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## VIGOR POST-RESTORATION MONITORING FOR FISH, JUVENILE SALMON DIETS, AND INVERTEBRATES, 2024-2025

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## Executive Summary

Vigor Marine Group completed habitat restoration at their Seattle shipyard along the Harbor Island shoreline in the Duwamish estuary in 2023. The Southwest Yard Habitat Project demolished existing overwater and in-water structures, creating 2.7 acres of intertidal, marsh and riparian habitat. The University of Washington and Long Live the Kings have partnered to conduct before and after restoration monitoring for fish, juvenile salmon diets, and insects. This will measure restoration effectiveness of the project, which is a priority for establishing how restoration in degraded watersheds that will continue to function as commercial working waterways can benefit threatened Chinook salmon, and/or reveal constraints that can inform future restoration.

This report documents post-restoration monitoring in Spring-Summer 2024 and 2025 at the Vigor shoreline and a reference site at Jack Block Park, to compare to pre-restoration monitoring conducted in 2021. We surveyed once a month March-June in each year to encompass the peak timing of juvenile salmon outmigration, using (1) net surveys for fish, (2) diet analysis to assess prey contents of sampled juvenile salmonids, and (3) fallout traps to survey for insects and other arthropods in vegetated areas, along with limited benthic invertebrate cores at the Vigor site post-restoration.

Juvenile salmon and forage fish were sampled at higher abundances at Vigor post-restoration in 2024 and 2025 as compared to pre-restoration in 2021, and at comparable or greater abundances than Jack Block, which is important as they are two target fish groups for improving habitat access and use at restoration sites. In 2021 pre-restoration sampling, juvenile chum salmon were the only salmonid caught at Vigor, whereas post-restoration many juvenile salmonids used the Vigor habitat – juvenile chum, wild and hatchery Chinook, wild and hatchery coho, wild and hatchery steelhead, and pink salmon during their 2024 outmigration year (pink outmigrate in alternate years). Additionally, the forage fish Pacific herring and sand lance were captured at Vigor post-restoration. These patterns in occurrence and abundance signify positive use of the site in the initial years post-restoration.

Across both post-restoration years when juvenile salmon diets were sampled at Vigor and Jack Block with enough sample sizes for statistical comparison, five of the six paired events had equal levels of instantaneous ration ( $p$ -values all above 0.25), showing that fish were feeding on equal amounts of prey mass at the two sites in that month. These five equal comparisons were for juvenile chum in April 2024 and March 2025, coho in May 2024, and Chinook in June 2024 and May 2025. The exception was juvenile coho in May 2025, when values of instantaneous ration were significantly higher at Jack Block than at Vigor; this was also the one time that Syllid polychaete worms were found in juvenile salmon

diets, as all five coho diets at Jack Block were full of Syllids, which are known to swarm during reproductive events (epitoky).

In the first year of post-restoration monitoring in 2024, benthic/epibenthic (mudflat) and terrestrial (vegetation) prey sources were fed on more by juvenile Chinook and chum at Vigor, as compared to Jack Block, where they fed mostly in the water column on planktonic/neritic prey sources. In the second year of post-restoration monitoring in 2025, terrestrial prey sources at Vigor were increasingly fed on by Chinook—as well as coho—with chum continuing to feed more on benthic/epibenthic prey sources. Juvenile chum at Jack Block in 2025 continued to feed primarily on planktonic/neretic prey sources, while Chinook and coho primarily fed on benthic/epibenthic prey sources.

Measurements of insect densities and taxa richness were equal along shoreline vegetation at the two sites in post-restoration years. There were some assemblage differences, with Chironomidae flies playing a large role in both abundance in the fallout traps and incorporation into juvenile salmon diets, primarily at Vigor. Benthic invertebrate collections also showed that juvenile salmon prey taxa, such as harpacticoid copepods, amphipods, and dipteran Chironomidae larvae, were present at the Vigor restored habitat in both years.

Continued post-restoration monitoring will provide a longer-term measure of the effectiveness of restoring intertidal marsh habitat in this heavily industrialized area. Effectiveness monitoring will be increasingly important in urbanized areas with limited restoration opportunities and potential for significant edge effects, to document how successful these projects are in rehabilitating degraded landscapes for endangered salmonids.

## **Introduction**

Recent work by Long Live the Kings' (LLTK) Salish Sea Marine Survival Project reinforces the dire need for Duwamish estuary habitat for juvenile Chinook salmon (Pearsall et al. 2021). Unlike Chinook populations that rear in intact estuary habitat, few Chinook early fry migrants in the Duwamish estuary end up growing and surviving to adulthood (Campbell and Claiborne 2017). Since the 1999 listing of Puget Sound Chinook salmon as threatened under the federal Endangered Species Act, restoration actions seek to improve habitat conditions in degraded areas such as the Duwamish estuary.

In Spring 2023, Vigor Marine Group completed habitat restoration along its Harbor Island shoreline in the Duwamish estuary. This restoration project provides a unique opportunity to examine a blue-green

infrastructure approach to working shorelines and to assess whether such actions result in meaningful, functional estuary habitat for salmon. Harbor Island is an artificial island, thus restoration efforts aim to provide natural functions similar to those provided by historical estuary habitat. The Southwest Yard Habitat Project (hereafter referred to as Vigor restoration) demolished overwater and in-water structures, creating 2.7 acres of marsh, intertidal, and riparian habitat with the goal of improving existing degraded habitat in this industrialized but ecologically important area (Floyd Snider 2021). We previously provided baseline data on pre-restoration conditions at the site for fish, juvenile salmon diet, and insects during Spring-Summer 2021 (Toft et al. 2022), to be compared to post-restoration conditions described herein beginning in 2024 after the restoration was completed.

Previous studies have identified fish and invertebrate assemblages along Duwamish and Elliott Bay shorelines modified by seawalls and piers as compared to reference sites (Toft et al. 2007, Morley et al. 2012, Munsch et al. 2014), and noted effectiveness of restoration actions along these urban shorelines (Cordell et al. 2011, Toft et al. 2013, Sawyer et al. 2020, Accola et al. 2024). Small-scale urban shoreline efforts amplify the restoration possibilities where they are limited, in addition to those in less impacted areas of Puget Sound where larger scale efforts are realistic (Hood 2020, Toft et al. 2021). Sampling before and after restoration with comparison to adjacent reference areas are important components of measuring restoration effectiveness. Our before-and-after restoration sampling at Vigor with comparison to a nearby reference site, Jack Block Park, provides a measure of how beneficial the restoration is for juvenile salmonids. We sample insects as they are a useful metric of the health of a site (Toft et al. 2013), and are valuable prey for juveniles of threatened populations of Chinook salmon that are out-migrating through the Green-Duwamish sub-watershed (Cordell et al. 2011).

Our main objectives for post-restoration monitoring at Vigor in spring-summer 2024 and 2025 were to:

1. Compare fish assemblages at Vigor and Jack Block Park.
2. Characterize diet contents of juvenile salmonids at the two sites.
3. Compare insect assemblages in vegetation along the shoreline at the two sites, and confirm presence of benthic invertebrates in the mudflats at Vigor.

## **Methods**

To compare post-restoration conditions to the pre-restoration baseline, we sampled fish, insects, and benthic invertebrates at Vigor and a nearby reference site, Jack Block Park, in spring-summer 2024 and 2025 (Fig. 1). We sampled once monthly, March through June, to encompass the peak timing of juvenile

salmon outmigration. At each sampling event, we netted fish as in past sampling (Cordell et al. 2011, Toft et al. 2017, 2022) to measure fish abundance, and obtain juvenile salmonid diet samples. We used two netting techniques in post-restoration sampling (Fig. 2):

- (1) A larger Puget Sound beach seine (37 m × 2 m, tapered down to 0.6 cm mesh at the bag; Nelson et al. 2004) is often used on Puget Sound beaches, and designed to fish low-gradient intertidal areas such as at Jack Block Park. When fully set using ropes on each end to haul in the net, it samples an area of 520 m<sup>2</sup>. We learned through initial sampling at Vigor in 2024 that we were able to effectively use this net at Vigor using shorter ropes on each side, sampling an area of 472 m<sup>2</sup> (Fig. 3).
- (2) A smaller river seine (20 m × 2 m, tapered down to 0.3 cm mesh at the bag; Nelson et al. 2004) has no ropes on each side, and is designed to enclose fish in a more limited space, sampling an area of 33 m<sup>2</sup> when deployed at Vigor (Fig. 4). We learned through initial sampling at Vigor in 2024 that this net is useful for sampling in spaces between placed logs on the upriver side of the site, where smaller juvenile salmon were found inhabiting shallow water earlier in the outmigration season (e.g., small juvenile chum and pink salmon).

In the 2021 pre-restoration sampling at the Vigor site reported previously (Toft et al. 2022), a lampara net was employed with similar dimensions because the amount of armor and debris along the shoreline precluded beach seine use.

If we did not capture juvenile salmon in the first net set, we would take additional samples at each site/month in order to more comprehensively survey for juvenile salmon; counts from multiple net sets were averaged. All sampled fish were identified and counted (Fig. 5), and the first 20 of each species/origin (wild or hatchery) measured for length (fork-length for juvenile salmon, standard lengths on other fish). Fish counts were converted to densities based on the dimensions of the nets and ropes used for hauling (#/m<sup>2</sup>). Juvenile salmon were separated into hatchery and wild categories when possible, based on adipose-fin clips and scanning with a coded-wire tag reader. Surface and bottom water temperature and salinity, and water depth of the net set were recorded.

We used non-lethal gastric lavage (n=5 per species when available, more if time allowed) to sample diet contents of juvenile Chinook salmon and other juvenile salmonids greater than 60 mm in length (Toft et al. 2007, Cordell et al. 2011, Munsch et al. 2015). Fish were placed in a tray of seawater with a small amount of the anesthetic MS-222 for approximately 30 seconds. Each fish was then measured for fork length and weight. Gut contents were removed using a modified garden pump sprayer and syringe with

a custom nozzle and filtered seawater (Fig. 6). Contents were washed into a 0.106 mm sieve (Figure 8) and fixed in 10% buffered formaldehyde solution. Fish were immediately placed in a bucket of ambient water for recovery (approximately 2–3 min), and then released. Diets of smaller juvenile chum and pink salmon that were too small to gastric lavage were obtained from whole fish samples (n=5, more if available), euthanized in MS-222 and then fixed in 10% formalin. Diet contents were processed in the laboratory for taxa, counts and weights. Taxa were identified to the lowest practical taxonomic level, given prey lifestage and levels of digestion.

Insects and other arthropods were sampled with passive fallout traps deployed along shoreline vegetation for 24 hours. Fallout traps were small plastic bins (40 x 25 cm) filled with 5 cm of water, with a drop of biodegradable odorless dishwashing soap in order to break water surface tension so that insects remain trapped (Toft et al. 2013, 2021). At each sampling date, we deployed five insect traps along the Vigor shoreline where vegetation was planted (Fig. 7), and five in shoreline vegetation at Jack Block Park. At collection, each trap was sieved through a 0.106 mm mesh sieve, and the sample fixed in a jar with 70% isopropanol. Insects and other arthropods were identified to the lowest practical taxonomic level with dissecting microscopes in the laboratory, and counts were standardized to density (#/m<sup>2</sup>) based on the surface area of the fallout trap. The insect sampling protocol is further detailed at the Shoreline Monitoring Database (<https://www.shoremonitoring.org/insects/>).

