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UNIVERSITY OF WASHINGTON – 2022 SEAWALL DATA REPORT

Jason D. Toft, Jeffery Cordell, Bob Oxborrow, Julia Kobelt, Cormac Toler-Scott, Mike Caputo, Arielle Tonus Ellis, Kerry Accola, Catalina Burch

School of Aquatic and Fishery Sciences
University of Washington

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Introduction

This data report summarizes the University of Washington's (UW) 2022 Year 5 post-construction fish monitoring within the completed Phase One Elliott Bay Seawall and appropriate reference areas. Year 4 (2021), Year 2 (2019) and Year 1 (2018) were completed in past sampling, and included three UW student publications (Sawyer et al. 2020, Accola et al. 2022a, 2022b) as well as technical reports (Anchor QEA and UW 2020, 2022). Data collected in 2022 allows evaluation of the effectiveness of habitat enhancements associated with the new seawall—addition of texture and relief to the wall; construction of shallow water benches; construction of the habitat intertidal zone (HIZ; formerly HIZ habitat beach or Zone 1 beach) located south of Colman Dock; addition of light penetrating glass block surfaces (LPS) to the sidewalk, and grating at Pier 62.

The UW conducted post-construction fish surveys March-October 2022, coinciding with presence of juvenile salmon near shore. Invertebrates were also sampled April-July 2022, and will be included in a separate report once samples are processed in the laboratory. Sampling occurred in areas extensively sampled before seawall construction (Munsch et al. 2014, Cordell et al. 2017a,b), and that were enhanced during the Phase I rebuild. Sampling occurred at six main sites (Fig. 1), under and in between piers at the first three:

1) Piers 54 and 55 (labeled as Spring St. North and South; Fig. 2),

2) Pier 56 (University St.),

3) the Seattle Aquarium (Fig. 3),

4) the Olympic Sculpture Park (OSP) as a reference that was created in 2007;

And, beginning in 2021,

5) the new Pier 62 with surface grating to allow for more light penetration (Fig. 4), and

6) the new HIZ beach next to the ferry terminal (Fig. 5).

Vine Street was also sampled as a seawall control for insect sampling related to the HIZ beach. The seawall between sampled piers did not have pier structure overhead, with exception of the section adjacent to Pier 55 (Spring St. North) which had some shading by an overhead deck associated with a food stand.

Pier 62 differs from other pier sites in that the grating is wider than the glass panels at other sites, and is also placed over a continuous shallower habitat bench that extends to the Aquarium (Fig. 4). The seawall at Pier 62 is the old seawall with no texture or ledges, and has pilings next to the seawall. The seawall extends farther from shore than at the other sites, because it was not set back behind sheet pile as was done during construction of the new seawall.

The HIZ beach is similar in overall size to the OSP pocket beach, but has a different configuration. The HIZ beach was constructed waterward of the existing seawall (Fig. 5), while the OSP beach was excavated landward of riprap armoring. The sediments placed in the intertidal of the HIZ beach are more angular and larger than at OSP. The area upland from the HIZ beach is planted with vegetation, and during 2022 was fenced and not accessible to the public, due to road construction associated with the new ferry terminal.

Research Questions addressed in this study were:

1. How does the addition of light penetrating surfaces (LPS) and texture and relief to the seawall affect use of seawall habitats by juvenile salmon and other fish?
2. How do assemblages and densities of small epibenthic invertebrates (e.g., amphipods, copepods) differ under LPS with textured/relief seawall in open areas vs under piers?
3. How do insects and benthic invertebrates respond to the HIZ beach?

A summary of the 2022 invertebrate fieldwork methods is included in this report; invertebrate samples are currently being processed in the laboratory, and data results for this effort will be included in a separate report in July 2023.

Figure 1. Seawall sampling locations in 2022.

Figure 2. Sampling locations at Spring Street, showing snorkel transects at Piers 54 and 55.

Figure 3. Underneath the Seattle Aquarium pier at low tide, showing habitat enhancements associated with the new seawall—addition of texture and relief to the wall; construction of shallow water benches; and addition of light penetrating glass block surfaces to the sidewalk.

Figure 4. Underneath the rebuilt Pier 62 at low tide, showing light through the grating.

Figure 5. Snorkelers conducting surveys at the HIZ Beach, with an insect fallout trap in the foreground vegetation.

Methods

Task 1-Invertebrates

Epibenthic invertebrates were sampled monthly April-July 2022 when juvenile salmon were abundant along the seawall using a standard epibenthic invertebrate suction pump that has been used at the Olympic Sculpture Park (Toft et al. 2013) and for previous seawall studies (Cordell et al. 2017a, Anchor QEA and UW 2020) (Fig. 6). Detailed methods are at the Shoreline Monitoring Database (https://www.shoremonitoring.org/epibenthic-invertebrates/). Sampling occurred on the seawall face under piers with LPS and between piers, plus on habitat benches both under and outside of the same piers, at the HIZ beach, and at the Olympic Sculpture Park bench as reference. Five samples were taken during each sampling event. A total of 420 samples were taken in 2022. Samples were sieved through a 0.106 mm sieve and preserved with 10% formalin.

Benthic invertebrates in bottom substrates were sampled monthly April-July with a benthic core 10 cm in diameter to a depth of 15 cm at the HIZ beach and Olympic Sculpture Park beach (reference site). Cores were taken along the beach surface (~0 feet MLLW). Seven replicate samples were collected at random points along the snorkel transect. Samples were sieved to 0.5 mm, preserved in 10% formalin, and returned to the lab for processing of taxa and number. Larger animals were noted in the field and released, such as crabs, sea cucumbers, sea urchins, mussels, and gunnels.

Seven fall-out traps (plastic storage bins 40 x 25 cm) were placed monthly April-July at random points along a transect through the terrestrial vegetation at the HIZ beach (Fig. 5). Vine Street was also sampled as a reference unvegetated seawall site. The bottom of each trap was covered with a mild soap solution and then deployed for 24 hours. Samples were sieved through a 0.106 mm sieve and preserved with 70 percent isopropanol.

Figure 6. Epibenthic invertebrate sampling along the seawall.

Task 2-Fish Surveys

Snorkel

Snorkel surveys were conducted March-October 2022, to collect data on fish abundance, size, distribution, and behavior patterns (Toft et al. 2007, 2013, Munsch et al. 2014, Sawyer et al. 2020). Each site was sampled twice per month March through July during the peak juvenile salmon outmigration, and once per month August-October. Transects were sampled ~3 m and 10 m from the seawall edge, corresponding to (1) shallow water under the LPS and over the habitat bench, and (2) deeper water not under the LPS (Fig. 2). Each survey consisted of one snorkeler at each transect, snorkeling at the same time parallel to shore (Fig. 7). Transects were conducted at both high and low tides. Observations were standardized by transect length and visibility, allowing density estimates (numbers/m^2). Location of the shade line of the piers, which varied with the sun angle, was recorded if present. Water temperature, salinity, weather, and horizontal secchi disk visibility were also recorded. Complete methods are at the Shoreline Monitoring Database (https://www.shoremonitoring.org/fish/).

Starting from the pier edge, transects under piers were all 25 m in length. Transects in between piers were also 25 m at the University St. and Aquarium sites, and were of 12.5 m lengths at

Spring St. North and South piers due to the limited space available. At the Olympic Sculpture Park the entire 35 m of the pocket beach (PB) was surveyed, and a 75 m transect was surveyed at the habitat bench (HB). At the HIZ beach the entire 35 m beach was surveyed (Fig. 5). At the beaches, an additional pair of transects was conducted at high tide to account for the shallow gradient at the beach that was not present at the seawall sites. An additional pair of transects was surveyed at the extended bench at the Aquarium to account for the extra shallow water space.

Statistical analyses were conducted on juvenile salmon densities and feeding. These analyses used data from surveys at seawall and pier sites, in which juvenile salmon were observed during a given survey. Linear models were conducted on log-transformed densities, with fixed parameters of habitat class, tide, and site. We used model selection based on Akaike Information Criteria (AIC). When habitat was significant ($p < 0.05$), Tukey multiple comparisons were made between the different habitats. To determine foraging patterns, analyses focused on discrete observations of juvenile salmon, with behavior classified as "feeding" or "not feeding." We analyzed these data using a Chi-square test on between and under-pier habitats, separately for nearshore (shallow) and offshore (deep) transects.

Figure 7. Two snorkelers surveying for fish along the seawall.

SCUBA

SCUBA transects were conducted once per month April through July 2022. Two paired divers surveyed transects parallel to shore at both shallow and deep depths, similar to snorkel surveys (Fig. 8). Shallow depths were over the habitat bench, and deep depths were at the base of the sheet pile wall supporting the bench. Transect lengths were identical to snorkel survey lengths. Surveys were conducted at high tides when there was water over the benches. Observations were standardized by transect length and visibility, to estimate densities (#/m^2) of demersal fish and crabs. For each fish observation, habitat (e.g., sediment types) and algae (e.g., green) types were recorded when pertinent to the fish observation. Number of bull kelp stipes (*Nereocystis luetkeana*) were counted along the entire transect.

