough and aid in the development of management options for the future.

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Appendix 1. Map of South Slough estuary’s study sites