Benthic invertebrates were sampled with cores at Vigor once each year in May. Samples were collected to a depth of 10 centimeters (cm) using hand cores of 10-cm diameter (Fig. 8). Five samples total were collected at two elevation strata: two samples in the marsh (MMP-1 and MMP-4 at approximately +8 feet MLLW) and three samples in the intertidal area (MMP-2 and MMP-3 at approximately +1 feet MLLW and MMP-5 at approximately +3 feet MLLW).

Data was entered into Microsoft Excel, and univariate ANOVA tests (alpha = 0.05) were used to analyze data when replication was appropriate (site and year as a fixed factor, month as a random factor). We analyzed prey mass by comparing measurements of instantaneous ration in juvenile salmon, the weight of prey taxa divided by the weight of the fish, using the equation: Instantaneous Ration (IR) = [Diet wt/(Fish wt – Diet wt)] x 100 (Weitkamp et al. 2022). Taxa richness in insect samples was measured as the total number of taxa recorded in each fallout trap. Insect assemblages were also analyzed using permutational multivariate analysis of variance (PERMANOVA) analysis (Primer software). These analyses uncover patterns in multivariate groupings of the data, which is useful when analyzing assemblage datasets with multiple species compositions. Densities were log-transformed for

PERMANOVA tests, and taxa accounting for less than 3% of the total abundance of any one sample were not included.



Figure 1. Study site locations near the mouth of the Duwamish River at Vigor’s Harbor Island shipyard and the reference site Jack Block Park (yellow triangles). Inset map shows the location of study sites (white box) within Seattle, WA, USA.



Figure 2. Netting general locations for the two seine sizes at Vigor.



Figure 3. Sampling with the larger Puget Sound beach seine (37 m) at Vigor in 2025.



Figure 4. Sampling with the smaller river seine (20 m) at Vigor in 2024.



Figure 5. Processing fish captured at Vigor in March 2025.



Figure 6. Sampling a juvenile salmon diet with gastric lavage.



Figure 7. Insect fallout trap at Vigor.



Figure 8. Benthic core at Vigor.

## Results

Juvenile salmon and forage fish had higher abundances at Vigor post-restoration in 2024 and 2025 as compared to pre-restoration in 2021, and at comparable or greater abundances than Jack Block, which is important as they are two target fish groups for improving habitat access and use at restoration sites (Fig. 9). In 2021, juvenile chum salmon were the only salmonid caught at Vigor, whereas post-restoration many juvenile salmonids used the Vigor habitat – juvenile chum (Fig. 10), wild and hatchery Chinook (Fig. 11), wild and hatchery coho, wild and hatchery steelhead, and pink salmon during their 2024 outmigration year (pink outmigrate in alternate years) (Fig. 12). Additionally, the forage fish Pacific herring and sand lance were captured at Vigor post-restoration (Fig 12). These changes in occurrence and abundance signify positive use, although we are limited to qualitative interpretations given the limited replication of four net samplings each year (thorough statistical analyses would require increased replication).

Other fish that had high abundances at Vigor in post-restoration years were sculpin and shiner perch (Fig. 12). There were also fish and crabs that were only sampled at either Vigor or Jack Block in post-restoration years – steelhead, sand lance, and starry flounder were only found at Vigor, whereas juvenile sockeye salmon, surf smelt, pile perch, river lamprey, tubesnout, and graceful rock crab were only found at Jack Block (Fig. 12, Table 1). This may be due to the subtle differences in physical habitat and location between the two sites, as Jack Block is more exposed to Elliott Bay and had deeper water depths (Table 2).

Monthly sampling in post-restoration years showed that juvenile chum and pink salmon occurred earlier in the season with higher abundances in March and April, and juvenile Chinook, coho, and steelhead were more abundant in May and June, regardless of wild or hatchery origin (Figs. 13 and 14). Juvenile chum salmon were particularly abundant at Vigor in March 2025 (Fig. 14). Small juvenile sculpin were present at Vigor in all months after restoration and were particularly abundant in the first year after restoration (2024) (Fig. 13, Table 1). Shiner perch occurred in May and June in both post-restoration years at Vigor (Figs. 13 and 14). Juvenile chum and pink salmon had lower average fish lengths than other salmonids, steelhead and coho the highest, with Chinook in between (Table 1).

Water temperatures and salinities reflected the estuarine transition from the Duwamish River to Elliott Bay (Table 2). Average water depths at the deepest edge of net deployment at Vigor were 7.0 ft (2024) and 7.3 ft (2025), and at Jack Block were greater at 20.3 ft (2024) and 23.7 ft (2025).

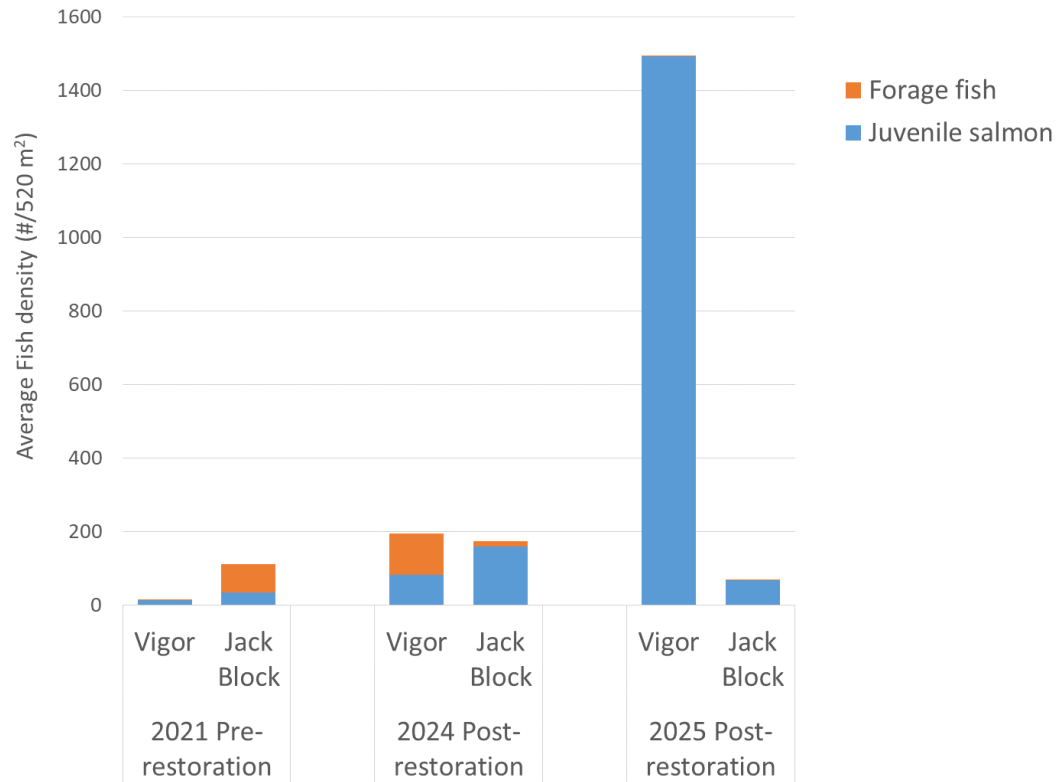


Figure 9. Average juvenile salmon and forage fish densities from 2021 (pre-restoration), 2024 and 2025 (post-restoration) net sampling at Vigor and Jack Block Park (densities scaled to the 520 m<sup>2</sup> surface area sampled with the larger beach seine).



Figure 10. Juvenile chum salmon captured at Vigor in April 2025.

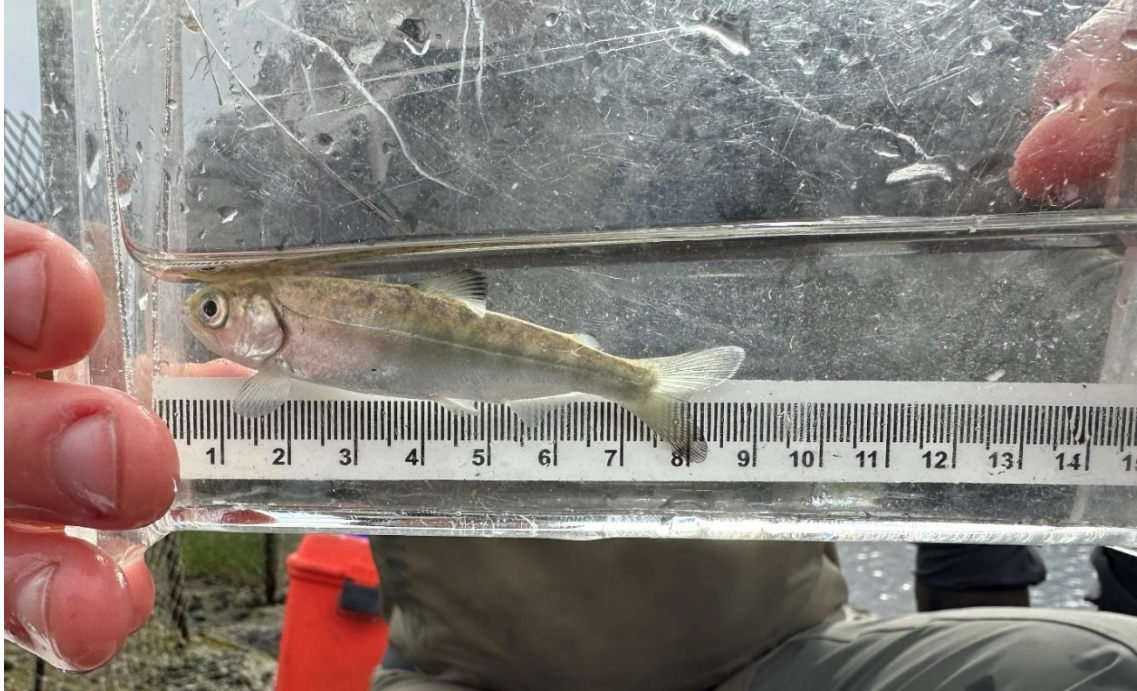


Figure 11. Juvenile Chinook salmon captured at Vigor in June 2024.