At the Aquarium site, numerous under-pier pilings precluded conducting a deep transect at the base of the sheet pile. As in previous years, this effort was shifted to surveying a 30m transect around the perimeter of the extended bench in between the piers.

Figure 8. Preparing for SCUBA transects at Pier 62 and the Seattle Aquarium.

Results and Discussion

Task 1-Invertebrates

Invertebrate samples are currently being processed in the laboratory. Data for this effort will be included in a separate report in July 2023.

Task 2-Fish Surveys

Snorkel Surveys

Water salinities and temperature were similar to previous sampling, with temperatures around 8 °C and salinities of 22 ppt at the start of sampling in March, and temperatures peaking later in the summer around 14 °C with salinities of 28 ppt. Water depths during snorkel surveys varied with site, strata, transect, and tide (Table 1). At the Spring and University Street sites, shallow transect depths were over the habitat bench and under the LPS, and deep transect depths were off the habitat bench over deeper water. At the Aquarium site there is an extended bench farther from shore with shallow depths, including the adjacent Pier 62. Shallowest depths were at the HIZ and OSP beaches, and the OSP habitat bench.

Table 1. Average of water depths at strata sampled during snorkel surveys in 2022.

			Average of Water Depth (m)	
Site	**Strata**	**Transect Depth**	**High Tide**	**Low Tide**
Spring	Seawall	Shallow	2.8	1.9
		Deep	6.5	5.4
	Pier	Shallow	2.7	1.9
		Deep	6.7	5.8
University	Seawall	Shallow	2.4	1.8
		Deep	6.0	5.2
	Pier	Shallow	2.4	1.8
		Deep	6.1	5.4
Aquarium	Seawall	Shallow	2.6	2.0
		Deep	2.8	2.0
	Pier	Shallow	2.7	2.0
		Deep	2.9	1.9
	Extended Bench	Shallow	3.2	2.7
		Deep	3.4	2.8
Pier 62	Pier	Shallow	2.1	1.5
		Deep	2.5	2.0
HIZ	Beach	Shallow	1.3	0.5
		Deep	2.4	0.8
OSP	Beach	Shallow	1.8	0.5
		Deep	2.9	1.1
	Habitat Bench	Shallow	2.0	1.4
		Deep	2.9	1.8

The 2022 fish surveys represented a juvenile pink salmon outmigration year, which alternate years, and were very abundant. Juvenile pink and chum salmon were observed at the start of sampling in March, peaking with very high numbers in April, and continuing through June (Table 2). Juvenile Chinook salmon were observed from May through October, with relatively high numbers June through August. Coho, sockeye, and trout were rare, although there was one day in May where several large schools could not be identified beyond a Chinook/coho grouping. Herring were the most abundant forage fish, occurring June-October, followed by sand lance, which occurred June-August. Larval fish occurred March through June, with very high numbers in June. Tubesnout and surfperches were fairly consistent throughout sampling, especially shiner perch and striped seaperch for the surfperches. Red rock and kelp crabs were the most abundant crabs. Demersal fish such as sculpins, gunnels, lingcod, and rockfish were relatively rare, and more difficult to observe with surface snorkel surveys. Three-spined stickleback and adult salmon occurred in later months.

Table 2. Sum of fish counts during snorkel surveys for each sampling event in 2022.

Fish Group	Fish Species	Mar(1)	Mar(2)	Apr(1)	Apr(2)	May(1)	May(2)	Jun(1)	Jun(2)	July (1)	Jul(2)	Aug(1)	Sep(1)	Oct(1)
Juvenile Salmon	Pink/Chum	1397	8945	45470	7230	7365	732	1000	300					
	Pink	161	71	4002	1584	1		4562	9					
	Chum		117	6175	2774	201	121	1	4					
	Chinook					1	6	18	29	15	159	181		3
	Chinook/Coho						2338				1		1	
	Coho							1				1	1	
	Juvenile salmon, unk.				250	55		619	3	1			1	
	Trout						3			1			1	
	Sockeye						2							
Forage fish	Herring								886	13115	34542	2562	538	1327
	Sand Lance							100	1881	4305	6216	312		
	Sand lance/Herring							10000	450	650	300			
Larval Fish	Larval Fish	10	189	8			5000	56201	700					
Tubesnout	Tubesnout				10646	1	1	3		404	1158	108	239	109
Surfperch	Shiner Perch				1530	100	1801	362	244	707	332	695	1584	1957
	Striped Seaperch		1		12	23	19	76	7	52	25	45	29	35
	Kelp Perch					3		17		6	8	2	7	9
	Pile Perch							9	2	2	1		3	2
	Shiner/kelp perch													4
Crab	Red Rock Crab	1		1	5	20	15	16	11	20	14	11	28	10
	Kelp Crab	3	4	8	5	1	5	3	3	3	4	4	6	18
	Graceful crab									1	2	2		
	Decorator crab								3					
	Helmet Crab						1	1						
Demersal fish	Tidepool Sculpin					12			2				14	1
	Sculpin, unk.		1	1	1		3	1	2		6	2	5	2
	Lingcod			1		1		3					1	3
	Gunnel, unk.							2		1		1		1
	Ratfish												4	1
	Brown rockfish												3	1
	Rockfish, unk.											1	2	
	Manacled sculpin	1						1						
	Flatfish												1	
	Northern clingfish					1								
	Starry flounder													1
	Red Irish Lord		1											
Other	Three-spined stickleback										15	100	1196	334
	Adult Salmon												30	12

Juvenile Chinook salmon occurred mostly in the middle and surface of the water column with an average minimum length of 10.5 cm (Table 3). Pink and chum salmon were smaller in size, averaging between 3.2-3.7 cm for average minimum length, and were more in surface waters. Juvenile salmon were rarely observed in the bottom of the water column. Forage fish were centered in the middle of the water column, as were larval fish. Three-spined stickleback were observed more in surface waters. Surfperches and tubesnout were observed lower down in the middle to bottom of the water column, as were crabs and demersal fish.

Table 3. Average lengths of main fish groups during snorkel surveys in 2022, and percent of observations per water column position at surface, middle, and bottom. Crabs and demersal fish that were in the middle or surface of the water column were observed on a piling, on the seawall face, or on bull kelp.

Fish Group	Average of min Length (cm)	Surface	Middle	Bottom	sum
Juvenile Salmon					
Chinook	10.5	35.4%	61.5%	3.1%	65
Chinook/Coho	10.5	20.0%	80.0%	0.0%	10
Coho	10.0	66.7%	33.3%	0.0%	3
Chum	3.5	80.6%	9.7%	9.7%	31
Pink/Chum	3.2	58.1%	38.7%	3.2%	93
Pink	3.7	60.0%	40.0%	0.0%	45
Sockeye	10.0	50.0%	50.0%	0.0%	2
Trout	12.5	20.0%	80.0%	0.0%	5
Forage fish					
Herring	6.3	12.2%	78.4%	9.5%	76
Sand Lance	7.4	1.2%	85.5%	13.3%	85
Surfperch					
Shiner Perch	6.7	2.3%	60.8%	37.0%	265
Striped Seaperch	12.1	0.0%	31.6%	68.4%	135
Pile Perch	11.9	0.0%	75.0%	25.0%	12
Kelp Perch	9.2	0.0%	76.0%	24.0%	25
Larval Fish	0.5	8.7%	82.6%	8.7%	23
Tubesnout	8.1	1.7%	65.5%	32.8%	59
Three-spined stickleback	2.5	61.1%	38.9%	0.0%	18
Crab	12.6	0.0%	32.8%	67.2%	196
Demersal fish	18.6	0.0%	21.4%	78.6%	56

Overall fish densities were highest at the Olympic Sculpture Park beach and habitat bench in 2022, owing largely to high numbers of larval fish (Fig. 9). Forage fish were abundant at most sites except the HIZ beach, and lower numbers at the seawall sites. Juvenile salmon densities were highest at the seawall sites, OSP bench, and under Pier 62. Surfperches were most abundant at the HIZ beach.

