SWINOMISH LARVAL AND JUVENILE DUNGENESS CRAB MONITORING REPORT FOR 2018

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ABSTRACT

The Dungeness crab (*Metacarcinus magister*) is one of the most highly-valued marine species in the Pacific Northwest. Throughout the region, the species forms the basis for many local fishing economies and is prized for its cultural and recreational significance. Although the biology and ecology of *M. magister* is relatively well-understood compared to other marine invertebrates, fundamental gaps still exist, notably in crab populations within the inland waters of the Salish Sea. In 2018, the Swinomish Fisheries Department began monitoring the larval flux, juvenile settlement and growth, and ecology of Dungeness crab at sites in northern Whidbey and southern San Juan Basins. Over the course of the 2018 monitoring season, both larval and juvenile Dungeness crab were observed at larval flux and intertidal sites from May to August, with peak larval delivery and juvenile densities observed from mid-June to mid-July. Relative to other crab species observed, Dungeness crab had the longest larval contribution period with near constant presence from May to early August. However, post larval and early instar Dungeness crab sizes were found to vary by month, with early arriving megalopae and first stage instars having significantly larger carapace dimensions than later arriving cohorts. Developing a better understanding of larval and juvenile dynamics across San Juan and Whidbey Basins could have far-reaching implications for continued successful management of this essential fishery and provide valuable baseline data to inform future management practices as environmental conditions change.

Keywords Dungeness crab, *Metacarcinus magister*, larval flux, recruitment, juvenile, Puget Sound

INTRODUCTION

This report summarizes the annual dynamics of early life-history phases of Dungeness crab (*Metacarcinus magister*) in northern Whidbey and southern San Juan Basins during the spring and summer of 2018. Included in this report are data summaries from the larval flux and intertidal density and growth surveys conducted by the Swinomish Fisheries Department. These monitoring activities are the basis of a long-term monitoring effort developed with the aim of resolving extensive gaps in our knowledge of early life history phases of *M. magister* in Swinomish management regions. In addition, we aim to develop a baseline of biological and physical metrics in the region in order to determine potential limitations to adult populations and assess the need for more adaptive management strategies.

METHODS

Dungeness crab larval flux surveys

From 3 May to 17 September 2018 we deployed light traps to monitor the relative abundance of larval Dungeness crab at three locations: Cornet Bay (COR), Rosario Head (ROS), and Skyline Marina (SKY) (Figure 1, Table 1). Larval crab catch (inclusive of megalopae and instars which molted in the trap between site visits) was standardized by CPUE (catch/hr). In addition, carapace dimensions [including carapace width (CW), carapace height (CH), and total height (TH)] of 10 megalopae and instars (if present from megalopae that molted in the trap) were measured per week, per site. A more detailed explanation of methods can be found in Cook et al. (2018).

Table 1. Location metadata of larval flux sites in 2018.

Site Code	Location	Basin	Management Area	Catch Area
COR	Cornet Bay, Oak Harbor, WA	Whidbey	2E	24A
ROS	Rosario Head, Oak Harbor, WA	San Juan	1	22A
SKY	Skyline Marina, Anacortes, WA	San Juan	1	22A

Juvenile Dungeness crab intertidal surveys

Intertidal surveys were conducted on a bi-weekly basis from 16 May to 7 September 2018 during low tides. Surveys were conducted using a randomized sampling scheme of n = 10 0.25 m^2 quadrat samples per beach per low tide series through the juvenile settlement period. At each sample site, quadrats were excavated to a depth of 3 cm and all materials were collected in a 4 mm sieve and rinsed with local seawater to remove material < 4 mm from the bulk sample. The remaining materials were sorted through and all Dungeness crab instars and megalopae were enumerated and CW and CH were recorded. Intertidal areas of six beaches in two different basins were monitored: Bowman Bay adjacent the Rosario

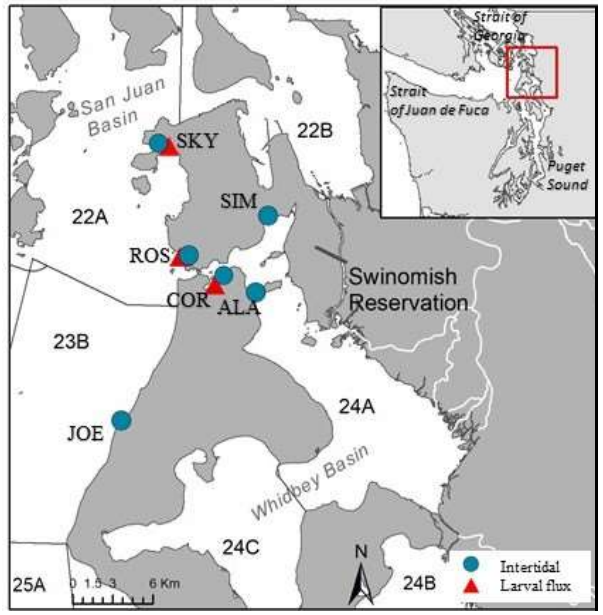

Figure 1. Location of larval flux and intertidal monitoring locations in San Juan and Whidbey Basins.

Head larval monitoring site (ROS), Cabana Park near Skyline Marina (SKY), Joseph Whidbey State Park (JOE), Cornet Bay (COR), Similk Beach (SIM), and Ala Spit (ALA) (Table 2). Detailed methods on how to conduct our intertidal surveys can be found in Grossman et al. (2021).

Table 2. Location metadata for intertidal sampling beaches.

Site Code	Location	Basin	Management Area	Catch Area
ROS	Bowman Bay, Oak Harbor, WA	San Juan	1	22A
SKY	Cabana Park, Anacortes, WA	San Juan	1	22A
JOE	Joseph Whidbey SP, Oak Harbor, WA	San Juan	3-1	23B
COR	Cornet Bay, Oak Harbor, WA	Whidbey	2E	24A
SIM	Similk Beach, WA	Whidbey	2E	24A
ALA	Ala Spit, WA	Whidbey	2E	24A

Ecological context

In addition to monitoring for Dungeness crab larval and juvenile abundance we quantified bycatch in both our light trap and intertidal excavated quadrat samples. When possible, all decapod species captured were identified to the lowest taxonomic group possible and enumerated.

Analysis

Simple summary statistics were used to characterize Dungeness crab larval abundance at sites through time. The larval crab monitoring season was broken up into three time periods, each summarizing catch rates over periods of six weeks: early-season (ES) 2 May to 14 June, mid-season (MS) 15 June to 25 July, and late-season (LS) 26 July to 17 September.