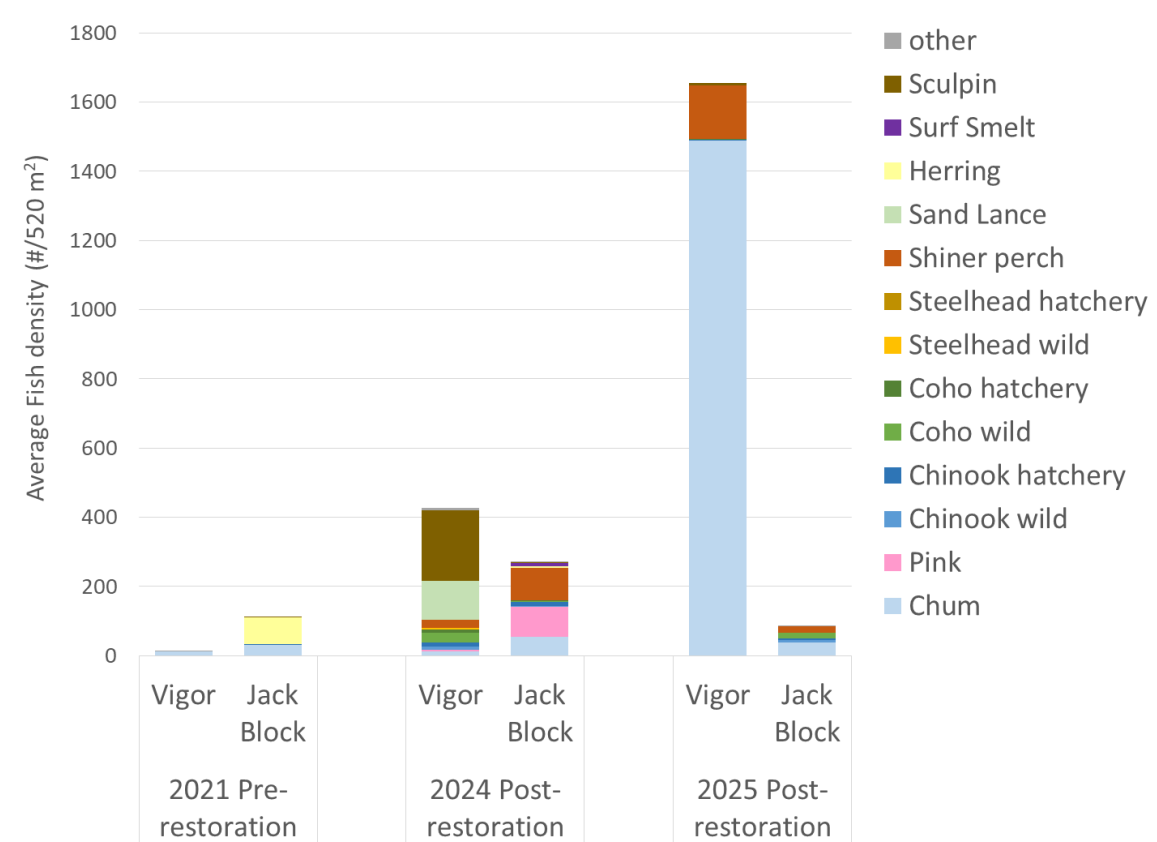


Figure 12. Average fish densities from 2021 (pre-restoration), 2024 and 2025 (post-restoration) net sampling at Vigor and Jack Block Park.

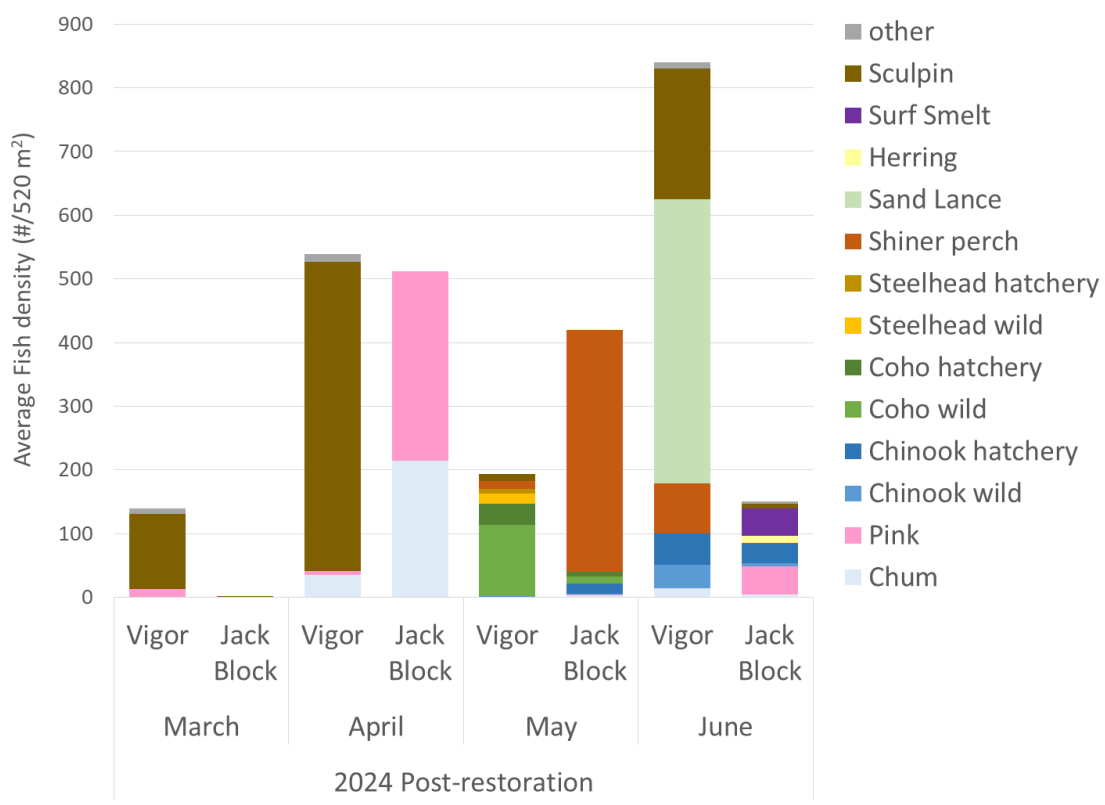


Figure 13. Fish densities from net sampling at Vigor and Jack Block Park for each month in 2024.

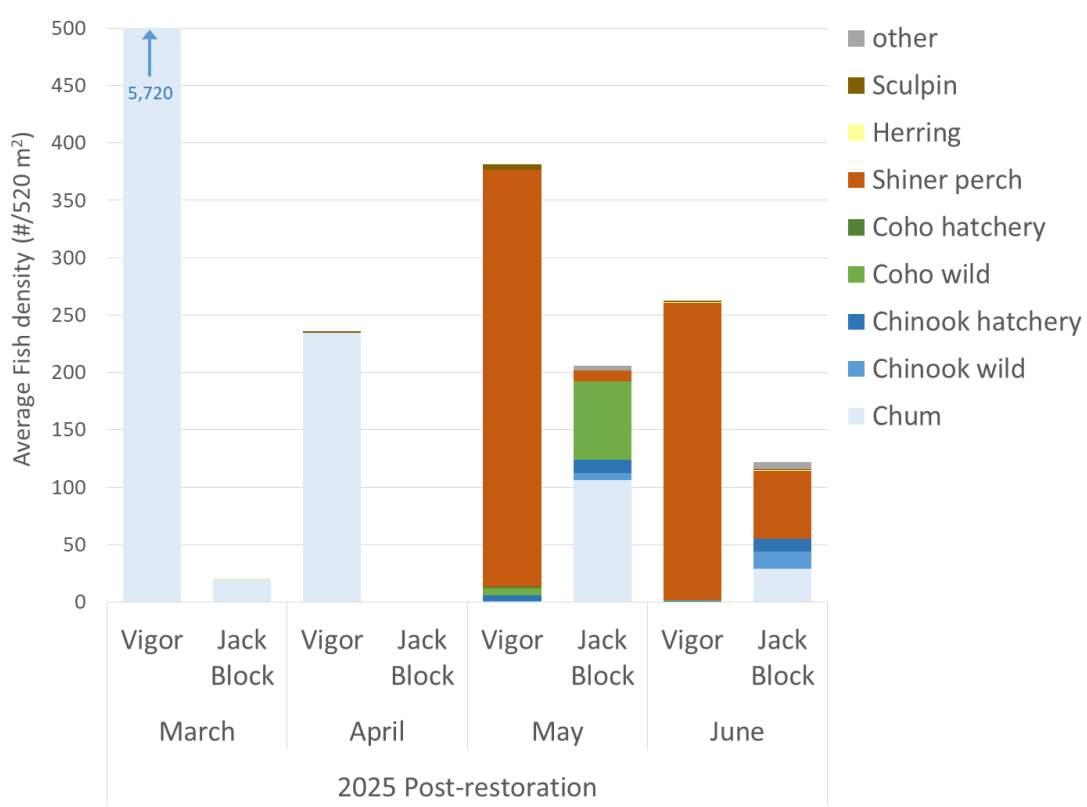


Figure 14. Fish densities from net sampling at Vigor and Jack Block Park for each month in 2025.

Table 1. Average fish lengths (L; fork-length for juvenile salmon, standard lengths for other fish) and sample size of measurements (#).

Group	Species	Vigor						Jack Block					
		2021		2024		2025		2021		2024		2025	
		L	#	L	#	L	#	L	#	L	#	L	#
Juvenile salmon	Chinook wild			80	12	70	1	85	8	79	7	81	21
	Chinook hatchery			75	13	77	6	82	6	89	45	82	23
	Chum	53	20	54	16	39	59	46	36	55	27	62	71
	Coho wild			138	23	126	7			119	12	110	24
	Coho hatchery			140	22	122	1			122	7	124	1
	Pink			32	5					51	41		
	Sockeye											68	1
	Steelhead wild			156	15								
	Steelhead hatchery			141	7								
Forage fish	Pacific herring	75	1			156	1	87	81	124	12	94	2
	Sand Lance			83	20			97	2				
	Surf Smelt									147	20		
Perch	Shiner perch			89	31	79	40			70	21	79	30
	Pile perch											108	4
Sculpin	Sculpin			27	132	35	15	44	1	45	1	55	1
Stickleback	Three-spined stickleback	60	2	50	2	22	1					42	2
Lamprey	River Lamprey									131	3		
Flatfish	Starry Flounder			93	7								
Tubesnout	Tubesnout											135	1
Crab	Graceful rock crab											48	2

Table 2. Monthly water temperature and salinity in 2024 and 2025.

		Surface	Surface	Bottom	Bottom
		Temperature (°C)	Salinity (ppt)	Temperature (°C)	Salinity (ppt)
<b>2024</b>	March	10.7	16.4	10.0	27.6
	April	11.3	16.0	11.3	25.1
	May	12.8	23.5	10.3	29.4
	June	11.6	10.1	11.3	29.2
<b>2025</b>	March	9.5	14.8	8.7	28.5
	April	10.2	22.1	10.3	28.0
	May	10.9	28.8	10.3	29.1
	June	14.0	28.4	12.7	28.8

When captured, juvenile salmon diets were processed using gastric lavage for each species/origin when available, or whole fish in the case of smaller chum and pink salmon that were not large enough to gastric lavage (Table 3). The same species were not caught at both sites in the same month during pre-restoration monitoring in 2021, so there were no directly overlapping comparisons at Vigor and Jack Block in the same month of sampling for pre-restoration conditions (Toft et al. 2022). In post-restoration years when diet samples overlapped in time and space, there were no significant differences in Instantaneous Ration (IR: weight of prey contents divided by weight of fish; a measurement of prey acquisition and fullness) for juvenile chum salmon captured in April 2024 ( $p=0.78$ ), showing that they fed on equal amounts of prey at Vigor and Jack Block. Juvenile pink salmon also had high values of IR at Vigor during the 2024 outmigration year, although sample sizes were too low for statistical comparisons between sites (Table 3). Juvenile coho in May 2024 showed no IR significant differences between sites ( $p=0.88$ ), and steelhead captured at Vigor in May 2024 had fairly low values of IR, but none were captured at Jack Block for comparison (Table 3). Juvenile Chinook in June 2024 similarly showed no IR significant differences between sites ( $p=0.96$ ).

Juvenile chum salmon sampled in March 2025 had no IR significant differences between sites ( $p=0.25$ ). The highest values of IR for juvenile chum during post-restoration years was in April 2025, but none were captured at Jack Block for comparison (Table 3). Juvenile Chinook in May 2025 had no significant differences between sites ( $p=0.35$ ). The one significant difference in all IR measurements between sites was for juvenile coho in May 2025, which had significantly higher IR values at Jack Block than Vigor ( $p=0.00001$ ). These juvenile coho had the highest IR values throughout all of the sampling, due to high amounts of Syllid polychaete worms in their diets, which are known to swarm during reproductive events (epitoky).