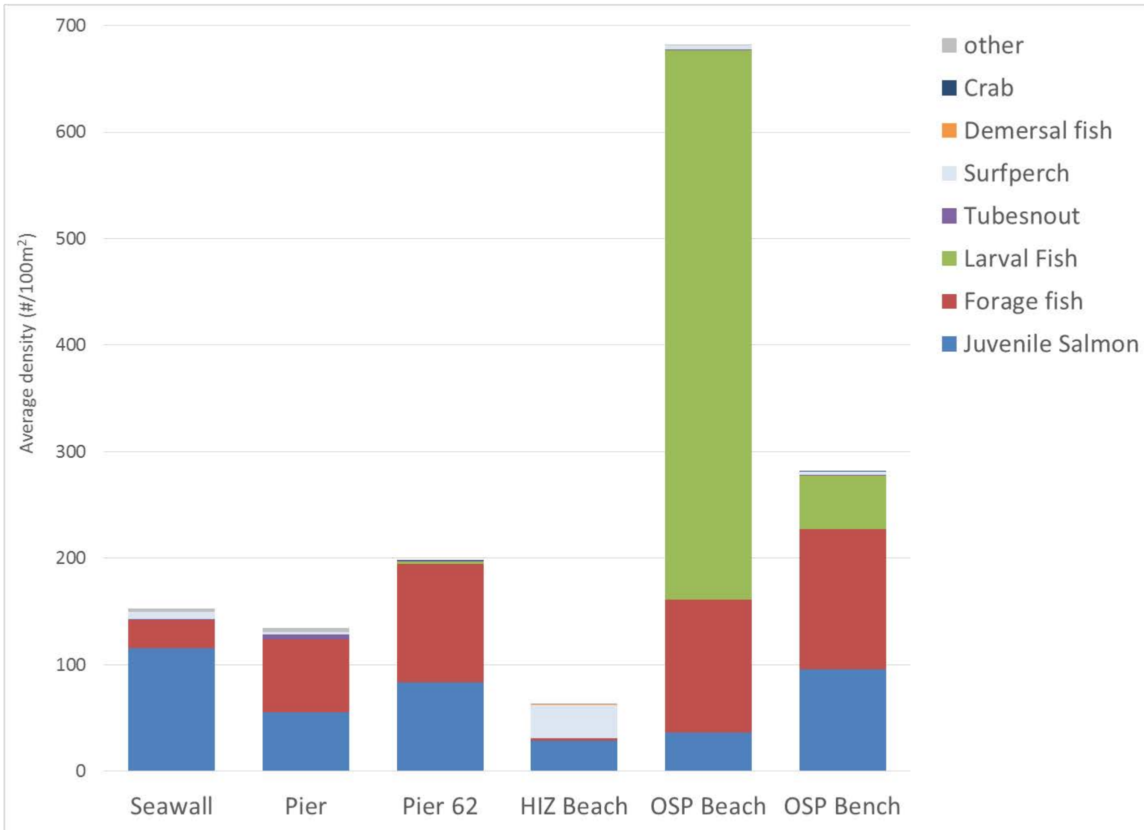

Figure 9. Average fish densities across strata during snorkel surveys in 2022. "Seawall" and "Pier" refer to the University, Spring, and Aquarium sites.

Chum and pink were the most abundant juvenile salmonids in 2022, with highest densities at the seawall, pier, and OSP bench locations (Fig. 10). Definite Chinook identifications had the highest densities at the HIZ and OSP beaches, intermediate densities at the seawall between piers and the OSP bench, and lowest densities underneath the piers. Of the forage fish, herring were more abundant than sand lance (Supplemental Fig. S7). Three-spined stickleback had highest densities at the seawall and pier locations.

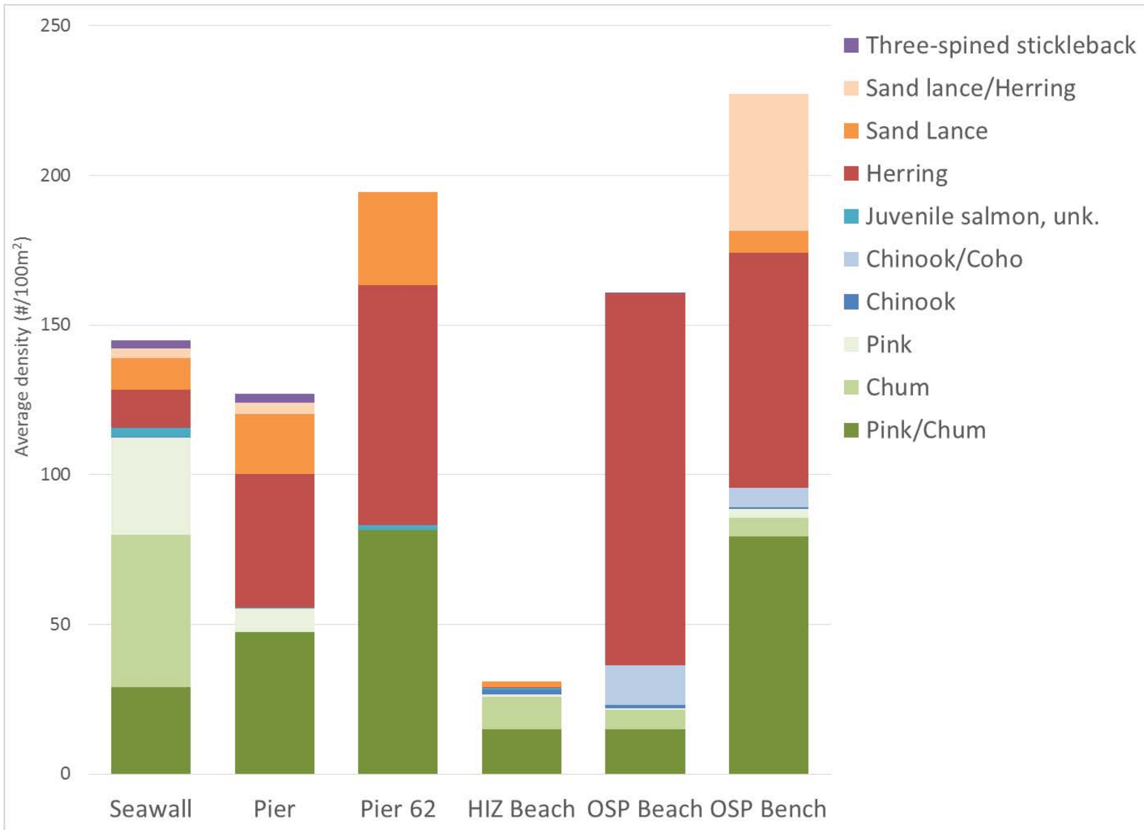

Figure 10. Average densities, across strata, for species categories of juvenile salmon, forage fish (herring and sand lance), as well as three-spined stickleback, during snorkel surveys in 2022.

In 2022, juvenile salmon along the seawall and pier sites had slightly higher densities underneath the LPS at piers than at seawall sites in shallow transects at both high and low tides (Figs. 11 and 12). In deep transects, juvenile salmon densities were higher at seawall sites during high tides, but were more equal between seawall and pier sites at low tide. Statistical testing verified this, with no significant differences in juvenile salmon densities between outside and under piers in shallow transects ($p = 0.16$), and borderline no differences between outside and under piers in deeper transects ($p = 0.07$). This was almost identical to that found in previous years, with no significant differences in juvenile salmon densities between outside and under piers in shallow transects in 2018 ($p = 0.98$), 2019 ($p = 0.16$), and 2021 ($p = 0.96$) but significant differences between outside and under piers in deeper transects in 2018 ($p < 0.001$), 2019 ($p < 0.001$), and 2021 ($p < 0.006$) (Supplemental figures; also see Anchor QEA and UW 2020, 2022). This indicates that an equal proportion of the juvenile salmon along the seawall were using the areas under piers illuminated by LPS. This is in contrast to pre-construction results that showed very few juvenile salmon occurring under piers (Munsch et al. 2014).

Pier 62 has a different configuration than the other piers, and also had different patterns of juvenile salmon occurrences. At Pier 62 the grating is wider than the glass panels at other sites, and both shallow and deep snorkel transects were underneath the grating and not in shaded darker sections of the pier (Fig. 4). The grating is also placed over a continuous shallower habitat bench that extends to the Aquarium. The seawall itself at Pier 62 is the old seawall with no texture or ledges, and has pilings next to the seawall. It therefore also extends farther from shore than at the other sites, because it was not setback during construction. Juvenile salmon underneath Pier 62 were more abundant at shallow transects during high tides, and deep transects at low tides.

The HIZ beach had comparable juvenile salmon densities to that at the OSP beach and bench at high tides, mostly in shallow water. Densities were lower during low tides at the OSP and HIZ beaches, when there was not as much water and therefore not as much inhabitable space for fish. Forage fish were observed in patchy schools across sites and tide/depth transects, with lowest densities at the HIZ Beach.