Carapace widths of Dungeness crab megalopae were compared both between sites and by month. Using a non-

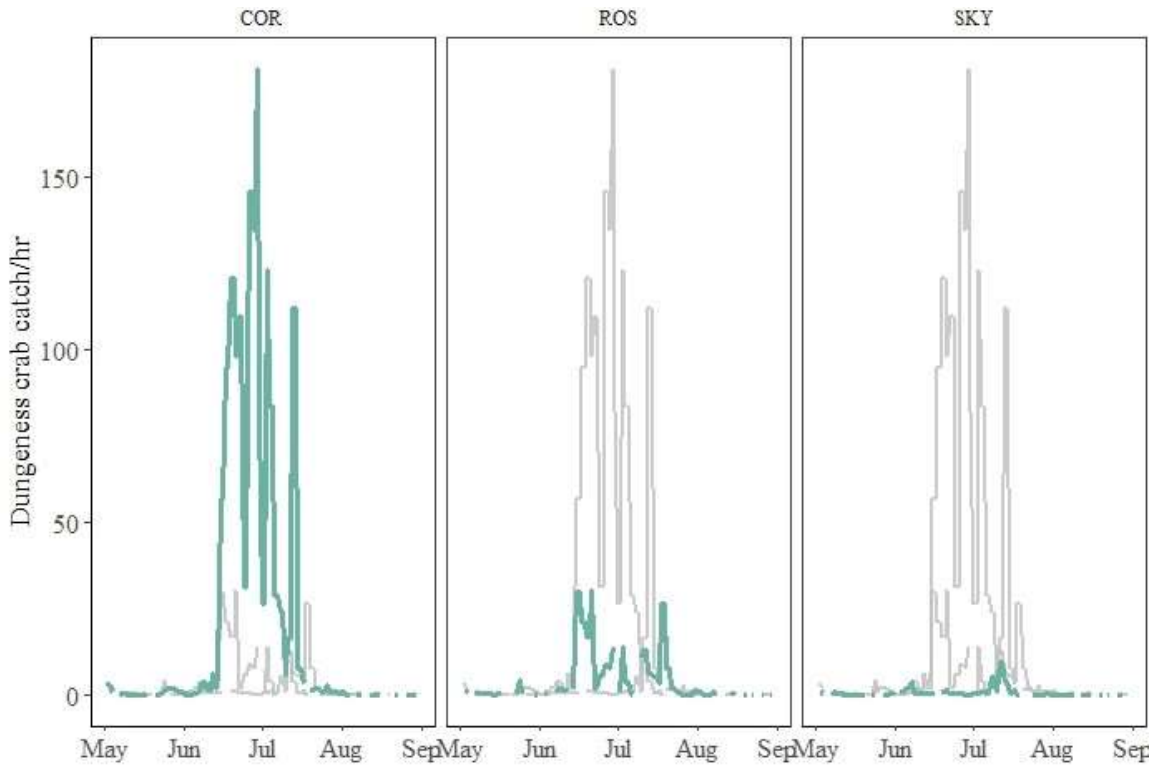

Figure 2. Dungeness crab catch per hour at Cornet Bay (COR), Rosario (ROS), and Skyline (SKY) from May to September 2018. Gray lines represent the catch from all three sites overlaid with green lines representing the catch from the individual site.

parametric Kruskal-Wallis (KW) test it was determined that there was no difference in CW of megalopae across sites, so CW measurements from all sites were pooled for a subsequent temporal analysis using a KW test and the post-hoc Conover-Inman test (Sokal & Rohlf 2012). Whenever multiple pairwise comparisons were conducted we used a Bonferroni-adjusted alpha value in the analysis (Sokal & Rohlf 2012).

Intertidal densities were qualitatively assessed and described with summary statistics. To examine the relationship between Dungeness crab settlement (as defined here by megalopae and/or J1 instars) and recruitment (J2+ instars), and their relative contributions to total crab intertidal density, the densities of settlers and recruits were plotted by sampling date. To qualitatively examine the temporal relationship between larval flux and intertidal settlement, megalopal abundance was totaled for the time period between intertidal sampling dates (i.e., biweekly cumulative larval abundance) and plotted against the intertidal density of J1 instars. The intertidal J1 densities at each site were plotted against megalopal abundances for both COR and ROS larval flux sites to determine whether the catches at either light trap better correlated with settlement.

The carapace widths of J1 instars found during intertidal surveys were analyzed using non-parametric KW tests to investigate differences in the sizes of J1 instars by site and by month. Because differences in CW were detected between sites, we compared CWs across months for each site using a KW test and the post-hoc Conover-Inman test. Whenever multiple pairwise comparisons were conducted we used a Bonferroni-adjusted alpha value in the analysis (Sokal & Rohlf 2012).

RESULTS AND DISCUSSION

2018 Dungeness crab larval catch

Total Dungeness crab larval abundance over the entire monitoring period was highest at COR (n = 20,592), followed by ROS (n = 3,716), and SKY (n = 572). The highest daily peak was 181.4 catch/hr recorded at COR on 29 June 2018 (Figure 2, Table 3). The highest daily peak for ROS was observed (30.2 catch/hr) a week prior to the COR peak on 21 June 2018. The highest daily peak at SKY (9.7 catch/hr) was recorded nearly a month later than the two other locations on 12 July. While Dungeness crab megalopae were caught on the first night the light traps were deployed (indicating we missed the beginning of the larval delivery season), we believe significant delivery of megalopae to the region did not occur until mid-season (Figure 2, Table 3). The last megalopae were caught between 20 to 23 August at all three sites.

Table 2. CPUE (catch/hr) minimum, maximum, mean and standard error (se), sum of *M. magister* larvae captured, and days sampled by period from 2 May to 17 September 2018. Statistics tallied by early-season (2 May to 14 June), mid-season (15 June to 25 July), late-season (26 July to 17 September), and total season.

	2 May to 14 Jun	COR	ROS	SKY
Early-season	min CPUE	0.0	0.0	0.0
	max CPUE	6.2	4.0	3.9
	mean CPUE ± se	1.1 ± 0.3	0.7 ± 0.2	0.4 ± 0.1
	Total catch	386	178	116
	Days sampled	40	28	36
	15 Jun to 25 Jul	**COR**	**ROS**	**SKY**
Mid-season	min CPUE	0.7	0.0	0.0
	max CPUE	181.4	30.2	9.7
	mean CPUE ± se	56.1 ± 8.2	9.5 ± 1.4	1.3 ± 0.4
	Total catch	20,129	3,492	440
	Days sampled	42	41	38
	26 Jul to 17 Sep	**COR**	**ROS**	**SKY**
Late-season	min CPUE	0.0	0.0	0.0
	max CPUE	1.0	1.2	0.2
	mean CPUE ± se	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
	Total catch	52	45	11
	Days sampled	36	41	42
	2 May to 17 Sep	**COR**	**ROS**	**SKY**
2018 Total	min CPUE	0.0	0.0	0.0
	max CPUE	181.4	30.2	9.7
	mean CPUE ± se	20.4 ± 3.8	3.8 ± 0.7	0.6 ± 0.1
	Total catch	20,592	3,716	572
	Days sampled	118	110	116

During the early-season Dungeness crab megalopae catches were low but consistent, with a mean catch/hr of 1.1 ± 0.3 SE at COR, 0.7 ± 0.2 SE at ROS, and 0.4 ± 0.1 SE at SKY (Table 3). During this period, daily catch rates did not exceed 6.2 catch/hr at any site (Figure 2). In the mid-season, catch rates increased dramatically, with a mean catch/hr at COR of 56.1 ± 8.2 SE, 9.5 ± 1.4 SE at ROS, and 1.3 ± 0.4 SE at SKY (Table 3). Though the mid-season catches were highest at each of the three sites, larval delivery was highly variable, with several days of high catches followed by several days of lower catches. This cyclical pattern of delivery suggests that underlying oceanographic conditions are potentially regulating delivery to the sites. Our lowest catches were observed during the late-season with a mean catch/hr of 0.1 ± 0.0 SE, 0.1 ± 0.0 SE, and 0.0 ± 0.0 SE, at COR, ROS, and SKY respectively (Table 3).