In 2024, juvenile Chinook and chum salmon fed more on benthic/epibenthic and terrestrial sources of prey at Vigor, and mostly on planktonic/neritic prey sources at Jack Block (Fig. 15, Appendix 1). Pink salmon also fed more on benthic/epibenthic prey sources at Vigor, while coho fed predominantly on planktonic/neritic sources at both sites, as did steelhead at Vigor (Fig. 15).

In 2025, terrestrial prey sources were even more preferred for juvenile Chinook sampled at Vigor, as they were for coho at Vigor as well; for both, benthic/epibenthic prey sources contributed more at Jack Block than in 2024 (Fig. 16). Juvenile chum salmon again fed more on benthic/epibenthic prey sources at Vigor than Jack Block (Fig. 16).

Table 3. Summary of juvenile salmon processed for diet contents. Highlighted in green are the post-restoration samples for each species that had suitable numbers at both Jack Block and Vigor on the same sample date for comparison (greater than 5 at each site).

Year	Month	Site	Species	Average of fish Length (mm)	Average of Fish weight (g)	Average of Instantaneous Ration (prey wt/fish wt)	Number of samples	
2021	March	Jack Block	Chum	40.2	0.5	2.03	5	
	April	Jack Block	Chum	47.4	0.9	3.02	5	
	May	Jack Block	Chinook	82.3	5.6	0.11	6	
		Vigor	Chum	54.4	1.3	2.47	5	
	June	Jack Block	Chinook	88.2	8.1	0.26	6	
				Chum	63.0	2.7	0.03	1
2024	March	Vigor	Pink	30.5	0.2	3.04	2	
	April	Jack Block	Chum	50.8	0.7	1.99	10	
				Pink	34.5	0.2	3.64	12
		Vigor	Chum	43.3	0.6	1.79	10	
				Pink	33.0	0.2	3.34	2
	May	Jack Block	Chinook	95.8	9.0	1.45	4	
				Coho	123.8	21.1	1.67	5
		Vigor	Chinook	108.0	20.0	0.00	1	
				Coho	143.2	26.9	1.51	5
	June	Jack Block	Steelhead	169.6	47.8	0.21	5	
				Chinook	79.5	5.9	0.06	14
				Chum	78.0	6.3	1.00	2
Vigor		Chinook	74.1	5.4	0.06	10		
			Chum	75.8	5.0	0.03	5	
2025	March	Jack Block	Chum	35.3	0.3	1.03	8	
		Vigor	Chum	35.4	0.3	0.56	10	
	April	Vigor	Chum	44.2	0.7	2.63	10	
	May	Jack Block	Chinook	77.0	5.3	0.19	5	
				Chum	95.0	11.8	0.20	2
				Coho	107.8	17.4	3.85	5
		Vigor	Chinook	75.2	4.2	0.06	5	
				Coho	123.6	18.8	0.06	7
	June	Jack Block	Chinook	90.0	9.5	0.09	10	
				Chum	83.8	7.3	0.30	6
		Vigor	Chinook	79.0	5.5	0.30	2	
			Coho	139.0	22.4	0.00	1	

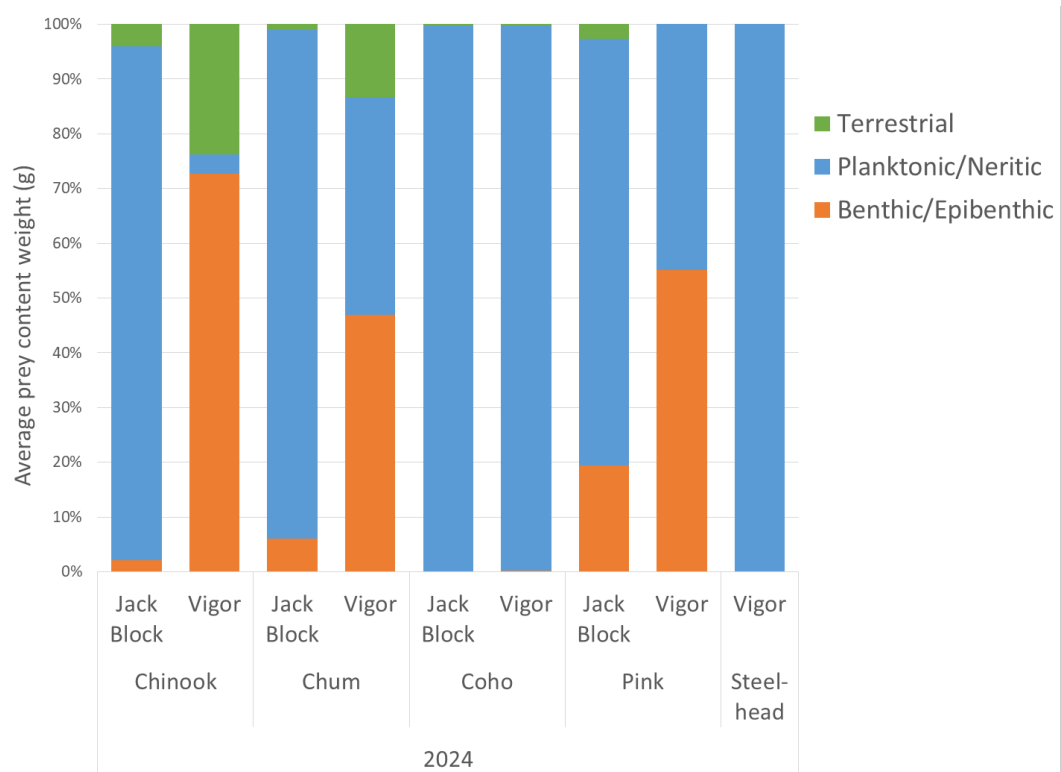


Figure 15. Juvenile salmon average prey content weight in 2024, coded by ecological category of prey source.

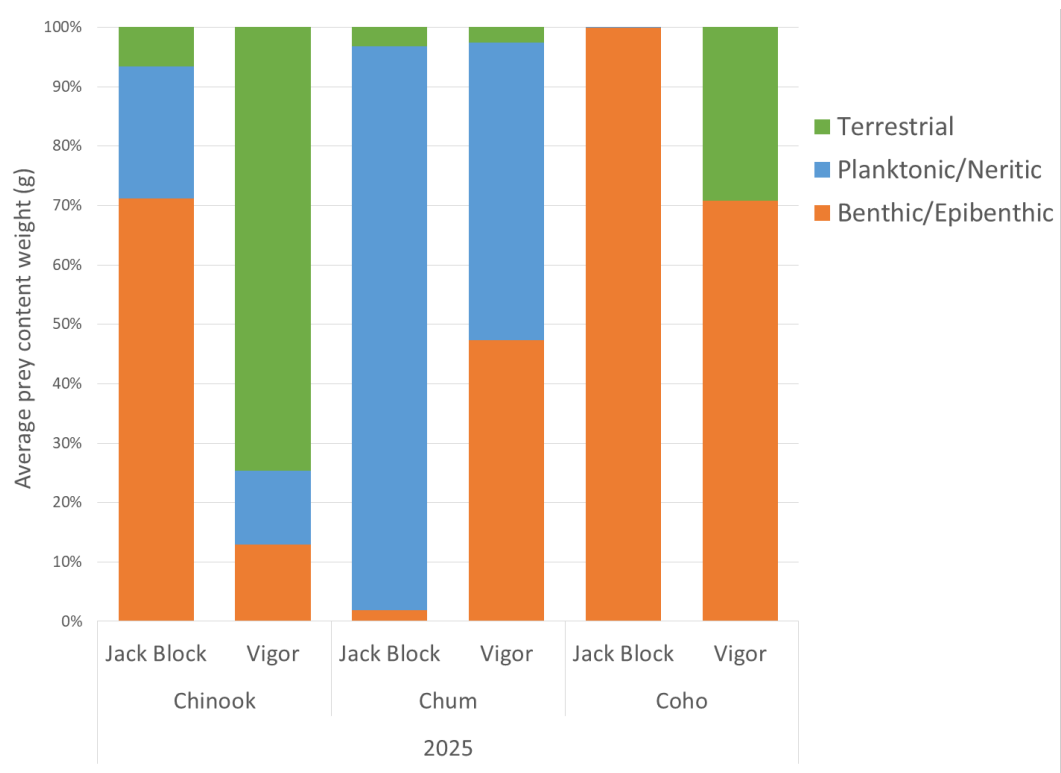


Figure 16. Juvenile salmon average prey content weight in 2025, coded by ecological category of prey source.

Specific taxa identified from juvenile Chinook salmon diets captured at both Jack Block and Vigor on the same sample date illustrate the diversity of Chinook prey (Fig. 17). In June 2024 primary juvenile Chinook salmon prey by weight at Vigor were the benthic/epibenthic prey Decapoda megalopa larva and the terrestrial prey Chironomidae (non-biting midges), and at Jack Block, prey from the water column such as Decapoda zoea larva, calanoid copepods, and fish; also amphipods. In May 2025 Vigor Chinook had more of a mix of decapods and amphipods, while Jack Block had mostly barnacles (adult and larval stages), amphipods, and benthic/epibenthic harpacticoid copepods.

Although taxa prey weight represents the quality of prey contents and applies most to fish growth, counts of prey items can also be informative of the quantity of prey and have a greater representation of smaller taxa (Fig. 18). Compared to weights, counts of juvenile Chinook salmon prey in June 2024 had a greater proportion of Chironomid flies at Vigor, and calanoid copepods at Jack Block. Proportional counts of prey in May 2025 had high amounts of copepod nauplii larva at both sites.

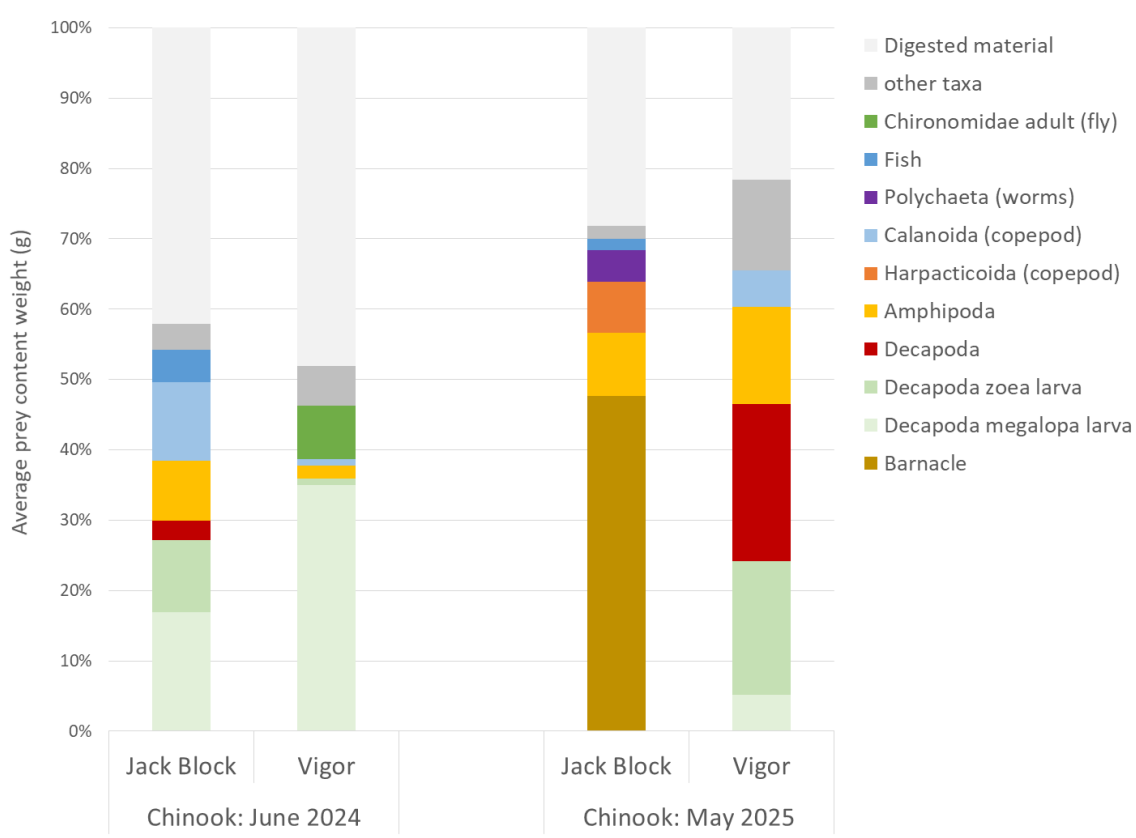


Figure 17. Juvenile Chinook salmon average prey content weight, from Vigor and Jack Block in June 2024 and May 2025.