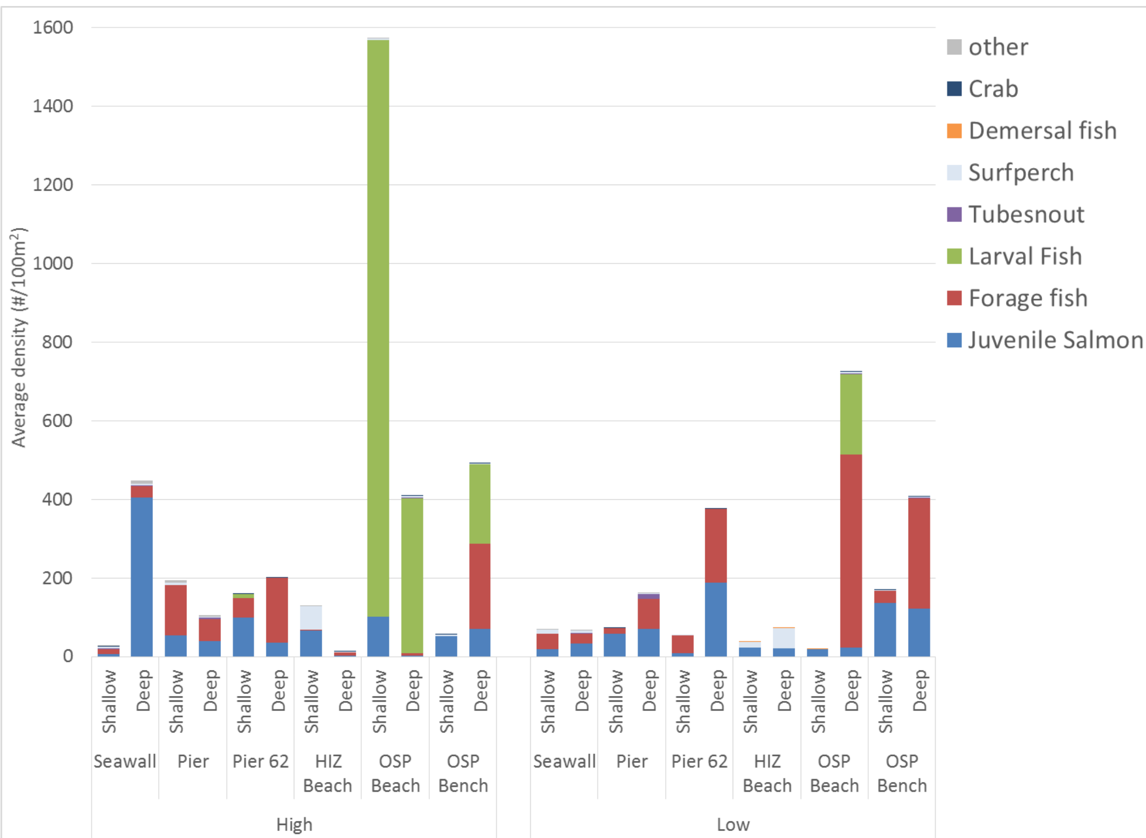

Figure 11. Average fish densities during snorkel surveys across strata, for high and low tides, and shallow and deep transects in 2022.

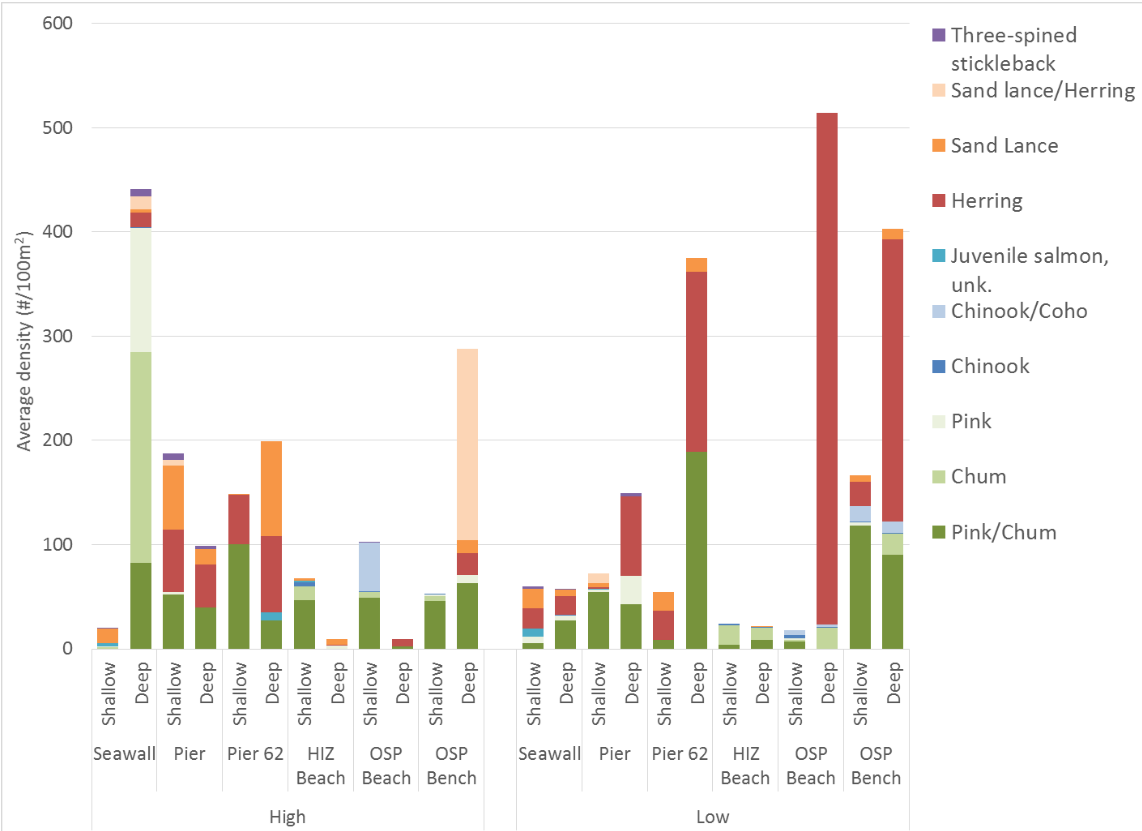

Figure 12. Average densities of species categories of juvenile salmon, forage fish (herring and sand lance), as well as three-spined stickleback during snorkel surveys, across strata, for high and low tides, and shallow and deep transects in 2022.

At the Aquarium extended bench in 2022, juvenile pink and chum were more abundant farther from shore along the extended bench (Fig. 13). The extended bench also had higher densities of tubesnout and surfperches (not shown), mostly consisting of schools of shiner perch, which is where there is more bull kelp along the outer edge of the extended bench. Herring and sand lance were more evenly distributed across all transects.

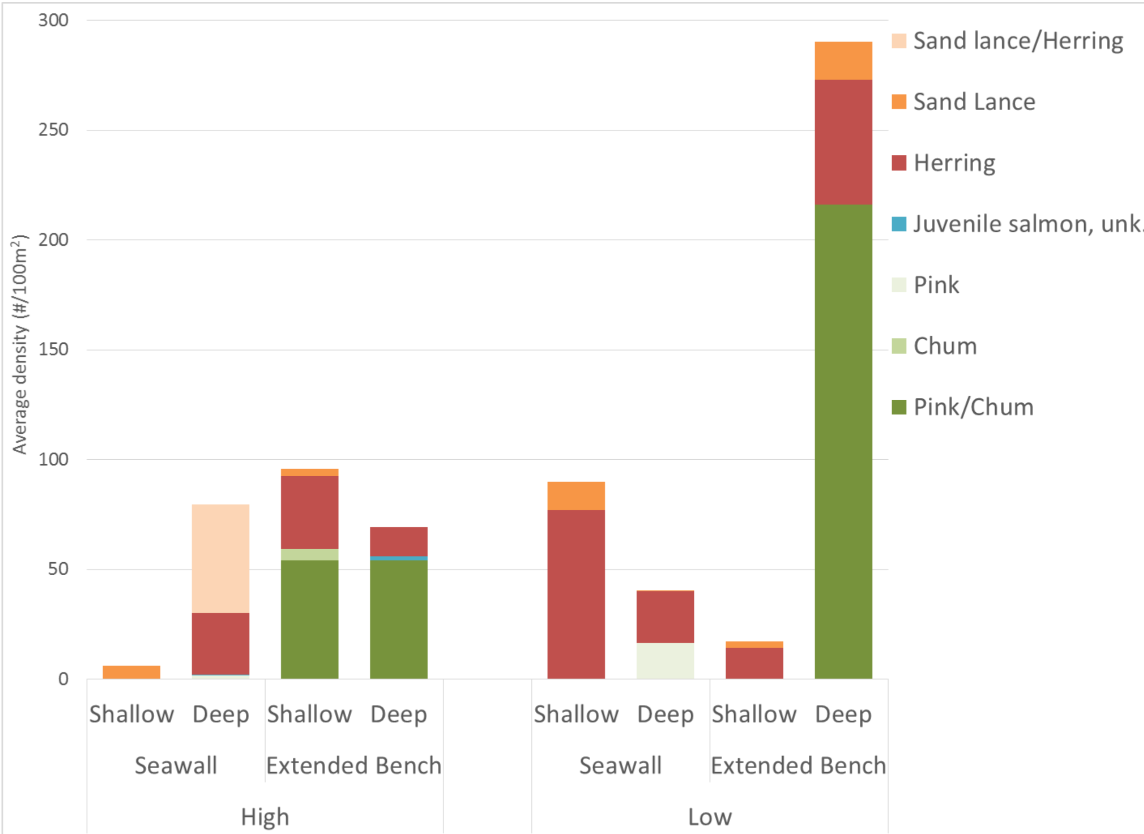

Figure 13. Average densities of species categories of juvenile salmon and forage fish, comparing snorkel surveys at the Aquarium seawall and extended bench in 2022.