Dungeness crab megalopae carapace width

A steady decline in the mean carapace width (CW) of Dungeness crab megalopae was observed over the 2018 monitoring period (Figure 3). Regardless of month, we found no significant difference in CW between the three sites (COR, ROS, and SKY) in 2018 (Figure 4, $X^2 = 1.653$, df = 2, p = 0.438). Additionally, we found no difference by site within individual months (Table 4). There was, however, a significant difference in CW by month with all sites combined ($X^2 = 159.661$, df = 3, p <0.001). Carapace widths were significantly different from one month to the next except for the megalopae caught in July and August (Figure 3, Table 5). Carapace widths were generally larger in May with sizes ranging from 3.2 to 4.7 mm (Figure 3). Starting the week of 8 June at COR, smaller megalopae (< 3.2 mm) arrived in the region. These smaller crabs arrived at SKY by 15 June but were not recorded at ROS until the week of 25 June. The observed decrease in CW from before and after 15 June (start of the mid-season delivery period described above) corresponds with the observed increase in abundance at sites (Figure 2). Conversely, megalopae > 3.5 mm were not recorded after the week of 22 June 2018 at COR and ROS and the week of 25 June 2018 at SKY (Figure 3).

The megalopae delivered to sites throughout the May to September monitoring season were primarily made up of megalopae with a CW < 3.2 mm, with the smaller late-season sizes arriving after 15 June (Figures 2 & 3). It is our hypothesis that the low abundance of larger megalopae caught in the light traps prior to 15 June were

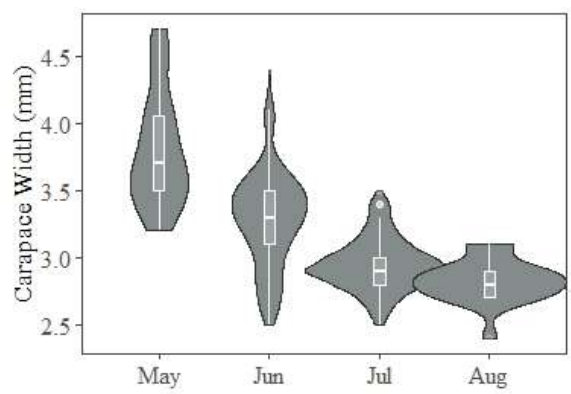

Figure 3. Violin plots depicting the relative distribution and proportion of carapace width (mm) of Dungeness crab megalopae caught in light traps from May to September 2018.

Table 4. Results of individual Kruskal-Wallis (X^2) and p-value of carapace width by site (COR, ROS, and SKY) within each month.

	May	Jun	Jul	Aug
X^2	2.14	0.43	2.41	1.09
p - value	0.343	0.807	0.300	0.580

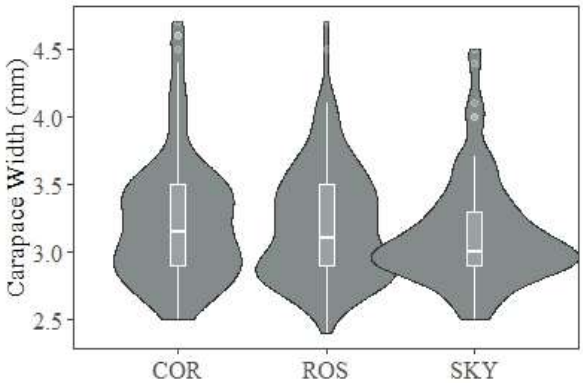

Figure 4. Violin plots depicting the relative distribution and proportion of carapace widths (mm) by site of Dungeness crab megalopae caught in light traps from May to September 2018.

primarily sourced from populations originating from the Pacific coast, whereas the smaller megalopae caught after the arrival of a peak in abundance on 15 June were sourced from populations within the Salish Sea. This hypothesis, originally proposed by Dinnel et al. (1993), suggests that the periodic reversal of surface currents (that predominantly flow out of the Strait of Juan de Fuca) could allow for outer coast megalopae to be transported into the Salish Sea during some years.

Juvenile Dungeness crab intertidal surveys

2018 Dungeness crab juvenile settlement density

Juvenile Dungeness crab were observed on beaches during the week of 16 May 2018 at four of the six sites monitored (Figure 5). As with the larval crab monitoring, we missed the start of the settlement season, which likely started in mid- to late-April 2018; future sampling will occur earlier in the season. Dungeness crab mean density across all dates was highest at SKY 7.5 ± 1.2 SE m^{-2} (n = 97) and lowest at ROS 0.6 ± 0.2 SE m^{-2} (n = 98). Early-season crab were present in higher densities at beaches in San Juan Basin (0.4 ± 0.3 SE to 3.3 ± 1.2 SE m^{-2}) compared to Whidbey Basin (0.3 ± 0.2 SE to 1.1 ± 0.4 SE m^{-2}), with the exception of ROS which had low densities of Dungeness crab instars throughout the settlement season (Figure 5). Early-season mean densities ranged from 0.3 ± 0.2 SE m^{-2} (n = 29) at COR to 3.3 ± 1.2 SE m^{-2} at JOE (n = 30). On the first sampling event, the mean density of Dungeness crab at JOE was 5.2 ± 3.2 SE m^{-2} (n = 10), the highest of all six sites (Figure 5). However, during the next sampling event at JOE the mean density dropped precipitously to 0.8 ± 0.5 SE m^{-2} (n = 10), highlighting the temporal patchiness of Dungeness crab settlement on beaches.

Table 5. Kruskal-Wallis (X^2) and Conover-Inman (t-statistic) follow-up test results of carapace width with all sites pooled by month.

Kruskal-Wallis $X^2 = 159.661$, df = 3, p-value = < 0.001*

		May	June	July
Jun	t	7.45		
	p	< 0.001*		
Jul	t	15.52	10.34	
	p	< 0.001*	< 0.001*	
Aug	t	11.98	7.84	2.37
	p	< 0.001*	< 0.001*	0.055

Bonferroni p-adjusted alpha = 0.05

Peak intertidal densities across all sites were highest during mid-season, corresponding with peak larval flux, ranging from a mean density of 0.8 ± 0.5 SE m^{-2} at ROS to 15.3 ± 2.7 SE m^{-2} at SKY (Figure 5). The highest mean density for a single sampling event was recorded at SKY (26.8 ± 4.7 SE m^{-2}, n = 10) on 10 July 2018 (Figure 5). All sites (except SIM) had the highest intertidal densities observed across the entire sampling season on 10 July 2018 (Figure 5). By late-season, Dungeness crab densities across all beaches decreased from the mid-season peaks. Interestingly, mean densities were near zero at SIM, JOE, and ROS by late-season (Figures 5 & 6), indicating that despite the presence of recent settlers (J1) early in the monitoring period, longer term juvenile (J2+) recruitment was not detected at these sites.

At the first monitoring dates in May, Dungeness crab were found at higher densities at the San Juan Basin sites (i.e., JOE and SKY, Figure 5) than at the Whidbey Basin sites. Importantly, this finding describes juvenile settlement earlier than previous Puget Sound studies (Dinnel et al. 1993). In particular, second and third instars were observed at JOE during the 16 May sampling event, indicating they could have settled approximately a month earlier relative to our other sites. We hypothesize that sites within the Strait of Juan de Fuca complex (the waterway connecting the Pacific Ocean to the Salish Sea) may have seen earlier settlement because megalopae originating from outer coast populations would have been delivered to these beaches first, and likely, in higher densities than locations further from the Strait.