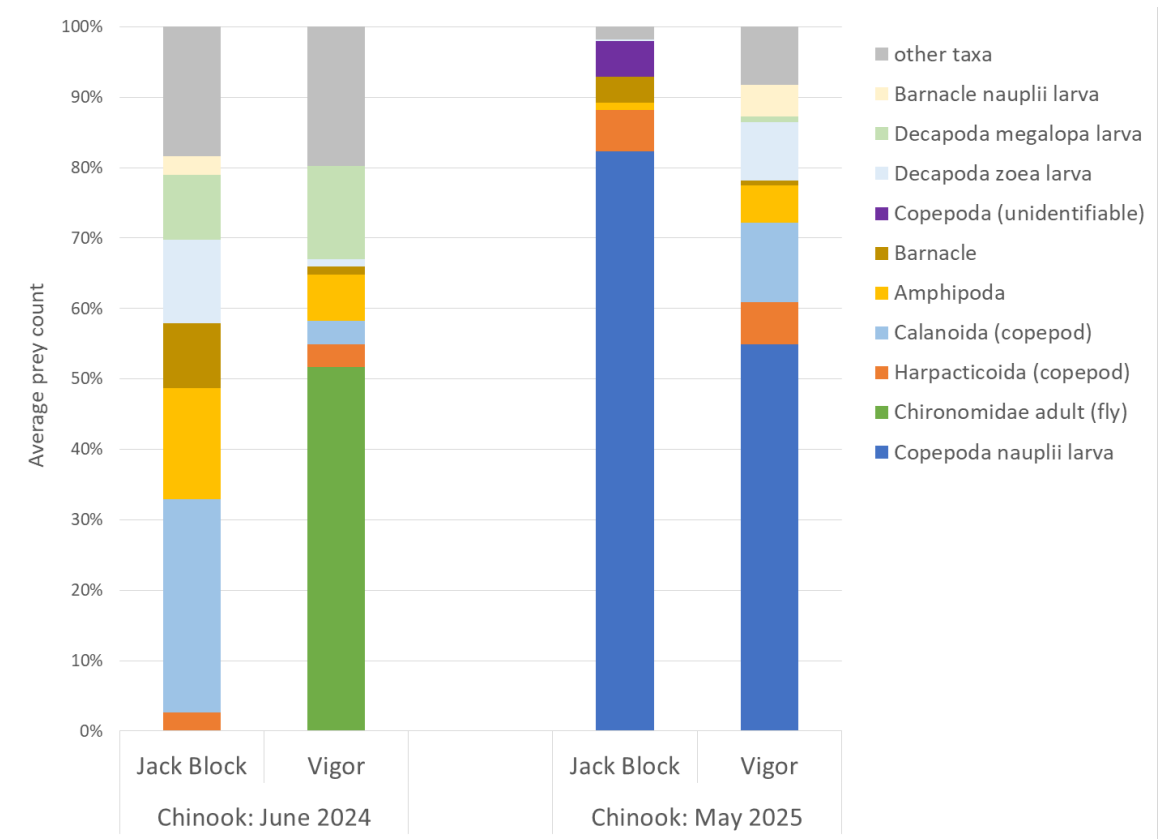


Figure 18. Juvenile Chinook salmon average prey content count, from Vigor and Jack Block in June 2024 and May 2025.

Juvenile coho salmon diets captured at both Jack Block and Vigor on the same sample date showed dominance by a few taxa that were high in weight (Fig. 19). In May 2024 fish (too digested to identify) accounted for almost all of the prey weight proportions at both sites, with low counts of chironomids, amphipods, and hemiptera (true bugs) (Fig. 20). In May 2025 almost all of the prey weight and counts were Syllidae polychaete worms at Jack Block, and amphipods and other Diptera (flies) at Vigor for weights, with low counts (Figs. 19, 20).

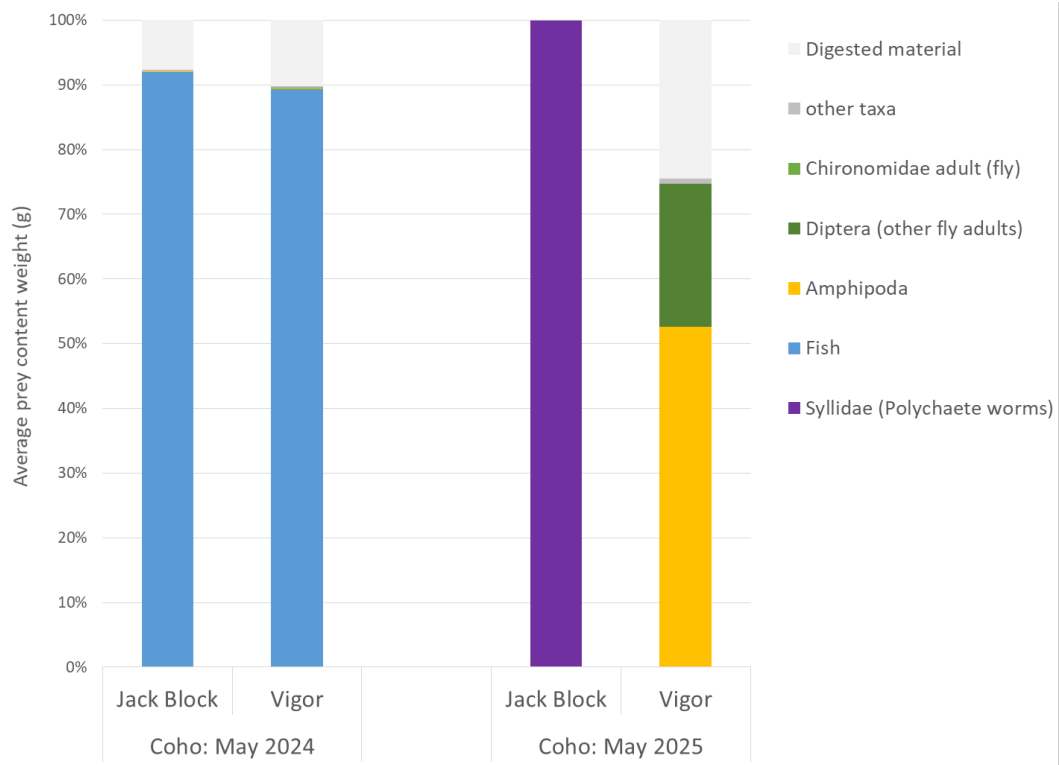


Figure 19. Juvenile coho salmon average prey content weight, from Vigor and Jack Block in May 2024 and 2025.

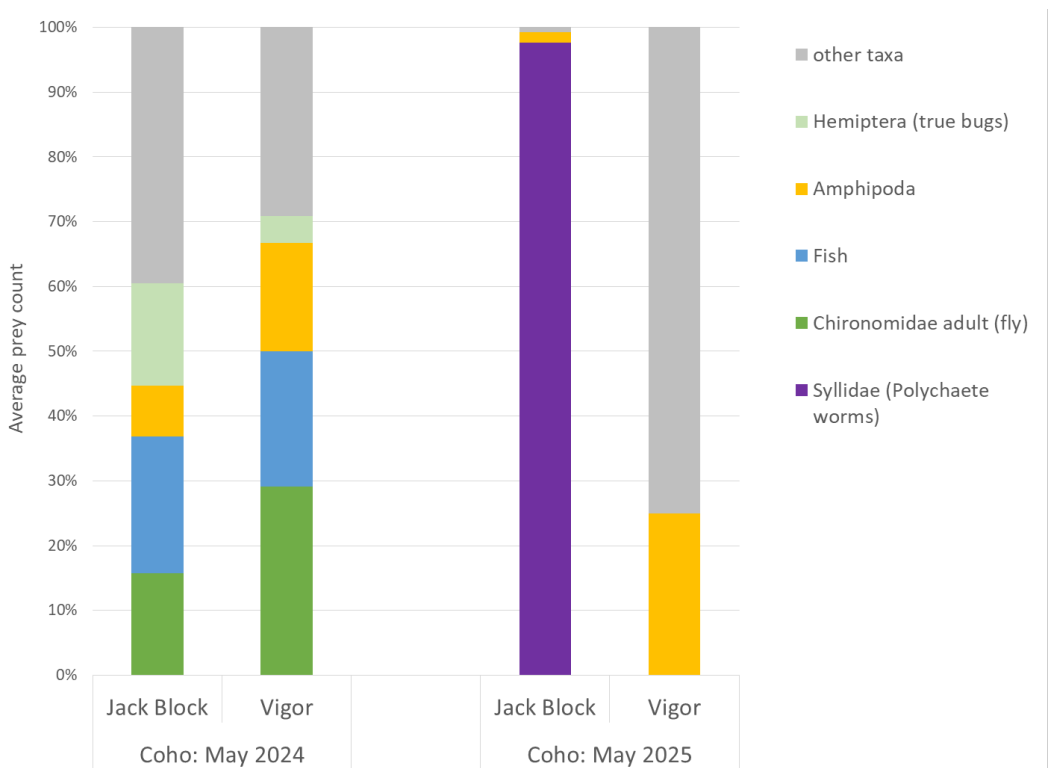


Figure 20. Juvenile coho salmon average prey content count, from Vigor and Jack Block in May 2024 and 2025.

Important juvenile chum salmon prey by weight for fish captured at both sites in April 2024 were amphipods, chironomid flies, and calanoid copepods at Vigor, and larvaceans (free-swimming tunicates), copepod nauplii larva, and polychaete worms at Jack Block (Fig. 21). In March 2025, weights had fairly equal proportions of chironomid flies at the two sites, with Vigor having more amphipods, chironomid larva, barnacle nauplii, and harpacticoid copepods. Counts were dominated by copepod nauplii at Jack Block in April 2024, and spread across a diversity of taxa at Vigor (Fig. 22). Counts in March 2025 were mostly barnacle nauplii and harpacticoid copepods.

Three of the five steelhead sampled for diets at Vigor in May 2024 were empty. The two that did have prey only had one fish and one barnacle cyprid larva that were identifiable. Four total pink salmon were captured and sampled for diets at Vigor, two in March and two in April 2024. These pink salmon were the smallest salmon we collected (Table 3), and so fed somewhat similar to the small chum salmon, on a mix of small harpacticoid and calanoid copepods and nauplii, chironomid fly larvae, larvaceans, mysids, and fish larva.