Among fish groups, juvenile salmon and herring had the highest percentage of feeding behaviors observed during snorkel surveys, with both exhibiting feeding behavior ~30% of the time (Table 4). Juvenile Chinook, chum, and pink salmon all had similar percentages of feeding behavior. Fish generally fed within their observed location in the water column (Table 3), except for juvenile Chinook salmon, which fed more at the surface (84%) than their occurrence there (35%), possibly due to preference for surface-associated prey such as insects on the water's surface or marine invertebrates in the neuston layer (Fig. 14). Although chum salmon did feed mostly at the surface (78%) where they were primarily located, they did feed 22% of the time at the bottom of the water column, with all bottom feeding observations at the HIZ beach.

At the main seawall and pier strata in 2022 (Spring, University, and Aquarium) juvenile salmon feeding at shallow transects with habitat enhancements was higher underneath the LPS at piers (22%) than at seawall sites (14%) (Table 5). Chi-square testing showed that there were no significant differences under and between piers in shallow transects (p = 0.70), as was the case in 2018 (p = 0.67), 2019 (p = 1.0), and 2021 (p = 1.0) (also see Anchor QEA and UW 2022). This is in contrast to prior to seawall replacement, when nearshore feeding was observed only between piers, and never under piers (Munsch et al. 2014). Deep transects in dark areas under piers in 2022 without habitat enhancements had lower juvenile salmon feeding behavior (7%) than the deep transects at seawall sites (30%). Juvenile salmon were observed to feed under the new grating at Pier 62 in deep transects (20%), but not in shallow transects. The HIZ Beach showed the highest percentage of feeding behavior, both in shallow and deep transects, higher even than the OSP beach and bench. Juvenile salmon feeding in the middle of the water column was highest at the seawall sites, feeding more at the surface elsewhere.

Of note is that there were still ongoing shoreline construction activities in 2022 that may have affected fish movement and behavior. For example, the south end of the seawall at the ferry terminal next to the HIZ beach was undergoing construction on the pier and road.

Figure 14. Juvenile Chinook salmon feeding at the water's surface at the HIZ Beach.

Table 4. Percent of main fish groups feeding during snorkel surveys in 2022, and where they were feeding in the water column.

Fish Group	Feeding %	Surface	Middle	Bottom
Juvenile Salmon				
Chinook	29%	84%	16%	0%
Chum	29%	78%	0%	22%
Pink	32%	57%	43%	0%
Herring	32%	17%	79%	4%
Sand Lance	11%	0%	100%	0%
Three-spined stickleback	11%	50%	50%	0%
Tubesnout	14%	0%	38%	63%
Crab	23%	0%	33%	67%
Demersal fish	2%	0%	0%	100%

Table 5. Percent of juvenile salmon feeding during snorkel surveys at different strata and depths in 2022, and where they were feeding in the water column.

Strata	Depth	Feeding %	Surface	Middle	Bottom
Seawall	Shallow	14%	33%	67%	
	Deep	30%	11%	89%	
Pier	Shallow	22%	63%	38%	
	Deep	7%	100%		
Pier 62	Shallow				
	Deep	20%	100%		
HIZ Beach	Shallow	39%	75%		25%
	Deep	50%	60%	40%	
OSP Beach	Shallow	34%	55%	45%	
	Deep	38%	100%		
OSP Bench	Shallow	17%	60%	40%	
	Deep	22%	100%		

<u>SCUBA Surveys</u>

Water depth data collected during SCUBA surveys are presented in Table 6. At the Spring and University Street sites, shallow transect depths were over the habitat bench, and deep transect depths were off the habitat bench at the base of the sheet pile supporting the bench. At the Aquarium site there is an extended bench farther from shore with less water depth at deep transects, also reflected in the depths at Pier 62. Water depths at the HIZ Beach were slightly deeper than at OSP.

Table 6. Average of water depths at strata sampled during SCUBA surveys in 2022.

Strata	Transect Depth	Average of Water Depth (m)
Spring/University sites	Shallow	3.1
	Deep	5.3
Aquarium Extended Bench	Shallow	3.6
	Deep	4.4
Pier 62	Shallow	2.4
	Deep	3.2
HIZ Beach	Shallow	5.2
	Deep	7.3
OSP Beach	Shallow	4.1
	Deep	4.9

The most abundant fish observed on the SCUBA transects were larval fish in 2022, similar to past years of sampling (Table 7). As with the snorkel data, tubesnout and shiner perch were relatively abundant and occurred across sampling periods, and other surfperches and crabs were also fairly consistent. Herring were also abundant in July, and sand lance in June and July. Other fish observations were relatively rare.

Table 7. Sum of fish counts during SCUBA surveys for each sampling event in 2022.

Fish group	Fish species	April	May	June	July
Larval fish	Larval fish	4,037	21,651	107,890	30,700
Tubesnout	Tubesnout	291	10	543	611
Forage fish	Herring				7,072
	Sand Lance			1,525	2,925
Juvenile salmon	Pink				200
	Chinook		1		
Surfperch	Shiner Perch	301	110	4	121
	Striped Seaperch	15	15	11	17
	Kelp Perch	1	11	8	2
	Pile Perch		7	3	2
Crab	Red Rock Crab	80	63	79	96
	Kelp Crab	6	6	5	3
	Helmet Crab	4	1	1	1
	Decorator crab	2			2
	Pygmy Rock Crab		1	1	2
	Crab, unk.			1	
Rockfish	Brown Rockfish			2	13
	Rockfish			1	7
	Quillback Rockfish			1	
Sculpin	Sculpin	2			3
	Tidepool Sculpin		1	2	1
other	Lingcod	14	4	3	6
	Pacific Snake Prickleback			5	
	Gunnel	1	1		
	Crescent Gunnel				1
	Fish, unk.			1	
	Rock Sole			1	
	Giant Pacific Octopus	1			

Most fish observed on SCUBA transects were not known predators of juvenile salmon (e.g., surfperches), were too small to feed on salmon (e.g., small lengths of observed sculpins), or did not co-occur with juvenile salmon because juvenile salmon were closer to shore or higher in the water column (Table 8). Only two schools of juvenile salmon were observed during SCUBA surveys in 2022, both in the middle of the water column. Twenty-seven observations of lingcod were recorded (a predator of smaller fish), which is more than in previous years, and occurred almost exclusively at the Olympic Sculpture Park pocket beach (Supplemental Fig. S8), with the exception of two observations at Pier 62. One Giant Pacific Octopus was observed, also at the OSP pocket beach.

Table 8. Average of fish group lengths (minimum value of size class range) during SCUBA surveys in 2022; percent of water column positions of observations in the middle, within 1 m of the bottom, and bottom; and sum of observations (i.e., each school, not total fish counts). Crabs that were in the middle of the water column were observed on a piling, the seawall, or bull kelp.

Fish group	Average of min Length (cm)	Middle	Within 1 meter of bottom	Bottom	Sum of observations
Larval fish	1.1	41.9%	45.2%	12.9%	31
Tubesnout	7.4	35.2%	47.7%	17.0%	89
Forage fish	5.0	92.5%	2.5%	5.0%	40
Juvenile salmon	5.0	100.0%			2
Surfperch	11.9	57.6%	35.6%	6.8%	59
Crab	12.8	6.9%		93.1%	203
Rockfish	14.0	11.1%	22.2%	66.7%	18
Sculpin	5.8			100.0%	9
other					
Gunnel	11.6	0.0%	0.0%	100.0%	3
Lingcod	40.9	3.7%	7.4%	88.9%	27
Flatfish	12.5		100.0%		1
Prickleback	5	0.0%	0.0%	100.0%	1
Octopus	30.0			100.0%	1

Larval fish were abundant in 2022 at all sites, and especially at the OSP pocket beach deep transect (Fig. 15), where they were patchy in distribution but occurred in large schools. Notably, larval fish were observed at Pier 62 and the HIZ Beach, which had no larval fish observations when they were first surveyed in 2021. From surveys in past years, divers have noted that larval fish in deep SCUBA transects typically had demersal fish morphologies (e.g., sculpins) while those in shallow snorkel transects had more elongated forage fish morphologies (e.g., forage fish). Forage fish had similar densities at shallow transects across sites, and similar densities at deep transects at the two beaches. Other fish groups had low densities. Demersal fish that could be considered predators on juvenile salmon (e.g., lingcod, larger sculpin, larger rockfish) were extremely rare. Although rockfish were rare, they did occur at every site except the Aquarium.