Contrary to what we expected, early in the monitoring period the intertidal catches were made up of a relatively even mix of settlers and recruits (Figure 6). In the late-June/early-July time period, the number of settlers observed on the beaches increased dramatically, corresponding with peaks in the larval flux data (Figure 2). By August, the densities of Dungeness crab observed on beaches was mostly driven by recruits, as the

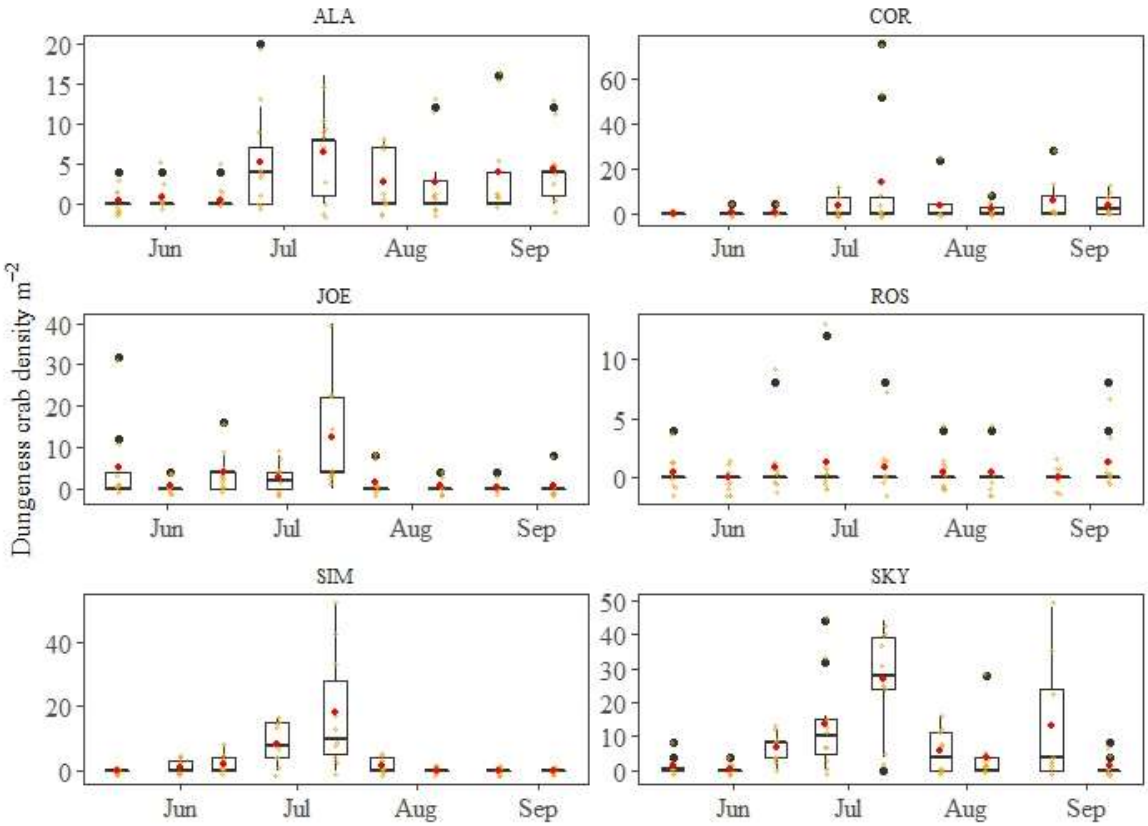

Figure 5. Median, distribution (yellow jitter), and mean (red) density of Dungeness crab m^{-2} at Ala Spit (ALA), Cornet Bay (COR), Joseph Whidbey State Park (JOE), Rosario Head (ROS), Similk Beach (SIM), and Skyline (SKY) from May to September 2018. Note the differences in scale.

settlement season appeared to have largely tapered off by mid-July (Figures 2 & 6). At JOE, a large influx of sand covered the rocky mid-beach habitat in late-July virtually eliminating all of our target intertidal habitat. As a result, we hypothesize that the JOE *M. magister* recruits could have migrated to the upper subtidal eelgrass habitat offshore, moved up/down the beach to other areas outside of the study domain, or perished. A similar pattern emerged at SIM, however in this instance we believe that crab may have left the study area to seek better food and shelter resources at a nearby shellfish farm. Perhaps at SIM the vulnerable settlers and early recruits sheltered where they settled on the beach (Gunderson et al. 1990) but as the crab grew they were better protected from predation and migrated to more favorable conditions, in this instance the oyster farm (presence confirmed by S. Thomas, Swinomish Shellfish Company, personal communication).

Evidence of a relationship between larval flux and the density of J1 instars at intertidal sites was unclear as results varied depending on the specific light trap and beach site (Figure 7). For example, the ROS light trap was located <1.0 km away from the intertidal site at the head of the embayment, yet large pulses of larvae did not produce a notable presence of J1 instars at the site. However, when we compared the ROS light trap to SKY and JOE intertidal sites (9 and 13 km away, respectively) we saw a clearer relationship between magnitude of larval delivery and settlement (Figure 7). The relationship between larval delivery and settlement is obviously complicated by a multitude of factors (e.g., hydrodynamic processes, larval patchiness, settlement preferences, habitat suitability) which we aim to further evaluate.

2018 Dungeness crab size and instar stage composition

In addition to tracking the larval flux and densities of Dungeness crab over time, we were interested in tracking growth and development of juvenile crab (up to ~25 to 40 mm CW; Armstrong et al. 1989, Gunderson et al. 1990) while they occupy intertidal nursery habitats. As with the megalopae captured in light traps, we observed a gradual decrease in CW of J1 instars that settled May through September at our intertidal sites (Table 6, Figure 8). The size of J1 instars varied significantly among sites (X^2 = 20.14, df = 5, p-value = <0.001) and by month (X^2 = 137.07, df = 4, p-value = <0.001). Follow-up tests revealed that the sizes of J1 instars varied significantly between ALA and the sites located in San Juan Basin (JOE, ROS, and SKY) but not COR and SIM (also located