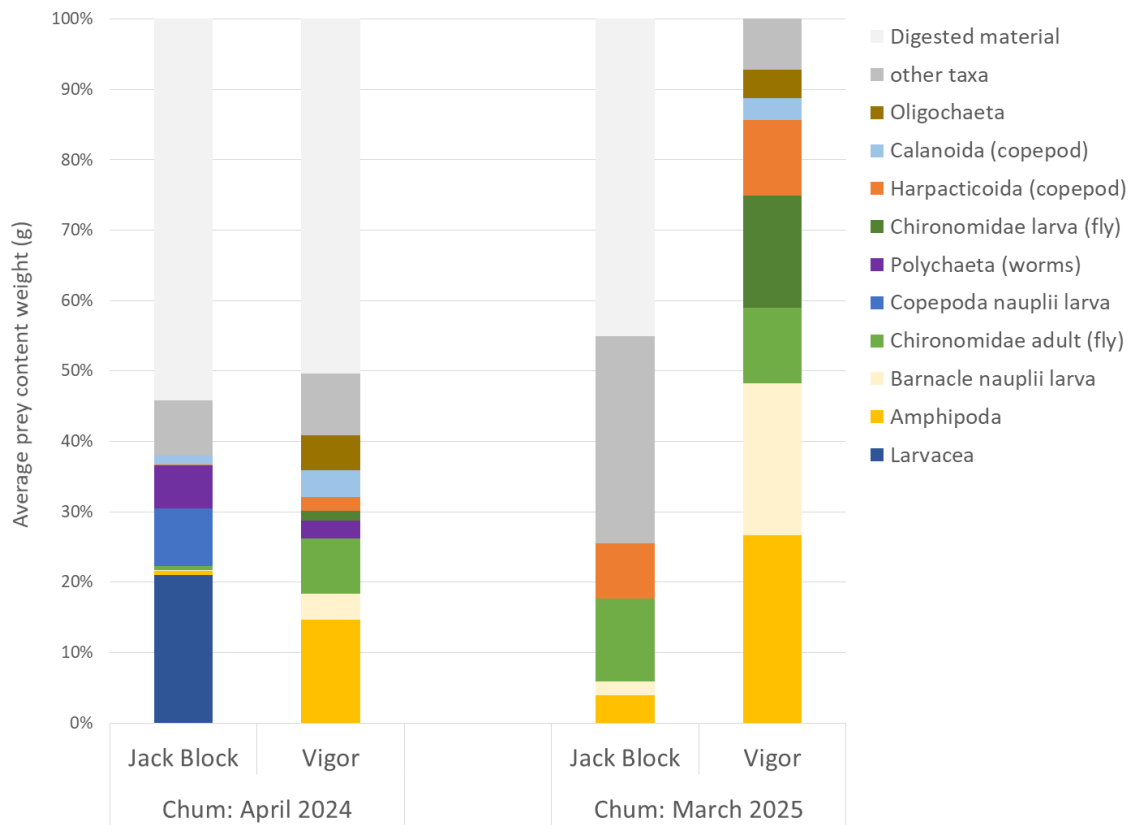


Figure 21. Juvenile chum salmon average prey content weight, from Vigor and Jack Block in April 2024 and March 2025.

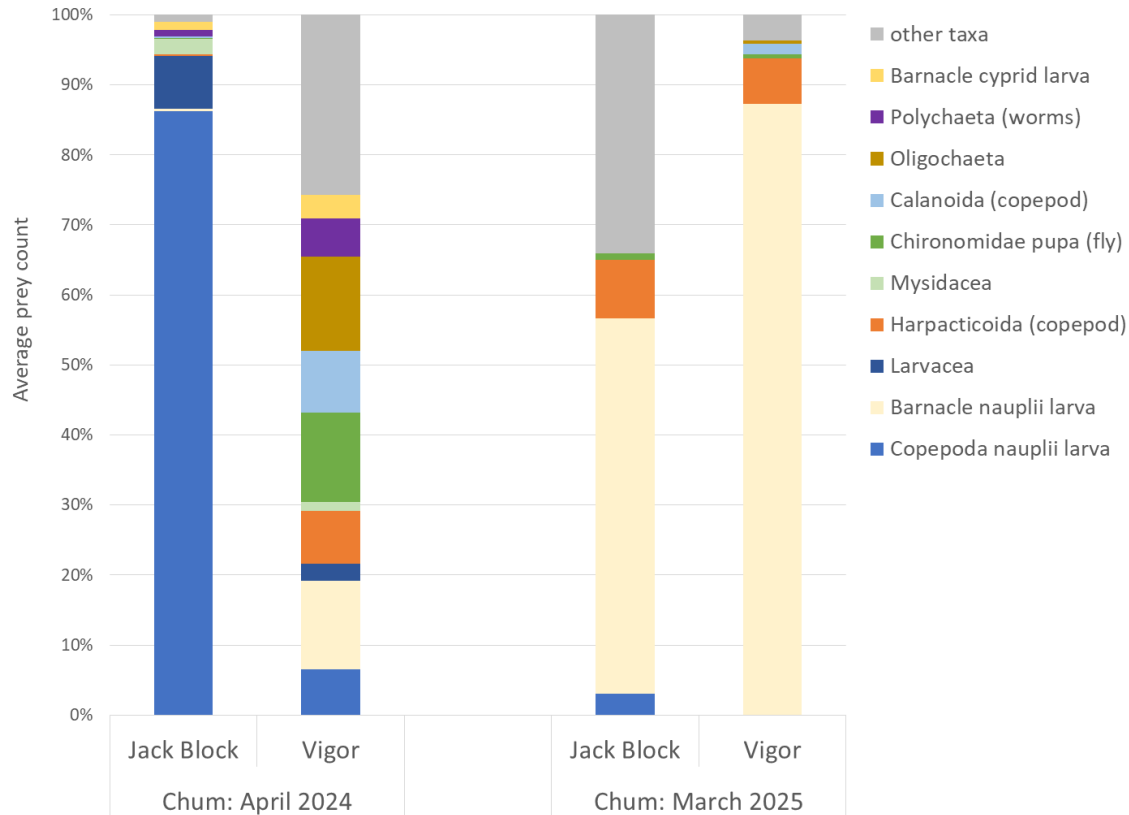


Figure 22. Juvenile chum salmon average prey content count, from Vigor and Jack Block in April 2024 and March 2025.

Insect densities and taxa richness in the fallout traps showed no significant differences between Vigor and Jack Block when tested against the interaction of years (log-transformed densities: Site  $p=0.11$ , Site  $\times$  Year  $p=0.98$ ) (taxa richness: Site  $p=0.17$ , Site  $\times$  Year  $p=0.15$ ) (Fig. 23, Appendix 2). Multivariate tests showed a significant assemblage difference between site and the interaction of year ( $p=0.017$ ), with post-hoc tests showing significant assemblage differences between Vigor and Jack Block in 2024 ( $p=0.044$ ) and borderline differences in 2025 ( $p=0.068$ ), with no differences pre-restoration in 2021 ( $p=0.29$ ). Assemblages were characterized by Diptera and Hemiptera (juvenile salmon prey items), of which Chironomidae (diptera) and Aphididae (hemiptera) were the most abundant families (Appendix 2, Appendix 3). Dipterans especially were common in juvenile salmon diet samples, and were abundant at the start of sampling in March and April of both post-restoration years at Vigor (Fig. 24). There were also high densities of plant-associated non-flying arthropods, Acari and Collembola.

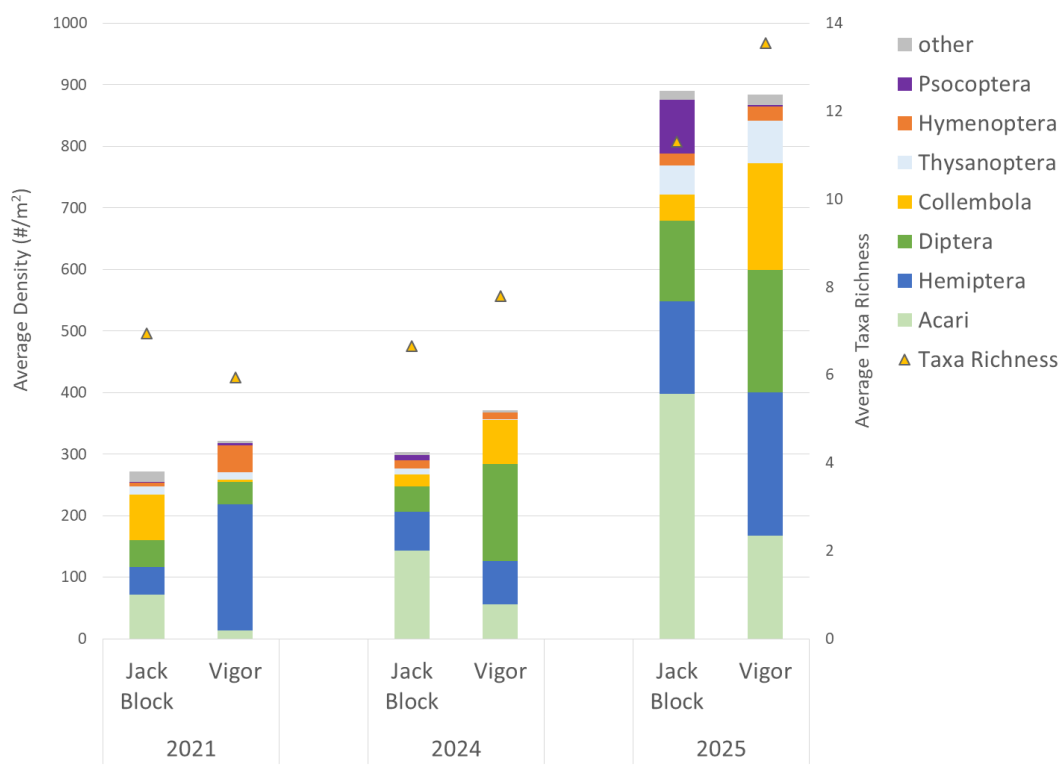


Figure 23. Average insect fallout trap densities and taxa richness at Vigor and Jack Block Park averaged for each year. Diptera and Hemiptera contain primary juvenile Chinook salmon insect prey items.

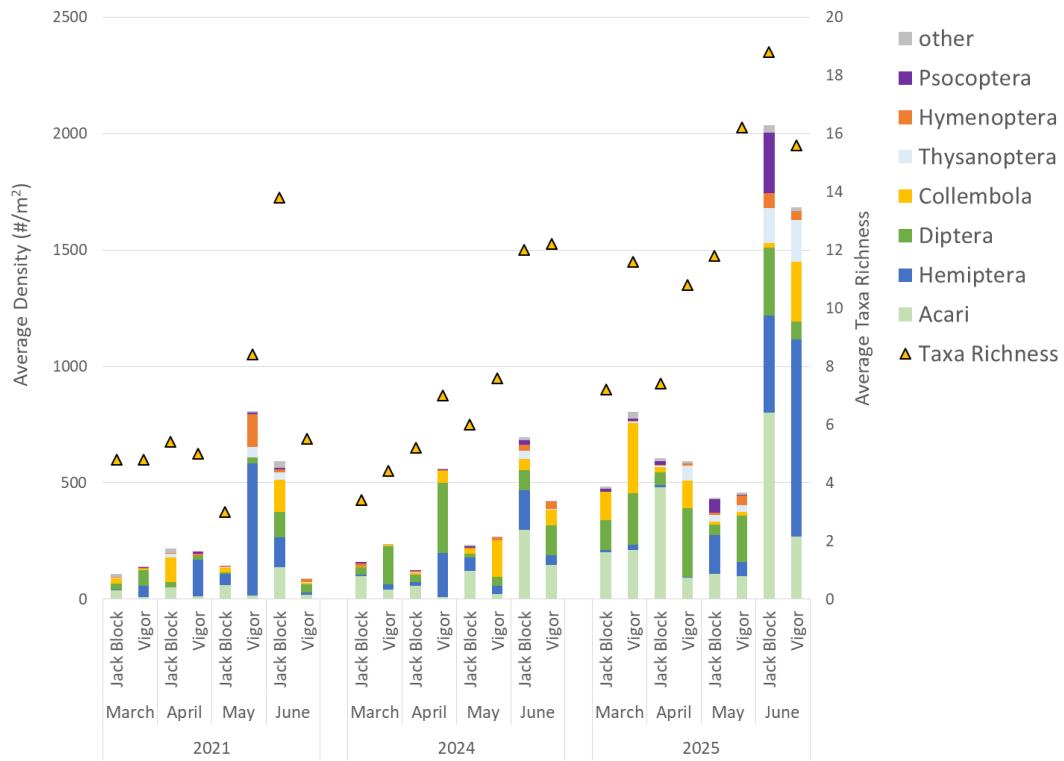


Figure 24. Average insect fallout trap densities and taxa richness at Vigor and Jack Block Park averaged for each month and year of sampling.

