Status of the European Green Crab, *Carcinus maenas*, in Oregon and Washington coastal Estuaries in 2018

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Executive Summary

The European green crab (*Carcinus maenas*) has persisted in Oregon and Washington coastal estuaries since the late 1990s. After the arrival of a strong year class in 1998, significant recruitment to the populations occurred only in 2003, 2005, 2006, 2010, 2015, 2016, 2017 and 2018. Warm winter water temperatures, high Pacific Decadal Oscillation (PDO) and Multivariate ENSO (El Niño Southern Oscillation) Indices, and a high abundance of southern copepods are all correlated with strong year classes and vice versa (Behrens Yamada Peterson and Kosro 2015). Prior to 2015, green crabs were too rare to exert measurable effects on the native benthic community and on shellfish culture in Oregon and Washington. Following the recent strong El Niño, however, we documented the arrival of four strong year classes in 2015, 2016, 2017 and 2018. Average catch rates over the last four years steadily increased from 0.5 to 0.8 to 2.2 and to 3.2 crabs per trap. The catches in the last 2 years are much higher than in any of the previous years, including 1998. Since green crabs live for 6 years, these four consecutive year classes will produce larvae until 2024. A switch to cooler ocean conditions in the coming years will result in poor recruitment, but a return to high PDO and strong El Niño patterns would signal good recruitment and higher green crab densities. For example, green crabs were first documented in New England in 1817, but it took warm ocean conditions during the 1950's for their numbers to build to a level at which they decimated the soft-shelled clam industry in Maine. With the recent warm trend on the East Coast, green crabs are again abundant. Not only are they preying on shellfish, they are also damaging valuable eelgrass habitat by ripping up the plants in search of food (Neckles 2015).

Even though green crab abundance in Oregon and Washington is still low when compared to Europe, eastern North America, Tasmania, California and the west coast of Vancouver Island, it is imperative to continue monitoring efforts for two reasons:

1) to elucidate the process of range expansion and population persistence of this model non-indigenous marine species with planktonic larvae, and
2) to predict the arrival of strong year classes from ocean conditions and alert managers and shellfish growers of possible increases in predation pressure from this invader.

Professional and Outreach Activities by Sylvia Behrens Yamada in 2018

Date	Talks / Outreach Activities	Location
March 20-22	Attended National Shellfish Association meeting, presented talk, organized and moderated special green crab session.	Renaissance Inn, Seattle, Washington
April 8-9, 2018	Set traps and checked them with Sally Hacker's Marine Biology (Bi 450) students. Gave guest lecture on the invasion history, biology and status of the European Green crab in Oregon and Washington.	Hatfield Marine Science Center, Newport, Oregon
May 1-4, 2018	Set traps with Bree Yednock, Ryan Scott of South Slough Estuarine Research Reserve and Mike Thomas of Oregon Institute of Marine Biology	Coos Bay, Oregon Institute of Marine Biology
July 6, 2018	Set traps and checked them with John Chapman's Marine Invasion Class (FW421) students. Gave guest lecture on the invasion history, biology and status of the European Green crab in Oregon and Washington.	Hatfield Marine Science Center, Newport, Oregon
Sept. 19, 2018	Gave two talks on the status of the European green crab to the Pacific Coast Shellfish Growers/ National Shellfish Association meeting: 1. Range Expansion of green crabs and 2. Feasibility of using Pheromones as a control tool.	Semiahmoo Resort, Blaine, Washington
October 1, 2018	The Eugene Dive Club invited me to be their after-dinner speaker. "Invasion History, Biology and the Status of the European green crab in Oregon and Washington."	Holiday Inn, 919 Kruse Way, Springfield, Oregon

Introduction

European green crabs (*Carcinus maenas)* made their way to the east coast of North America in sailing ships in the early 1800's (Say 1817). They arrived in San Francisco Bay during the 1980's, most likely via aerial shipment of Atlantic seafood or baitworms. From there, green crabs spread naturally via larvae carried in ocean currents, and by 2000, had dispersed as far north as Port Eliza on the northern west coast of Vancouver Island, British Columbia. Presently, green crabs are found around the Bella Bella area on the Central British Columbia coast and in the Salish Sea between Vancouver Island and the mainland (Behrens Yamada et al. 2017, Grason et al. 2018). It is estimated that their potential range could include Southeast Alaska (Behrens Yamada 2001, Carlton & Cohen 2003).

The green crab is a voracious predator that feeds on many types of organisms, including commercially valuable bivalve mollusks (e.g., clams, oysters, and mussels), polychaetes, and small crustaceans (Cohen et al. 1995). It also competes with native juvenile Dungeness crabs (*Metacarcinus magister*) and shore crabs for food and shelter (McDonald et al. 2001, Jensen et al. 2002, Behrens Yamada et al. 2010). Larger, more aggressive native crab species, such as the red rock crab (*Cancer productus*) and the Pacific brown rock crab (*Cancer antennarius*), have been shown to offer biotic resistance to this invader, but only in the cooler and more saline lower parts of estuaries (Hunt and Behrens Yamada 2003; Jensen et al. 2007). Scientists, managers and shellfish growers are concerned that increases in the abundance and distribution of this efficient predator and competitor could permanently alter native communities and threaten commercial species such as juvenile Dungeness crab, juvenile flatfish and bivalves (rand Kuris 1996, Jamieson et al. 1998, Behrens Yamada et al. 2010).