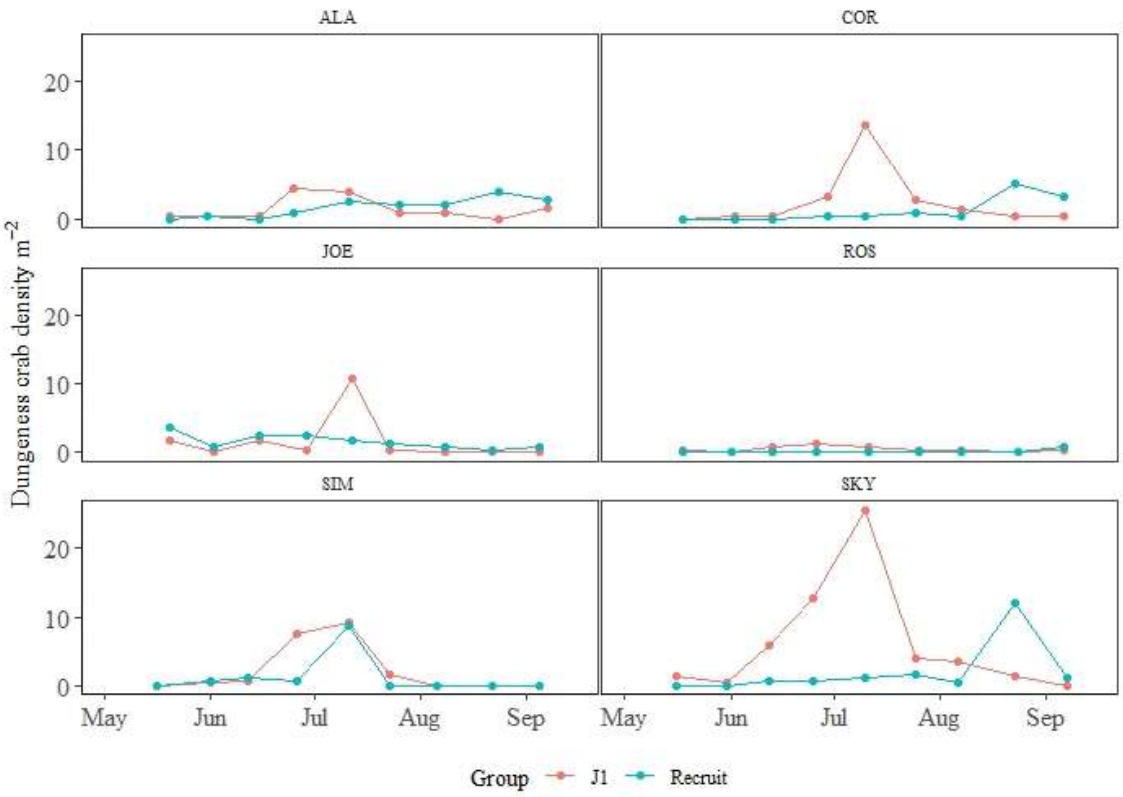

Figure 7. Mean density of Dungeness crab J1 instars (red, recent settlers) and recruits (blue, J2 and larger instars) at Ala Spit (ALA), Cornet Bay (COR), Joseph Whidbey State Park (JOE), Rosario Head (ROS), Similk Beach (SIM), and Skyline (SKY) from May to September 2018.

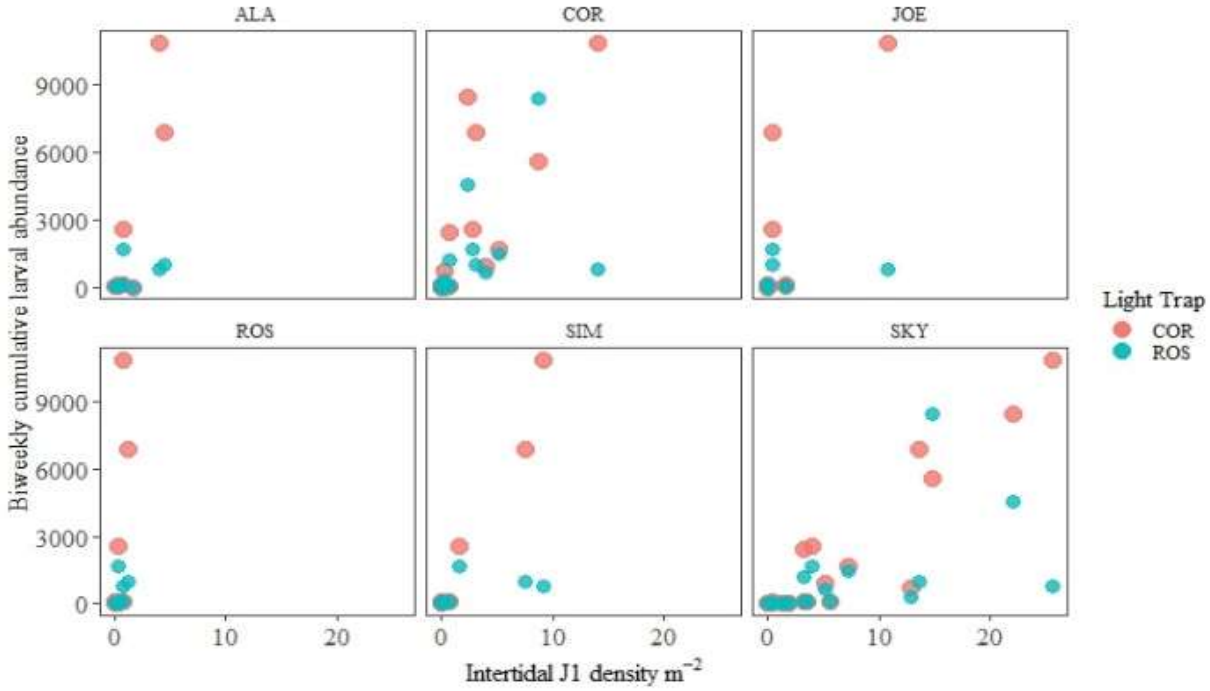

Figure 6. Mean density of Dungeness crab J1 instars (recent settlers) versus biweekly cumulative larval abundance from the Cornet Bay (COR) and Rosario Head (ROS) larval flux sites between intertidal sampling dates at Ala Spit (ALA), COR, Joseph Whidbey State Park (JOE), ROS, Similk Beach (SIM), and Skyline (SKY) intertidal sites from May to September 2018.

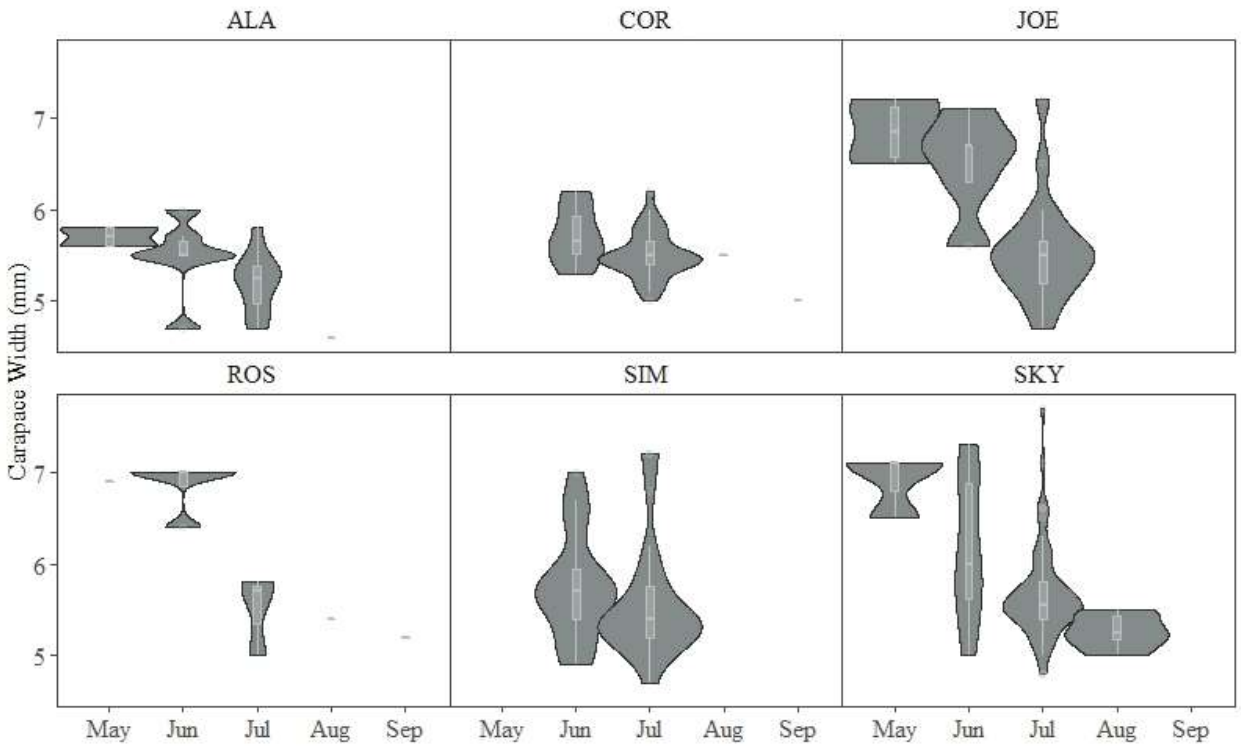

Figure 8. Violin plot depicting the relative distribution and proportion of carapace width (mm) of Dungeness crab instars from the Ala Spit (ALA), Cornet Bay (COR), Joseph Whidbey State Park (JOE), Rosario Head (ROS), Similk Beach (SIM), and Cabana Park near Skyline Marina (SKY) intertidal monitoring sites from May to September 2018.