Benthic invertebrate collections showed a snapshot of taxa that inhabited upper and lower intertidal areas at Vigor (Table 4). Juvenile salmon prey taxa, such as harpacticoid copepods, amphipods, and dipteran Chironomidae larvae were present at the Vigor restored habitat in both years.

Table 4. Benthic invertebrates collected in five replicate cores at Vigor from 2024 and 2025.

Taxa Group	Taxa	Elevation (MLLW)	Benthic Cores 5/13/24					Benthic Cores 5/27/25				
			+8	+1	+1	+8	+3	+8	+1	+1	+8	+4
			1	2	3	4	5	1	2	3	4	5
<b>Nematoda</b>	Nematoda		22	254	1002	263	129	11	74	78	6	70
<b>Oligochaeta</b>	Oligochaeta		8	7	38	49	160	90	18	51	80	214
<b>Harpacticoida</b>	Huntemannia sp		2	2	7	4	1		2	1		29
	Harpacticoida				11				6	8		
	Laophontidae			5	12	1						
	Harpacticus sp		1		5					8	1	
<b>Polychaeta</b>	Spionidae						3	8	2		6	4
	Eteone californica			2	11	2	2					
	Capitellidae				2				1		3	3
	Capitella capitata			2								
	Manayunkia sp						1					
	Polychaeta			1								
<b>Amphipoda</b>	Americorophium salmonis		1	3	2	1			6	9		
	Eogammarus sp				1				3	14		
<b>Diptera</b>	Chironomidae larva		1			3			1	13	2	1
	Dolichopodidae larva									1	1	
	Ceratopogonidae pupa											2
	Ephydriidae pupa				1							
	Brachycera larva							1				
<b>Bivalvia</b>	Clam siphons								3	2		
	Bivalvia				1					1		
<b>Coleoptera</b>	Bembidiini larva							2			3	
	Coleoptera larva											1
<b>Acari</b>	Acari		4					1			1	
<b>Grand Total</b>			<b>39</b>	<b>276</b>	<b>1093</b>	<b>323</b>	<b>296</b>	<b>113</b>	<b>116</b>	<b>186</b>	<b>104</b>	<b>323</b>
<b>Taxa Richness</b>			<b>7</b>	<b>8</b>	<b>12</b>	<b>7</b>	<b>6</b>	<b>6</b>	<b>10</b>	<b>11</b>	<b>10</b>	<b>7</b>

## Discussion

A synthesis by the Salish Sea Marine Survival Project has emphasized that addressing habitat degradation is especially crucial in estuary and nearshore marine habitats for juvenile Chinook salmon, and can be addressed by restoring habitat for juvenile salmon and their prey (Pearsall et al. 2021). Previous studies in the Duwamish River have shown that juvenile Chinook and chum salmon were the two salmonid species found to be the most numerous along shallow-water intertidal areas where restoration efforts have been focused, specifically at and around restoration sites in the upper estuary from late January to mid-May (Ruggerone et al. 2006, Cordell et al. 2011, Toft and Cordell 2017, Accola et al. 2024). Most of the restored sites that have been created and monitored in the Duwamish River are farther upstream than the Vigor shipyard, in the transition zone, river miles 1-10. This is considered an important area for juvenile fish making the physiological transition from freshwater to salt water as they migrate to Puget Sound from upriver (WRIA 9 2021), due to the first brackish, shallow, and lower velocity waters encountered. Vigor's restoration site is at a unique location where the west waterway enters Elliott Bay, and restoration actions have not been as prevalent in this heavily industrialized area. Monitoring at The Southwest Yard Habitat Project before and after restoration is an essential measure of the effectiveness of creating intertidal marsh habitat in this heavily industrialized area.

During our pre-restoration monitoring in 2021, juvenile Chinook salmon were not captured along the Vigor shoreline (Toft et al. 2022), only at the neighboring Jack Block Park. Our monitoring in the post-restoration years of 2024 and 2025 during juvenile salmon outmigration has established the presence of not only juvenile Chinook salmon at the Vigor restoration, but also chum, coho, pink, and steelhead trout. These juvenile salmonids were all able to access and use the site, signifying that restoration actions are feasible and effective at providing valuable habitat for endangered salmonids at this unique location in the urbanized Duwamish to Elliott Bay connection. We found that other fishes besides juvenile salmonids also benefit from the Vigor restored site, such as the forage fish Pacific herring and sand lance. Herring and other forage fish are important components of the Puget Sound food web (Siple et al. 2018), and are a key food source for salmon during their early residence in Puget Sound.

Juvenile Chinook salmon and other salmonids fed on a diversity of prey at the Vigor restoration site, including contributions of terrestrial (e.g., insects and linkages to emergent vegetation) and benthic/epibenthic prey (e.g., amphipods and harpacticoid copepod crustaceans that inhabit mudflats), in addition to the unique planktonic/neritic sources that occur in the water column (such as larval stages of decapods and barnacles). Insects at Vigor and Jack Block Park were similar in densities and taxa

richness, with some assemblage differences. While there was not a substantial difference in insect densities between the pre-restoration and post-restoration sampling, the acreage of planted habitat did dramatically increase at Vigor, thus increasing the overall availability of planted habitat and associated insects. Shoreline vegetation takes time to grow, so this initial signature in the first few years post-restoration is encouraging. For example, Chironomidae flies are already playing a large role in both abundance in the fallout traps and incorporation into juvenile salmon diets, primarily at Vigor. Benthic invertebrates that are juvenile salmon prey taxa, such as harpacticoid copepods, amphipods, and dipteran Chironomidae larvae, have also already inhabited the mudflats. As these communities develop through time, we would expect to see some shifts in taxa composition and continued incorporation of prey into juvenile salmon diets, thus increasing the capacity for supporting invertebrate prey resources (Simenstad and Cordell 2000).

Juvenile salmon prey at upriver Duwamish restored sites consist of a mix of terrestrial (e.g., chironomids and other adult insects) and aquatic benthic (e.g., nereid worms, gammarid amphipods) sources, which can be characteristic of intertidal restored areas (Cordell et al. 2012) and may improve growth potential of juvenile salmon in brackish waters (Cordell et al. 2011, David et al. 2016b). The Vigor restoration is at an important location at the intersection of the Duwamish River and Elliott Bay, and may be intermediate to that of upriver Duwamish restored sites and downstream beaches in Elliott Bay, where small juvenile chum salmon feed more on epibenthic harpacticoid copepods, in contrast to prey at artificial seawall sites (Munsch et al. 2015). Insects can be important prey for juvenile Chinook salmon throughout Puget Sound (Duffy et al. 2010) and can be impacted by shoreline armor (Toft et al. 2007). Terrestrial insects have been shown to respond rapidly to wetland restoration through increases in abundance, although taxa diversity measures may take longer to develop and depend in part on the amount of developed land cover, such as the high levels of development in the Duwamish sub-watershed (David et al. 2016a).

It is important to place the restoration effectiveness at Vigor into context with other restored sites in the vicinity of the lower Duwamish River and Elliott Bay. Herring's House (Tualtwx) is the closest intertidal restored mudflat and wetland habitat upstream of Vigor (river mile 1.1), but its higher elevation habitat with less inundation time and a confined inlet channel may constrain use by juvenile salmon (Toft and Cordell 2017). Apart from Jack Block Park, other nearby beaches in Elliott Bay include Seacrest Beach to the west, and the Olympic Sculpture Park to the north, both of which have been found to be beneficial to juvenile salmon (Toft et al. 2013, Munsch et al. 2014). Post-restoration monitoring in 2021 at the

Pioneer Square Habitat Beach adjacent to the Colman ferry terminal has also shown improved use and feeding behavior by juvenile salmon (Anchor QEA and UW 2022). These studies on restored sites in the vicinity of Vigor are encouraging, and can help place our post-restoration monitoring into context with the surroundings.

These monitoring results will be able to build on other fish sampling at restored sites in the upper Duwamish as well, such as the pre-restoration and post-restoration monitoring at Duwamish Gardens (river mile 6.8) that found improved use by juvenile Chinook salmon (Toft and Cordell 2017, King County 2019). More recent monitoring at three newer restoration sites upriver has also found that juvenile salmon used the sites in the initial years post-restoration (Chinook Wind, Riverton Flapgate Removal, and Duwamish River People's Park; Accola et al. 2024). A University of Washington study in 2016 on juvenile salmon at Duwamish restored sites recommended that future studies evaluate the role of physical barriers to fish movement and effects on juvenile Chinook salmon use of restored areas, by examining configurations of placed logs, relict fencing, and other impediments, with the goal of improving access to restored areas (Toft and Cordell 2017). Monitoring at the Vigor restoration also directly ties to WRIA 9 priorities, by addressing their Tier 1 category of "shallow water habitat creation" in the Duwamish sub-watershed, the highest ranked enhanced project effectiveness monitoring priority (WRIA 9 2021). This can address the recovery strategy of protecting, restoring and enhancing estuarine habitat, by conducting enhanced monitoring focused on understanding how fish use restoration projects (WRIA 9 2021).

The Vigor restoration has improved opportunity metrics at the site such as the range of tidal inundation and access to the main waterway, with further goals of improving the foraging capacity of the restored habitats to benefit juvenile wild and hatchery Chinook salmon (Simenstad and Cordell 2000). Future sampling could expand on these findings by surveying a broader temporal range than March-June, for example by starting in February to target the Chinook fry outmigration. There may also be an opportunity to coordinate the ongoing effectiveness monitoring at sites along the lower Duwamish River to better understand whether this chain of disconnected sites through an urbanized reach can offer enough 'rest stops' for Chinook as they migrate out to increase overall survival to the ocean. Effectiveness monitoring will be increasingly important in urbanized areas with limited land availability and restoration opportunities, as large-scale solutions can arise from small-scale successes, and help achieve larger ecosystem recovery goals through the injection of social values and optimism into recovery planning (McAfee et al. 2021).

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## Appendices

Appendix 1. Taxa listing of prey identified in juvenile salmon diets, by ecological category, throughout all years of sampling in 2021, 2024, and 2025.