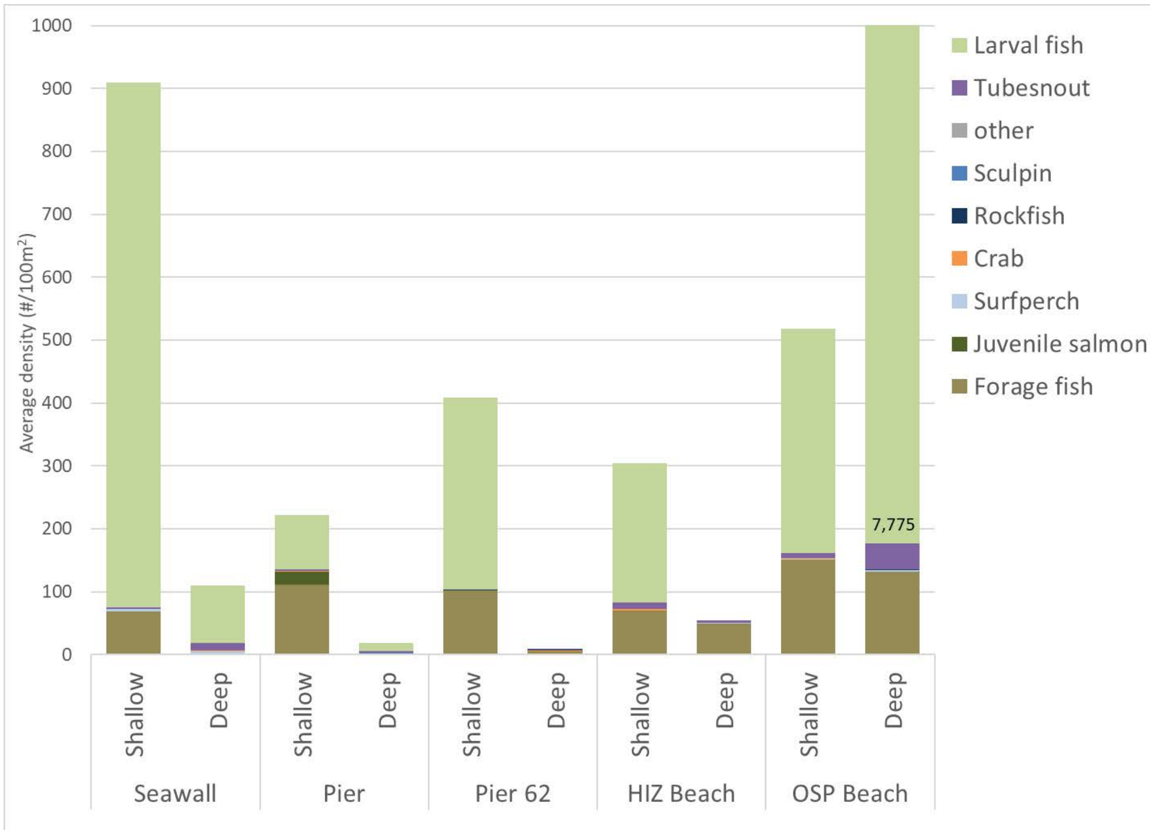

Figure 15. Average fish densities during SCUBA surveys across strata and shallow and deep transects in 2022 (y-axis truncated due to large numbers of larval fish at OSP beach deep). "Seawall" and "Pier" refer to the main University, Spring, and Aquarium sites.

Similar to 2018, 2019, and 2021, bull kelp had highest densities at the deep transect at the Aquarium seawall along the outer edge of the extended bench in 2022 (Table 9). Bull kelp was also recorded at the OSP beach deep transect.

Table 9. Average of bull kelp stipes/100m^2 at SCUBA transects in 2018, 2019, 2021, and 2022.

Site	Strata	Depth	2018	2019	2021	2022
Aquarium	Seawall	Shallow		29.5	3.3	22.3
		Deep	47.9	190.5	81.6	236.5
	Pier	Shallow		1.1		
University	Seawall	Shallow		0.1		
		Deep				
	Pier	Shallow				
		Deep				
Spring	Seawall	Shallow		6.3		
		Deep	0.3			
	Pier	Shallow				
		Deep				
OSP	Beach	Shallow			1.0	
		Deep	0.8		5.1	18.2
Pier 62	Pier	Shallow	NA	NA		
		Deep	NA	NA		
HIZ	Beach	Shallow	NA	NA		
		Deep	NA	NA	0.8	

Conclusion

Our Year 5 post-construction monitoring of fish within the completed Phase One Elliott Bay Seawall overall shows positive results for the effectiveness of habitat enhancements associated with the new seawall. The combination of adding texture and relief to the wall; construction of shallow water benches and the HIZ beach; and addition of light penetrating glass block surfaces to the sidewalk and grating at Pier 62 provide an enhanced outmigration corridor for juvenile salmon compared to the previous seawall.

Highlights of monitoring include:

(1) Chum, pink and Chinook were the most abundant juvenile salmonids in 2022. Juvenile pink and chum salmon were observed at the start of sampling in March, peaking with very high numbers in April, and continuing through June. Juvenile Chinook salmon were observed from May through October, with relatively high numbers June through August. Other fish besides juvenile salmon were also abundant, including herring and sand lance (forage fish), and larval fish.

(2) For the first time, juvenile salmon along the seawall and pier sites actually had slightly higher densities underneath the LPS at piers than at seawall sites in shallow transects at both high and low tides. This is in contrast to pre-construction when very few juvenile salmon occurred under piers. Fish observed underneath the grating at Pier 62 were somewhat similar to those observed underneath the glass panels at the other piers, and were predominantly forage fish and juvenile salmon. The HIZ beach had comparable

juvenile salmon densities to those at the OSP beach, although the OSP beach had much higher densities of forage fish and larval fish.

(3) Juvenile salmon and herring had the highest percent of feeding behaviors observed during snorkel surveys (~30%). Juvenile Chinook, chum, and pink salmon all had similar percentages of feeding behavior. For the first time, at the seawall and piers juvenile salmon feeding was actually higher underneath the LPS at piers (22%) than at seawall sites (14%), with low feeding (7%) observed under dark areas of piers without habitat enhancements. This is in contrast to prior to seawall replacement, when nearshore feeding was observed only between piers, and never under piers. The HIZ Beach had the highest percent of juvenile salmon feeding behavior.

(4) Most fish observed on SCUBA transects were not known predators of juvenile salmon, were too small to feed on salmon, or did not co-occur with juvenile salmon, which were closer to shore or higher in the water column. Lingcod (a predator of smaller fish) were observed twenty-seven times, mostly at the Olympic Sculpture Park pocket beach, where one Giant Pacific Octopus was also observed.

(5) Larval fish were abundant on SCUBA transects at all sites, and especially at the OSP pocket beach deep transect, where they were patchy in distribution but occurred in large schools. Notably, larval fish were observed at Pier 62 and the HIZ Beach, which had no larval fish observations when they were first surveyed in 2021. Although rockfish were rare, they did occur at almost every site. Similar to past years, bull kelp (*Nereocystis luetkeana*) had highest densities at the deep transect at the Aquarium seawall along the outer edge of the extended bench, with some bull kelp also recorded at the OSP beach deep transect.

(6) In addition to the monitoring highlights, outreach was also part of our 2022 sampling, exemplified by a cover story in the UW Magazine (Fig. 16), and kayak tours for the public with Friends of Waterfront (Fig. 17).

Figure 16. The cover of the September 2022 issue of UW Magazine.

Figure 17. Kayak tours with Friends of Waterfront (photo credit Tiare Bowman).