in Whidbey Basin). San Juan Basin sites did not vary significantly from COR and SIM (Table 7). These patterns in CW differences between sites were likely due to the lack of appreciable early-season settlement observed at the Whidbey Basin sites and the higher number of settlers San Juan Basin sites did not vary significantly from COR observed in July driving the mean values.

In May, the mean CW of J1 instars was greatest at 6.64 ± 0.56 SE and by August and September the mean CWs were 5.22 ± 0.29 SE and 5.10 ± 0.10 SE, respectively (Table 6). While the CWs decreased over the monitoring period, not all sites observed a significant difference in the sizes of J1 instars across months (Table 8). Significant differences in CW were detected by month at ALA, JOE, and SKY but not at COR, ROS, and SIM (Table 8). At JOE, CWs were not different between J1 instars caught in May and June but differences were observed between May and July as well as June and July. No J1 instars were caught at JOE in August. At SKY, differences in CW were observed between all months except for May and June. At ALA, the CWs differed significantly for J1 instars caught between May and July, May and August, as well as June and August but did not vary significantly between May and June, June and July, and July and August (Table 8). Sites where CWs did not vary significantly across months (ROS, COR, and SIM) did not exhibit appreciable (or any) settlement outside of June and July (Figure 8).

On the first intertidal sampling date, it was clear that we were observing both Dungeness crab settlers and juvenile recruits at the San Juan Basin sites. In May, Whidbey Basin sites only had J1 instars (maximum CW 5.8 mm) whereas San Juan Basin sites had up to J3 instars (maximum CW 12.3 mm) present in samples (Figure 9). By June, the largest instars found in San Juan Basin were

Table 6. Count and mean carapace width (± standard error) of J1 instars collected from intertidal habitats by site and month.

		Count	Mean ± se
Site	ALA	20	5.28 ± 0.10
	COR	47	5.56 ± 0.05
	JOE	29	5.89 ± 0.14
	ROS	9	6.24 ± 0.26
	SIM	46	5.65 ± 0.09
Month	May	10	6.64 ± 0.18
	Jun	81	6.08 ± 0.08
	Jul	168	5.58 ± 0.04
	Aug	17	5.22 ± 0.07
	Sep	2	5.10 ± 0.10

22.0 to 32.2 mm CW and 16.6 mm CW in Whidbey Basin. The 32.2 mm CW individual captured in San Juan Basin in June was most likely a recruit from the 2017 settlement season. San Juan Basin continued to have larger instars in samples, with the maximum CW 29.8 versus 19.1 mm for Whidbey Basin. By September, instars reached a maximum CW of 37.9 mm in San Juan Basin and 28.0 mm in Whidbey Basin (Figure 9).

As early as June, a clear divergence in the growth of the different settlement cohorts was observed, with three modes of CW (~18 mm, 13 mm, and 6 mm) representing April, May, and June settlement time frames. As the summer season progressed, the survivors from the earliest settling cohort in San Juan Basin were able to reach ~40 mm by September. The largest crabs from Whidbey Basin lagged behind the San Juan Basin crab by about 10 mm, with CWs approaching 30 mm by September. However, the vast majority of *M. magister* encountered in the intertidal from the 2018 settlement season were still < 20 mm at the end of the monitoring in September. Divergent growth patterns in Dungeness crab have been well documented from single settlement cohorts in coastal estuaries and adjacent nearshore areas in Washington (Gunderson et al. 1990). These divergent patterns are likely due to thermal gradients and associated food resources driving growth rates (Hartnoll 1982). The early settling cohort in our study mirror the settlement timing and growth patterns of Dungeness crab from coastal estuaries with young-of-the-year crab reaching 40 mm by fall (also documented in early settling crab in northern Puget Sound, McMillan et al. 1995). Meanwhile, the later settling crab in our study followed a growth trajectory more akin to the crab reared in cooler temperatures such as those described in southern British Columbia (MacKay & Weymouth 1935, Dinnel et al. 1993).

Table 7. Conover-Inman follow-up test results of carapace widths of J1 instars with all months combined by site.

Kruskal-Wallis $X^2 = 20.144$, df = 5, p-value = < 0.001*

		ALA	COR	JOE	ROS	SIM
COR	t	-1.83				
	p	0.510				
JOE	t	-3.09	-1.73			
	p	0.017*	0.635			
ROS	t	-3.36	-2.37	-1.19		
	p	0.007*	0.140	1.000		
SIM	t	-1.96	-0.18	1.57	2.26	
	p	0.381	1.000	0.882	0.184	
SKY	t	-3.56	-2.15	0.19	1.43	-1.93
	p	0.003*	0.241	1.000	1.000	0.413

Bonferroni p-adjusted alpha = 0.05

One of the goals of our monitoring program was to attempt to determine the instar stage of crab collected during intertidal surveys in order to assess growth and survival of settlers. In most studies of decapod growth, carapace widths of successive instar stages are assigned by determining modes in a size-frequency histogram of the population (Hartnoll 1982). However, this method was not strictly achievable for our study given 1) the relatively small sample size from our single year of monitoring, 2) the apparent differences in growth between San Juan and Whidbey Basin sites, and 3) the considerable discrepancies in J1 carapace widths between early- and late-settling juveniles. Indeed, the carapace widths of J1 instars from the early settlement period were up to 3.1 mm larger than instars from the late settlement period. The consequences of the differences in size at settlement and the prolonged settlement period result in further divergence in carapace widths between the settlement cohorts. Previous studies in northern Puget Sound have projected that this divergent growth pattern may result in early settling Dungeness crab reaching a carapace width of 100 mm (a size also associated with sexual maturity) in 10 molts by the spring of year two, whereas late settling crab may not overcome this threshold until 12 molts,

Table 3. Kruskal-Wallis (X^2) and post-hoc Conover-Inman (*t*-statistic) results on differences in carapace widths of J1 instars by month.