Ecology	Taxa Group	Taxa	
Benthic/Epibenthic/Algae	Amphipoda	Americorophium salmonis	
		Americorophium spinicorne	
		Ampithoe sp	
		Anisogammarus sp	
		Calliopiidae	
		Caprellidae	
		Corophiidae	
		Eogammarus confervicolus	
		Gammaridae	
		Grandidierella japonica	
		Paracalliopiella pratti	
		Chironomidae larva (fly)	Chironomidae larva
		Chironomidae pupa (fly)	Chironomidae pupa
		Cirripedia (barnacle)	Cirripedia
	Cumacea	Cumacea	
		Cumella vulgaris	
	Decapoda	Brachyura	
		Decapoda	
	Decapoda megalopa larva	Brachyura megalopa	
		Cancriidae megalopa	
		Decapoda megalopa	
		Pinnotheridae megalopa	
	Diptera (other fly larva)	Brachycera larva	
		Empidoidea larva	
	Diptera (other fly pupa)	Ceratopogonidae pupa	
	Gastropoda	Bivalvia	
		Gastropoda	
		Patellogastropoda	
	Harpacticoida (copepod)	Amonardia perturbata	
		Dactylopusia sp	
	Diosaccus sp		
	Harpacticoida		
	Harpacticus sp		
	Huntemannia sp		
	Scutellidium sp		
	Tisbe sp		
	Zaus sp		
Isopoda	Isopoda		
Nematoda	Nematoda		

**Planktonic/Neritic**

Oligochaeta  
Ostracoda  
Polychaeta (worms)

Amphipoda  
Barnacle cyprid larva  
Barnacle nauplii larva  
Calanoida (copepod)

Chaetognatha  
Cladocera (water fleas)

Copepoda nauplii larva  
Cyclopoid  
Decapoda zoea larva

Euphausiacea (krill)  
Fish  
Gastropoda  
Harpacticoida (copepod)  
Larvacea  
Mysidacea

Oligochaeta  
Ostracoda  
Capitellidae  
Magelonidae  
Nereididae  
Onuphidae  
Phyllodocidae  
Polychaeta  
Spionidae  
Syllidae  
Hyperiidea  
Cirripedia cyprid  
Cirripedia nauplii  
Aetidius sp  
Calanoida  
Calanus pacificus  
Calanus sp  
Centropages sp  
Corycaeus sp  
Diaptomidae  
Epilabidocera longipedata  
Paracalanus sp  
Paraeuchaeta elongata  
Pseudocalanus sp  
Sinocalanus sp  
Chaetognatha  
Evadne sp  
Pleopsis polyphemoides  
Podon sp  
Copepoda nauplii  
Oithona sp  
Brachyura zoea  
Caridea zoea  
Decapoda zoea  
Grapsidae zoea  
Mysidae zoea  
Pinnotheridae zoea  
Porcellanidae zoea  
Euphausiacea  
Fish  
Gastropoda veliger  
Microsetella rosea  
Larvacea  
Mysidae

**Terrestrial riparian**

Arachnida	Araneae
Chironomidae adult (fly)	Chironomidae
Coleoptera	Carabidae larva
	Coleoptera
	Coleoptera larva
	Psyllobora borealis
	Staphylinidae
Collembola	Entomobryiidae
	Hypogastruridae
	Isotomidae
	Onychiuridae
Diptera (other fly adults)	Cecidomyiidae
	Ceratopogonidae
	Coelopidae
	Empididae
	Mycetophilidae
	Nematocera
	Psychodidae
	Sciaridae
	Tipulidae
Hemiptera (true bugs)	Anthocoridae
	Aphididae (winged)
	Aphididae (wingless)
	Cicadellidae
	Delphacidae
	Hemiptera
	Psyllidae
	Saldidae
Hymenoptera (ants, wasps, bees)	Formicidae
	Hymenoptera
	Ichneumonidae
	Proctotrupidae
Insecta (parts)	Insect parts
Lepidoptera	Lepidoptera
Psocoptera	Psocoptera
Thysanoptera	Phlaeothripidae
	Thripidae

**No assigned category**

Acari	Acari
Algal matter	Algal matter
Amphipoda	Amphipoda
Animal matter	Animal matter
Copepoda	Copepoda
	Copepoda eggs
Crustacean parts	Crustacean parts

Egg	Egg mass
	Eggs
Inorganic matter	Inorganic matter
Organic matter	Organic matter
Plant matter	Plant matter

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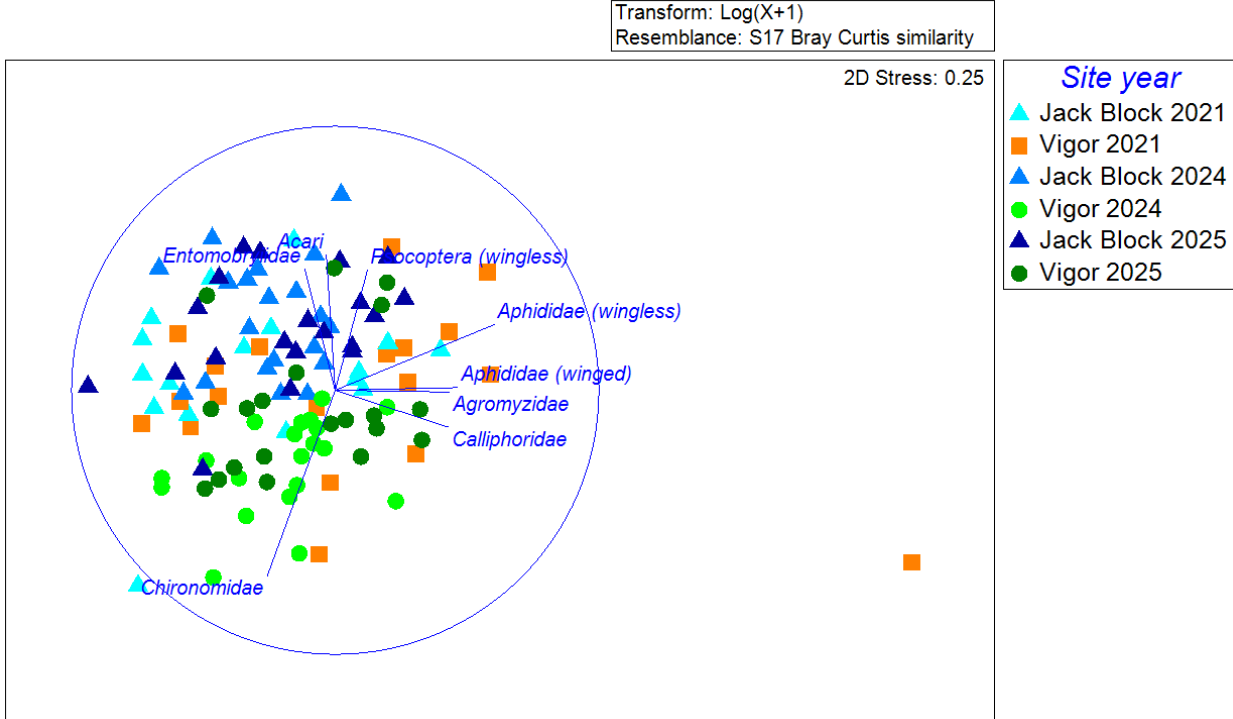
Appendix 2. Taxa listing of arthropods collected in the fallout traps, throughout all years of sampling in 2021, 2024, and 2025, sorted in descending order by count.

<b>Taxa Group</b>	<b>Taxa</b>	<b>Sum of Count</b>
<b>Acari</b>	Acari	1690
<b>Hemiptera</b>	Aphididae (wingless)	1245
	Coccoidea (wingless)	101
	Aphididae (winged)	94
	Cicadellidae	18
	Saldidae	14
	Cicadellidae (nymph)	11
	Hemiptera (nymph)	7
	Cercopidae	6
	Miridae	2
	Pentatomidae (nymph)	2
	Aphididae	2
	Coccoidea (winged)	2
	Delphacidae (nymph)	1
	Aleyrodidae	1
	Hemiptera	1
	Anthocoridae	1
	Oxycarenidae	1
<b>Diptera</b>	Chironomidae	581
	Sciaridae	211
	Phoridae	160
	Cecidomyiidae	68
	Ceratopogonidae	35
	Psychodidae	34
	Calliphoridae	21
	Ephydriidae	16
	Muscidae	12
	Hybotidae	11
	Chloropidae	9
	Dolichopodidae	8
	Sphaeroceridae	8
	Tipulidae	5
	Chironomidae (larva)	4
	Cecidomyiidae (larva)	4

	Canacidae	3
	Agromyzidae	3
	Brachycera (larva)	3
	Mycetophilidae	3
	Empididae	3
	Nabidae	1
	Chyromyidae	1
	Carnidae	1
	Fannidae	1
	Tachinidae	1
	Anthomyiidae	1
	Nematocera (pupa)	1
	Sarcophagidae	1
<b>Collembola</b>	Symphyleona	205
	Bourletiellidae	198
	Entomobryiidae	188
	Isotomidae	151
	Hypogastruridae	14
	Dicyrtomidae	7
<b>Thysanoptera</b>	Thysanoptera (nymph)	228
	Thripidae (winged)	26
	Thripidae	22
	Thysanoptera (wingless)	14
	Phlaeothripidae (winged)	5
	Thysanoptera (winged)	4
	Aeolothripidae	2
	Phlaeothripidae	1
	Thripidae (larva)	1
<b>Hymenoptera</b>	Braconidae	79
	Ichneumonidae	31
	Mymaridae	18
	Torymidae	16
	Crabronidae	15
	Eulophidae	15
	Andrenidae	10
	Platygastridae	4
	Encyrtidae	4
	Ophion sp	3
	Megaspilidae	3
	Formicidae (wingless)	3
	Apidae	2
	Tenthredinidae	2
	Scelionidae	2
	Aphelinidae	2

	Colletidae	2
	Eurytomidae	2
	Figitidae	2
	Spheciformes	1
	Cephidae	1
	Ceraphronidae	1
	Pemphredoninae	1
	Scelionidae (wingless)	1
	Platygasteridae	1
	Eupelmidae	1
	Chalcidoidea	1
	Diapriidae	1
	Pompilidae	1
<b>Psocoptera</b>	Psocidae	102
	Psocoptera (wingless)	75
	Psocoptera (winged)	10
	Ectopsocidae	8
	Psocoptera (nymph)	8
	Psocoptera	2
	Dasydemellidae (winged)	1
<b>Coleoptera</b>	Staphylinidae	13
	Throscidae	13
	Coleoptera (larva)	4
	Coccinellidae	2
	Scarabaeidae	2
	Coccinellidae (larva)	2
	Chrysomelidae	1
	Amphimallon sp	1
	Corylophidae	1
<b>Araneae</b>	Araneae	24
<b>Diplopoda</b>	Polyxenida	12
	Polyxenus sp	6
<b>Lepidoptera</b>	Lepidoptera (larva)	11
	Lepidoptera	6
<b>Neuroptera</b>	Neuroptera (larva)	5
	Hemerobiidae	2
<b>Amphipoda</b>	Traskorchestia traskiana	4
<b>Dermaptera</b>	Dermaptera (nymph)	2
<b>Oligochaeta</b>	Oligochaeta	2
<b>Isopoda</b>	Porcellio scaber	1
	Oniscidea	1
<b>Opiliones</b>	Opiliones	1
<b>Orthoptera</b>	Tettigoniidae	1
<b>Oniscidea</b>	Armadillidium sp	1

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Appendix 3. NMDS plot of insect samples. The 2D stress level is high (0.25; stress values over 0.2 are not that useful for visualizing data). Vectors show taxa correlations greater than 0.4, illustrating the main taxa driving associations in site and year. Chironomidae are the main dipteran family that are beneficial juvenile salmon prey and were abundant at Vigor in post-restoration years.