Acknowledgements

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Supplemental Material

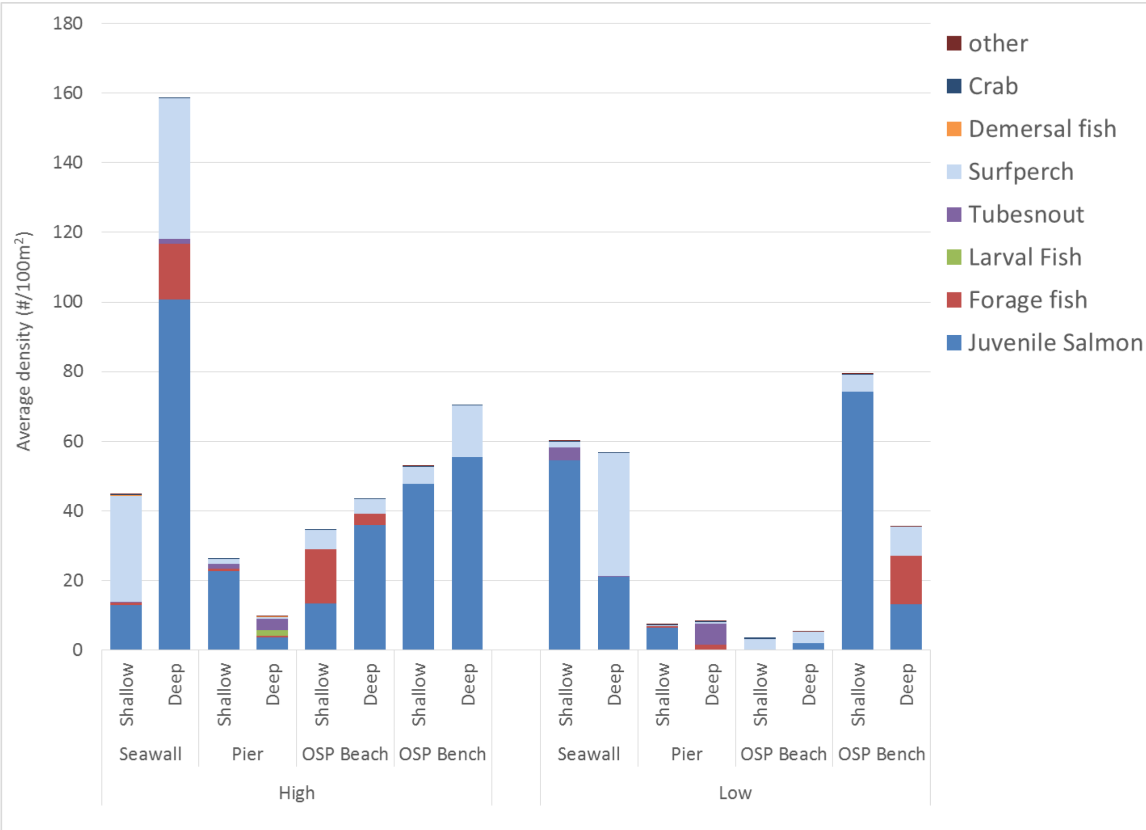

Figure S1. Average fish densities during snorkel surveys across strata, for high and low tides, and shallow and deep transects in 2018 (from Year 2 Report).

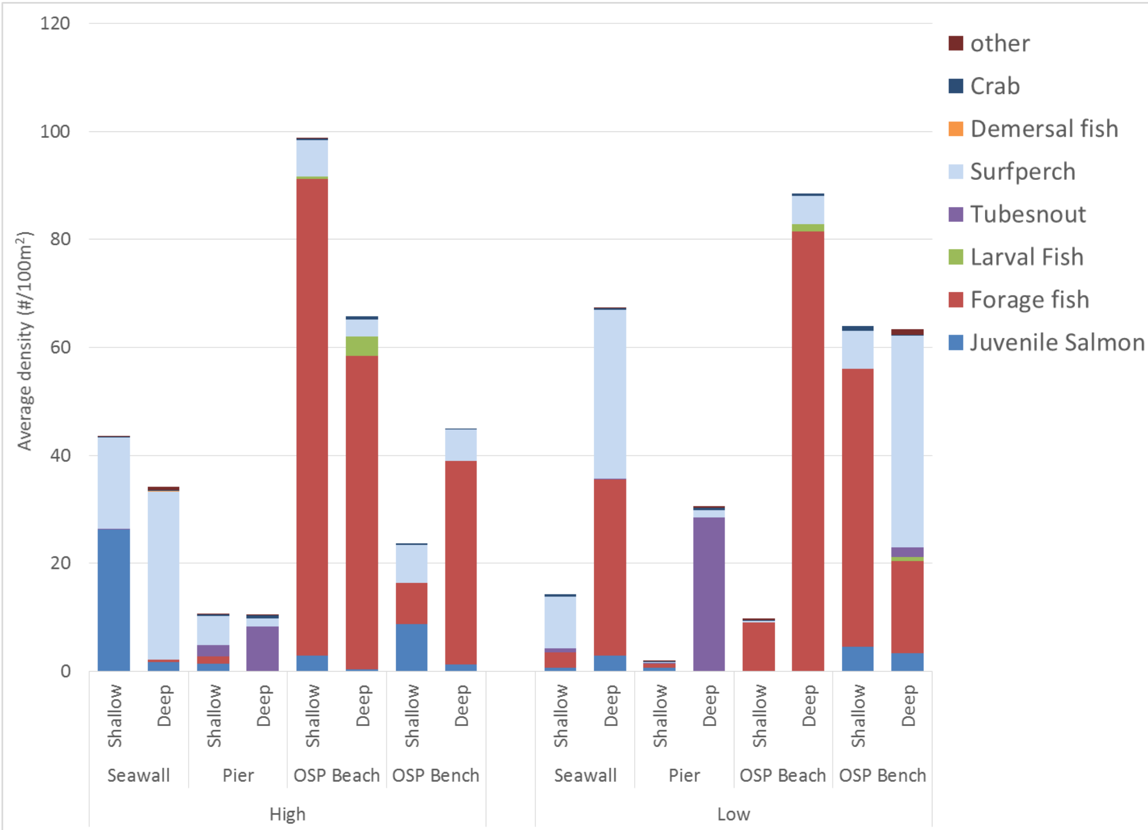

Figure S2. Average fish densities during snorkel surveys across strata, for high and low tides, and shallow and deep transects in 2019 (from Year 2 Report).

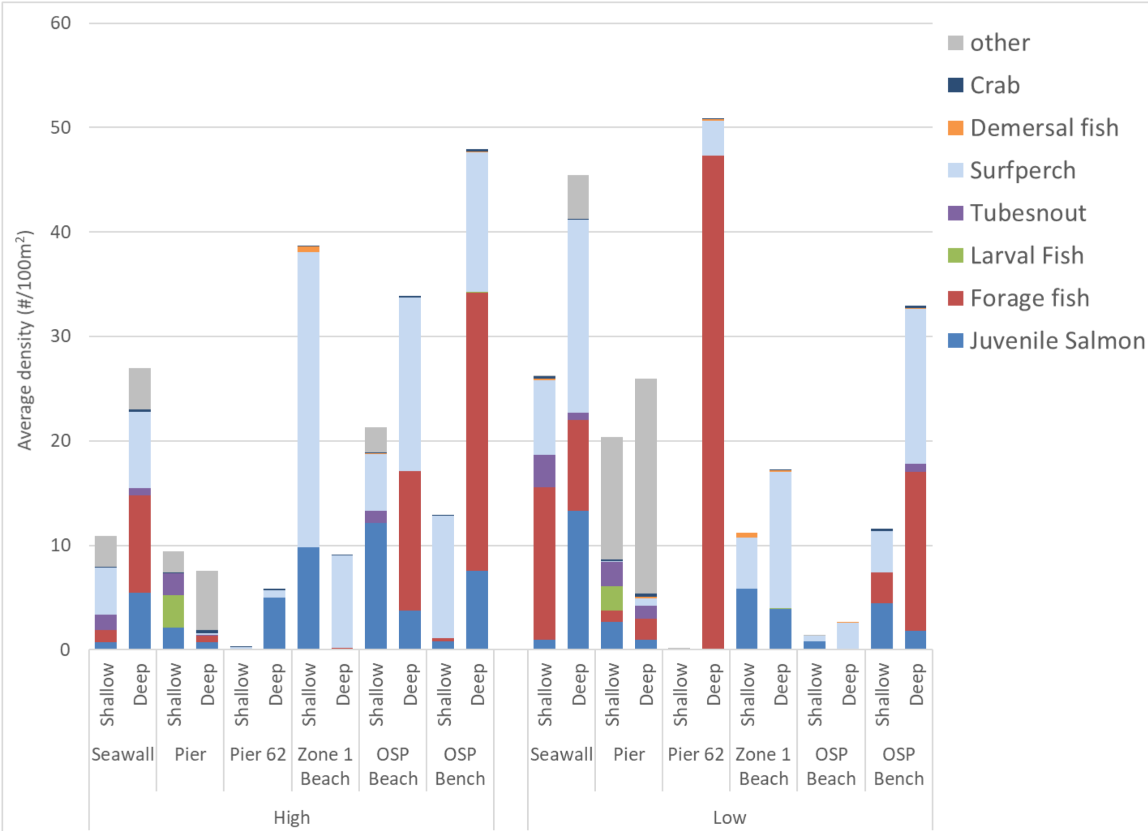

Figure S3. Average fish densities during snorkel surveys across strata, for high and low tides, and shallow and deep transects in 2021 (from Year 4 Report).