	San Juan Basin					Whidbey Basin			
	JOE		ROS	SKY		ALA		COR	SIM
X^2	12.53		7.28	31.05		11.54		5.35	2.08
p	0.002*		0.122	<0.000*		0.009*		0.148	0.149
	t	p	-	t	p	t	p	-	-
May vs. Jun	0.68	0.756		1.65	0.307	1.32	0.608		
May vs. Jul	3.79	0.001*		2.95	0.011*	3.28	0.013*		
May vs. Aug				4.26	< 0.000*	4.13	0.002*		
Jun vs. Jul	3.24	0.005*		3.89	0.001*	2.11	0.148		
Jun vs. Aug				5.39	< 0.000*	3.33	0.011*		
Jul vs. Aug				3.21	0.005*	2.11	0.148		

Bonferroni p-adjusted alpha = 0.05

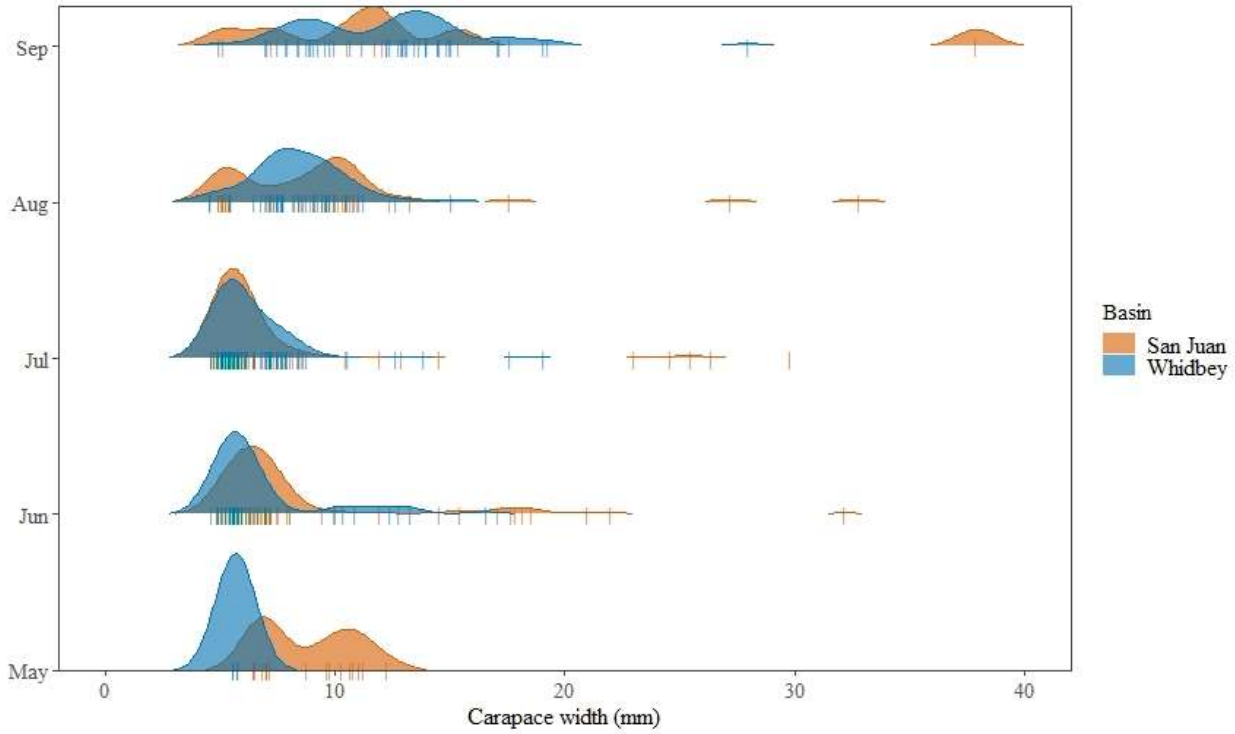

Figure 9. Relative frequency distribution of carapace widths (mm) of Dungeness crab instars caught from all monitoring sites pooled by San Juan Basin (orange) and Whidbey Basin (blue) May to September 2018.

occurring sometime during year three (MacKay & Weymouth 1935, Orensanz & Gallucci 1988).

Direct comparisons between the growth patterns presented here and previous studies conducted in Puget Sound have highlighted some interesting similarities and differences. Most notably, we were able to corroborate results from Orensanz & Gallucci (1988), Dinnel et al. (1993), and McMillan et al. (1995) of two settlement cohorts exhibiting distinct settlement timing and size differences. These studies, conducted in the 1980s and 1990s, hypothesized that larval Dungeness crab from populations originating on the outer coast of Washington were transported into Puget Sound around May. In addition, both studies observed a later settling cohort of crab with peak intertidal densities observed in August. While we did observe larvae settling in May (and likely mid- to late April to early June) our study differed from the previous studies in that we observed very little larval presence or settlement in the month of August. With only one year of data, it is impossible to determine if the peak of smaller crab observed in mid-June denotes a temporal shift in the later arriving cohort or if 2018 was an anomalous year for Dungeness crab settlement or transport. We hope our future studies will elucidate these patterns.

Ecological context

While Dungeness crab were the focus of this study, we also observed several other larval crab species, including the most abundant species: *Cancer productus*, *Glebocarcinus oregonensis*, *Lophopanopeus bellus*, *Hemigrapsus* spp. and *Pagurus* spp. Like Dungeness crab, delivery of larvae of these other species was not spatially distributed evenly between the three larval flux sites. However, unlike Dungeness crab larvae, each of these species were captured in the light traps during more discrete time periods. In early May 2018, a large pulse of *L. bellus* was observed across the study sites and was most abundant at SKY with 625 catch/hr observed on 8 May (Figures 10 and 11). Megalopae of *L. bellus* were observed in relatively high abundance (62.5 catch/hr) at SKY on the first day of monitoring (and were likely there several weeks prior) and were last observed on 7 June 2018. Megalopae of *C. productus* were first observed on 4 May and were found at sites until 3 July, with peak abundances observed on 11 June at SKY (27.8 catch/hr) and 14 June at COR (33.3 catch/hr). On 9 July we observed the first *G. oregonensis* and they were last observed on 13 August (Figure 10). The highest abundance of *G. oregonensis* (194.4 catch/hr) was observed at SKY on 12 July. The latest arriving megalopae found in our traps were *Hemigrapsus* spp. (due to equipment limitations we were unable to differentiate between *H. oregonensis* and *H. nudus*), first observed on

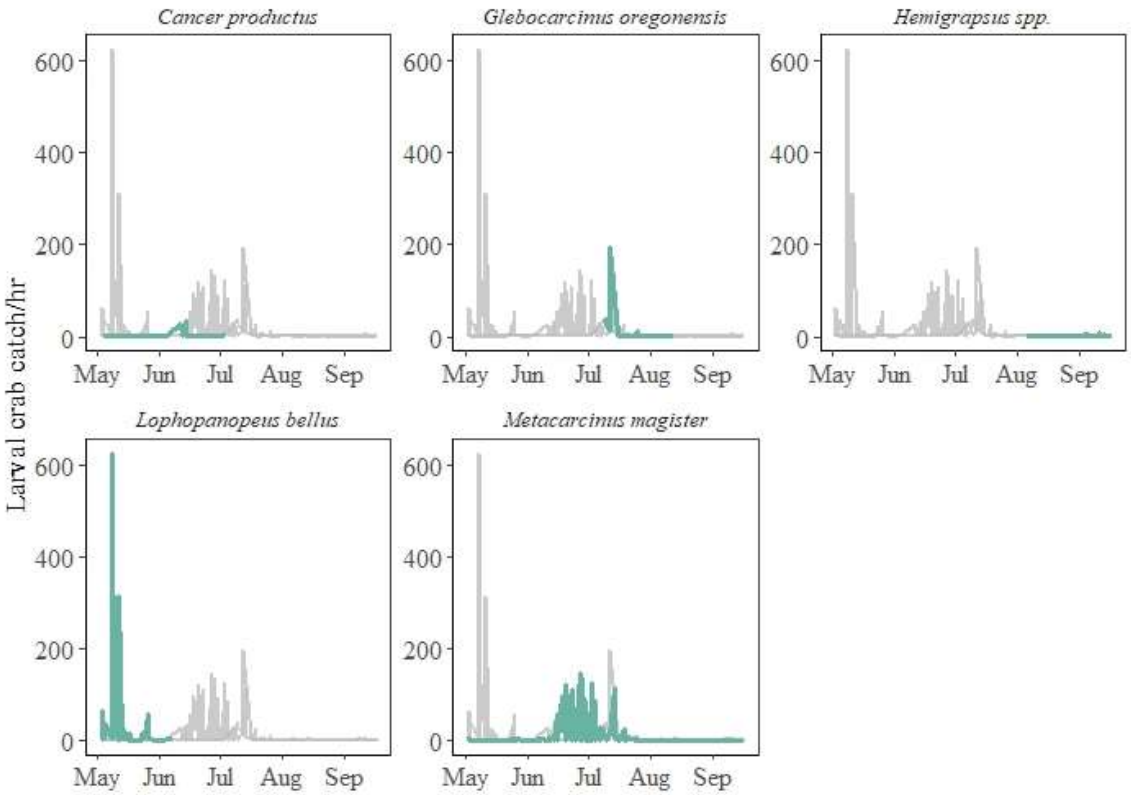

Figure 10. Total catch per hour (all sites combined) of *Cancer productus*, *Glebocarcinus oregonensis*, *Hemigrapsus* spp., *Lophopanopeus bellus*, and *Metacarcinus magister* (May to September 2018). Gray lines represent catch rates of all species and the overlaid green line represents the catch rates of the target species.

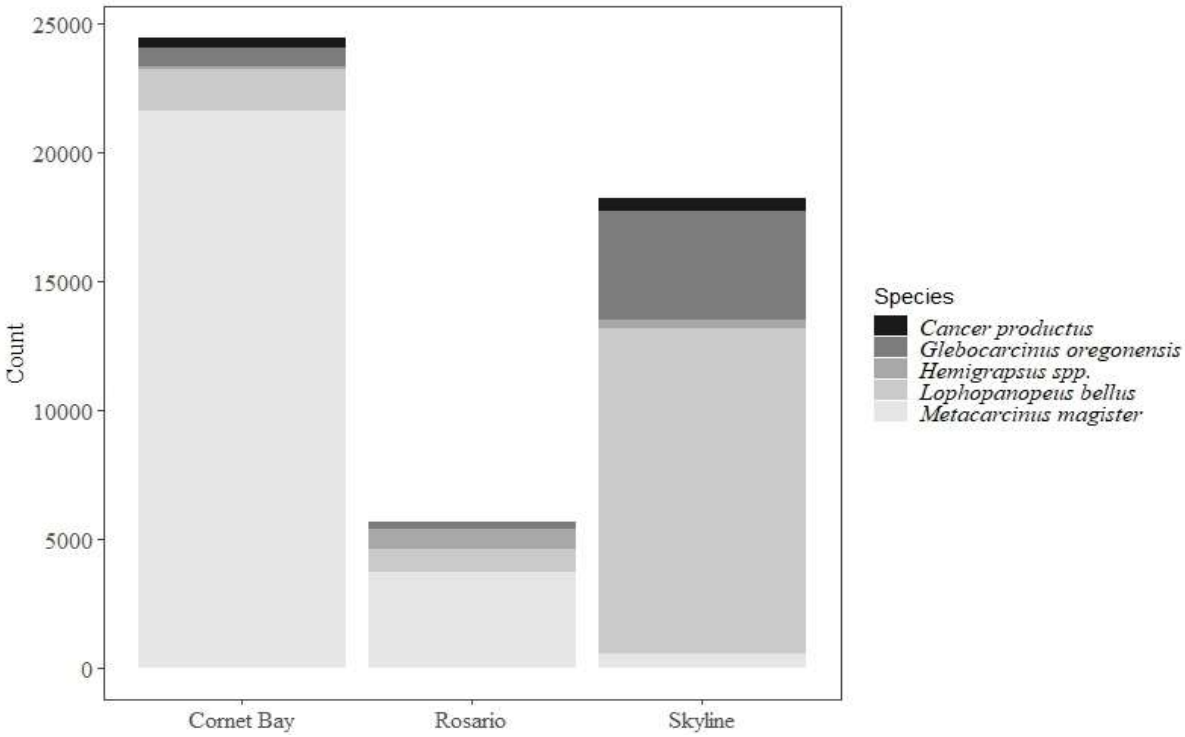

Figure 11. Cumulative megalopal abundance of *Cancer productus*, *Glebocarcinus oregonensis*, *Hemigrapsus* spp., *Lophopanopeus bellus*, and *Metacarcinus magister* at Cornet Bay, Rosario, and Skyline larval flux sites.

6 August 2018 at ROS. From 6 August - 17 September 2018 (the final sampling date), *Hemigrapsus* spp. were found in low abundances, peaking between September 3 to 11, 2018 (maximum 7.8 catch/hr, ROS).

Over the course of the 2018 monitoring season *M. magister* were the predominant species captured at both COR and ROS. However, the COR trap captured 5.5 times more *M. magister* compared to ROS (Figure 11). Dungeness crab megalopae catches were minimal at SKY (Figure 11). While the SKY trap did capture some *M. magister* megalopae, *L. bellus* and *G. oregonensis* were captured in much greater abundances here than at COR and ROS (Figure 11).

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REFERENCES

Armstrong DA, Botsford L, Jamieson G (1989) Ecology and population dynamics of juvenile Dungeness crab in Grays Harbor estuary and adjacent nearshore waters of the southern Washington coast. U.S. Army Corps of Engineers, Seattle, Washington

Cook C, Grossman S, Barber JS (2018) Swinomish crab abundance monitoring program light trap methods. Swinomish Indian Tribal Community Contribution SWIN-CR-2018-02:21 pp

Dinnel PA, Armstrong DA, McMillan RO (1993) Evidence for multiple recruitment-cohorts of Puget Sound Dungeness crab, *Cancer magister*. Marine Biology 115:53–63

Grossman SK, Cook CE, Barber JS (2021) Swinomish crab abundance monitoring program intertidal methods. Swinomish Indian Tribal Community Contribution SWIN-CR-2021-02:15 pp

Gunderson DR, Armstrong DA, Shi Y-B, McConnaughey RA (1990) Patterns of estuarine use by juvenile English sole (*Parophrys vetulus*) and Dungeness crab (*Cancer magister*). Estuaries 13:59

Hartnoll RG (1982) Growth. In: The Biology of Crustacea, 1st edn. Academic Press, p 111–196

MacKay D, Weymouth F (1935) The growth of the Pacific edible crab, *Cancer magister*, Dana. Journal of the Biological Board of Canada 1:191–212

McMillan RO, Armstrong DA, Dinnel PA (1995) Comparison of intertidal habitat use and growth rates of two northern Puget Sound cohorts of 0+ age Dungeness crab, *Cancer magister*. Estuaries 18:390-398

Orensanz JM, Gallucci VF (1988) Comparative study of postlarval life-history schedules in four sympatric species of Cancer (Decapoda: Brachyura: Cancridae). Journal of Crustacean Biology 8:187–220

Sokal RR, Rohlf FJ (2012) Biometry: The principles and practice of statistics in biological research [Extensively rev.] 4th ed. W.H. Freeman, New York