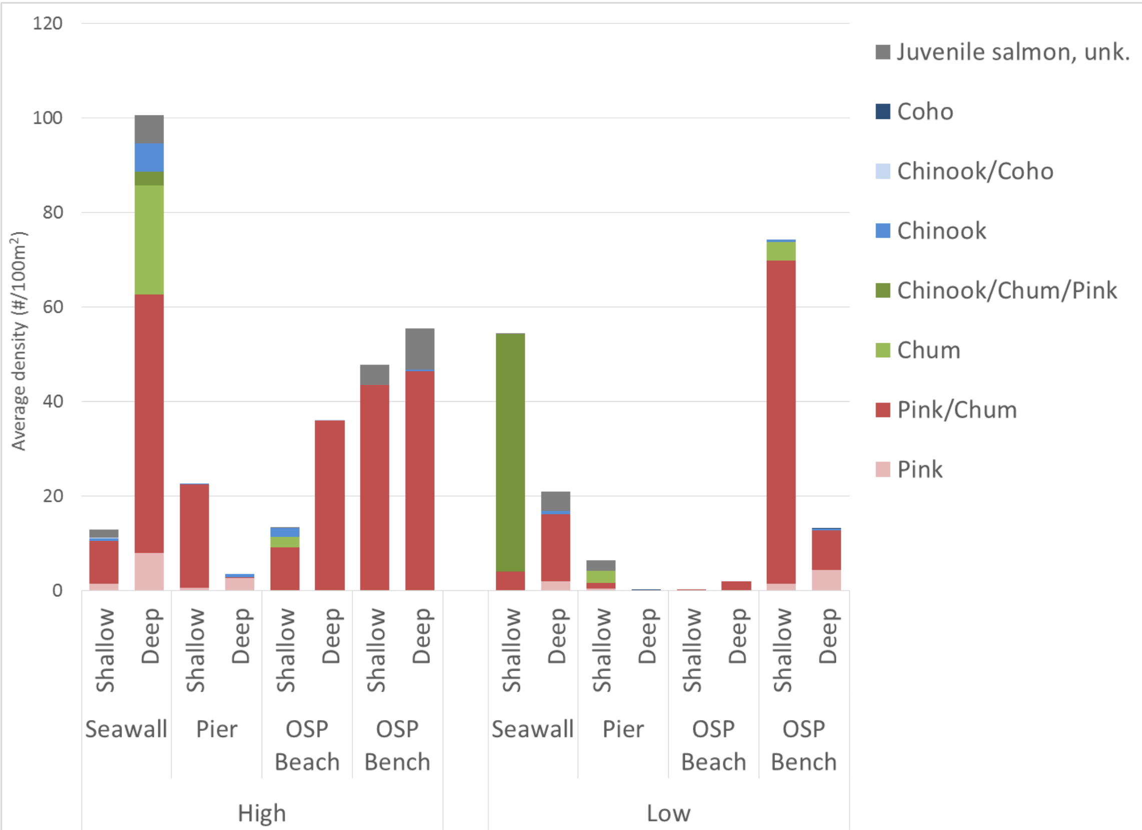

Figure S4. Average densities of species categories of juvenile salmon during snorkel surveys across strata, for high and low tides, and shallow and deep transects in 2018 (from Year 2 Report).

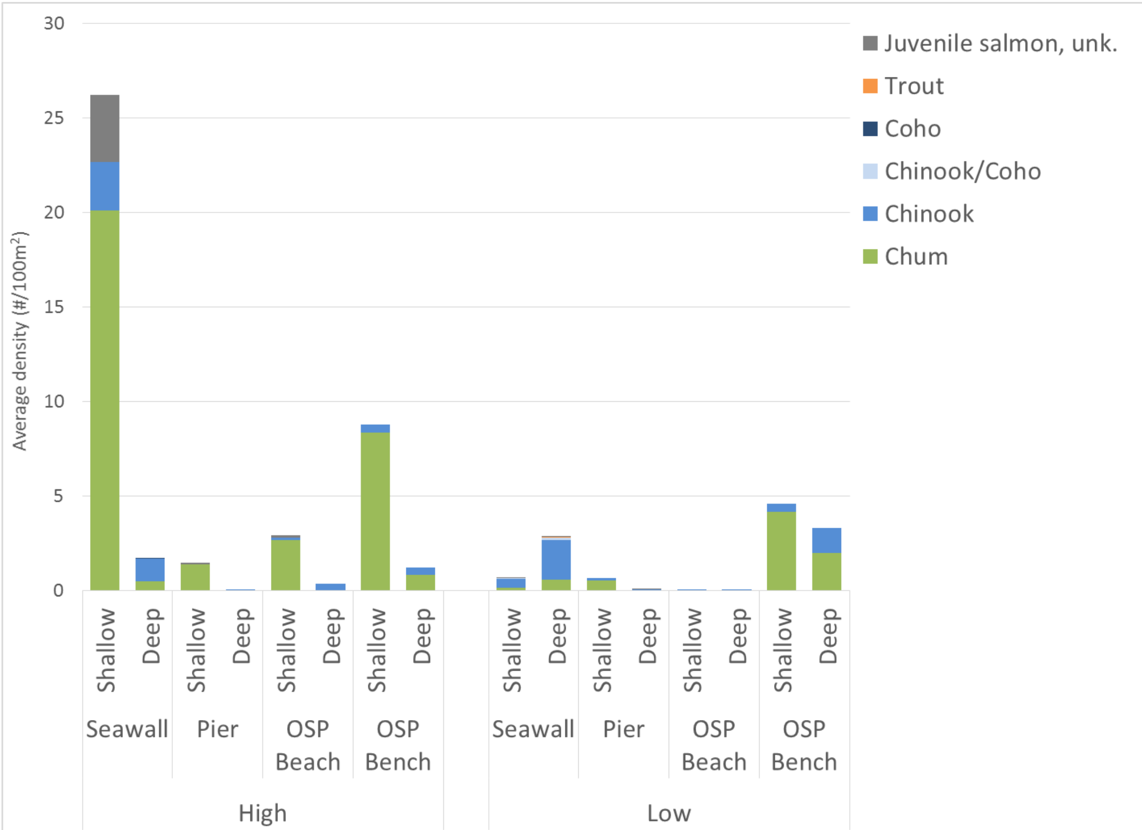

Figure S5. Average densities of species categories of juvenile salmon during snorkel surveys across strata, for high and low tides, and shallow and deep transects in 2019 (from Year 2 Report).

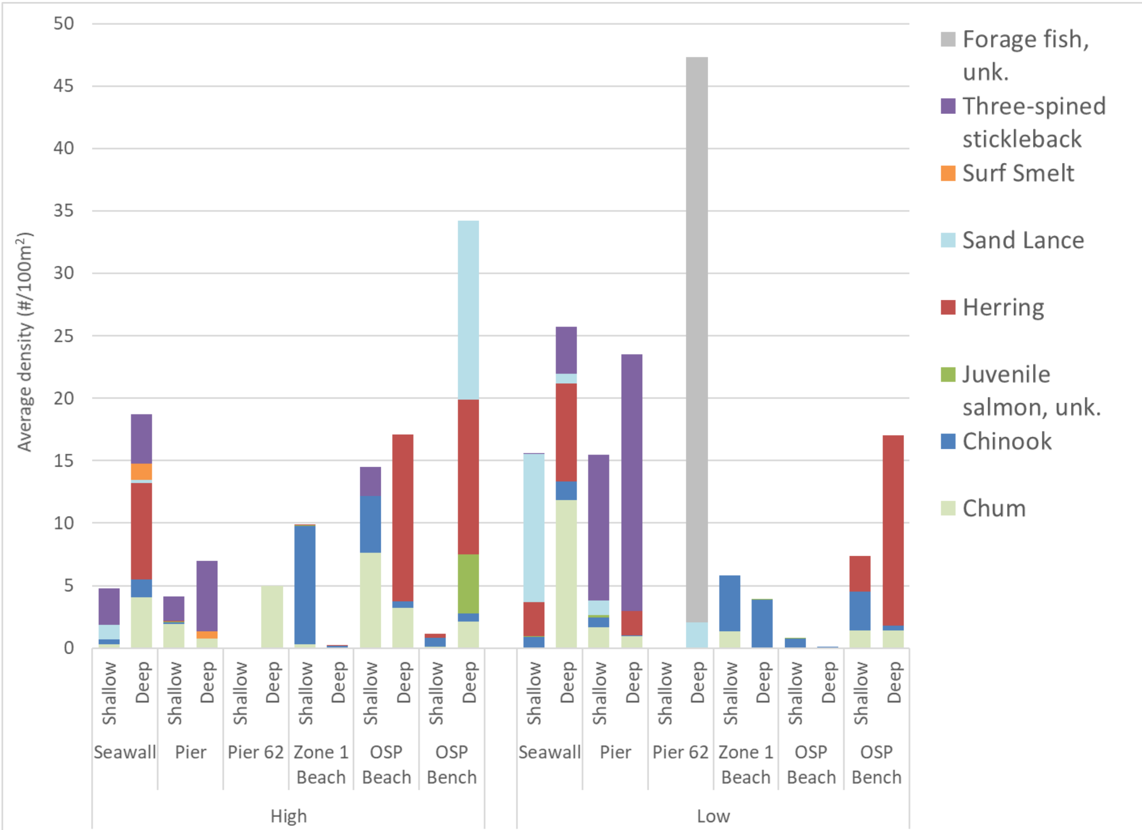

Figure S6. Average densities of species categories of juvenile salmon during snorkel surveys across strata, for high and low tides, and shallow and deep transects in 2021 (from Year 4 Report).

Figure S7. Herring and some sand lance at Pier 62.

Figure S8. Lingcod at the Olympic Sculpture Park