On the West Coast, the northward range expansion of green crabs during the 1990's is linked to favorable ocean conditions for larval transport during El Niño events (Behrens Yamada et al. 2005, Behrens Yamada and Kosro 2010, Behrens Yamada et al. 2015). Warm temperatures and strong northward moving coastal currents (>50 km/day) during the 1997/1998 El Niño were correlated with the appearance of a strong cohort of young green crabs in Pacific NW estuaries in the summer of 1998 (Behrens Yamada and Hunt 2000, Behrens Yamada et al. 2005). Recruitment has occurred in embayments from Coos Bay to the Central Coast of British Columbia. Year classes were more abundant following the warm winters and springs of 2003, 2005, 2006, 2010, 2015, 2016, 2017 and 2018. (Behrens Yamada & Gillespie 2008; Behrens Yamada & Kosro 2010, BehrensYamada et al. 2015).

Goals

The goal of this study is to document the present, and predict the future status of the European green crab in the Pacific Northwest. This is accomplished by:

1. Estimating the relative abundance of green crabs in Oregon and coastal Washington estuaries during the spring, summer and fall of 2018 by using baited Fukui fish traps and crayfish (minnow) traps (Tables 2, Figure 2).
2. Collaborating with scientists from Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, the Makah tribe, and Fisheries and Oceans Canada as well as with shellfish growers and sports fishers in order to compile all existing green crab data for the Pacific Northwest.
3. Estimating year-class strength of 0-age green crabs at the end of their first growing season by setting crayfish (minnow) and pit-fall traps in the high intertidal zone at the end of summer and early fall (Figure 3, Appendix 3). These data will predict adult abundance in following years.
4. Comparing patterns in the recruitment strength of 0-age crabs over time and correlating them to ocean conditions such as the Pacific Decadal Oscillation Index for March and southern copepod anomality. (For a complete list of correlations see Behrens Yamada et al. 2015).

Sampling Methods for Green Crabs

Our sampling effort in 2018 included one Washington and five Oregon estuaries: Willapa, Tillamook, Netarts, Nehalem, Yaquina and Coos Bay (Figure 1). Additional data for Makah Bay, Grays Harbor, Willapa Bay, Alsea and Coquille were supplied by agency biologist and shellfish growers. All Oregon estuaries were sampled at least twice during the 2018 trapping season, with Coos receiving additional sampling by biologists and interns from the South Slough National Estuarine Research Reserve. Willapa was only sampled once at the Stackpole site for young-of-the-year crabs. In the Oregon estuary, we selected study sites within various habitat types and tidal levels. Since green crabs are rare and patchily distributed, we did not choose our sites randomly. Instead, we preferentially sampled sites that have harbored green crabs in the past, such as tidal marshes, gradually sloping mudflats and tidal channels where salinities remain above 15‰ and water temperatures range between 12º-22º C in the summer (Behrens Yamada and Davidson 2002). Green crabs are noticeably absent from the cooler, more saline mouths of estuaries, which are dominated by the larger and more aggressive red rock crab, *Cancer productus* (Hunt and Behrens Yamada 2003). Since *C. maenas* larvae settle high on the shore (Zeng et al. 1999), and crabs move into deeper water as they age (Crothers 1968), we adapted our collecting methods and locations to effectively sample all age classes of *C. maenas.* Since traps differ in their sampling efficiency for different sizes of crabs, we mainly used two trap types (Table 1). Folding Fukui fish traps, with their wide slit-like openings, work well for adult crabs larger than 40 mm carapace width (CW), while crayfish traps with their small mesh size (0.5 cm) retain 0-age green crabs. Green crabs start entering these baited traps when they are around 20 mm in carapace width. Typically, we would trap larger adult crabs in the mid to low intertidal zones with folding Fukui fish traps and 0-age green crabs in the high intertidal vegetation with crayfish traps at the end of their first growing season (Appendix 1).

Table 1. Types of traps used for sampling *C. maenas* in Oregon and Washington estuaries. Size selectivity is given in carapace width (CW).

Trap Type	**Description**	**Dimensions**	**Tidal Height**	**Size Selectivity**
Fukui Fish trap	Plastic mesh (2 cm) with two slit openings (45 cm)	63 x 46 x 23 cm	Low to subtidal	>40 mm
Frabill Crayfish (minnow) trap	Wire mesh (0.5 cm) cylinder with two openings expanded to 5 cm	21 cm diameter 37 cm long	Medium to high	20-70 mm

On gravel shores, we added rocks to the crayfish and fish traps to weigh them down and to provide shelter for the crabs. On soft sediment, we pinned the traps down with thin metal stakes. We cut fish carcasses into sections and placed them into egg-shaped commercial bait containers (15 x 8 mm). Holes (0.5 cm) in the sides and lids of the containers allow bait odors to diffuse. One bait container with fresh bait was placed in a trap and left for one tidal cycle (typically 24 hours). We retrieved the traps at low tide, identified all crabs and other by-catch to species and noted the sex, carapace widths (CW) and molt stage of all green crabs. Green crabs were measured between the tips of their fifth anterio-lateral spines using digital calipers. Native crabs and other by-catch were released while green crabs were removed from the ecosystem. Data on crab characteristics (sex, carapace width, weight, and color of the abdomen) for sightings are tabulated in Appendix 2. those caught during our trapping program in the accompanying data file:

The trapping data used for this report can be found in Yamada, S. B., Yednock, B., Schooler, S., Carson, C., Prickett, J., & Randall, A. (2019). Dataset for Status of the European Green Crab, Carcinus maenas, in Oregon and Washington coastal Estuaries in 2018 (Version 1) [Data set]. Oregon State University. https://doi.org/10.7267/tt44pt057

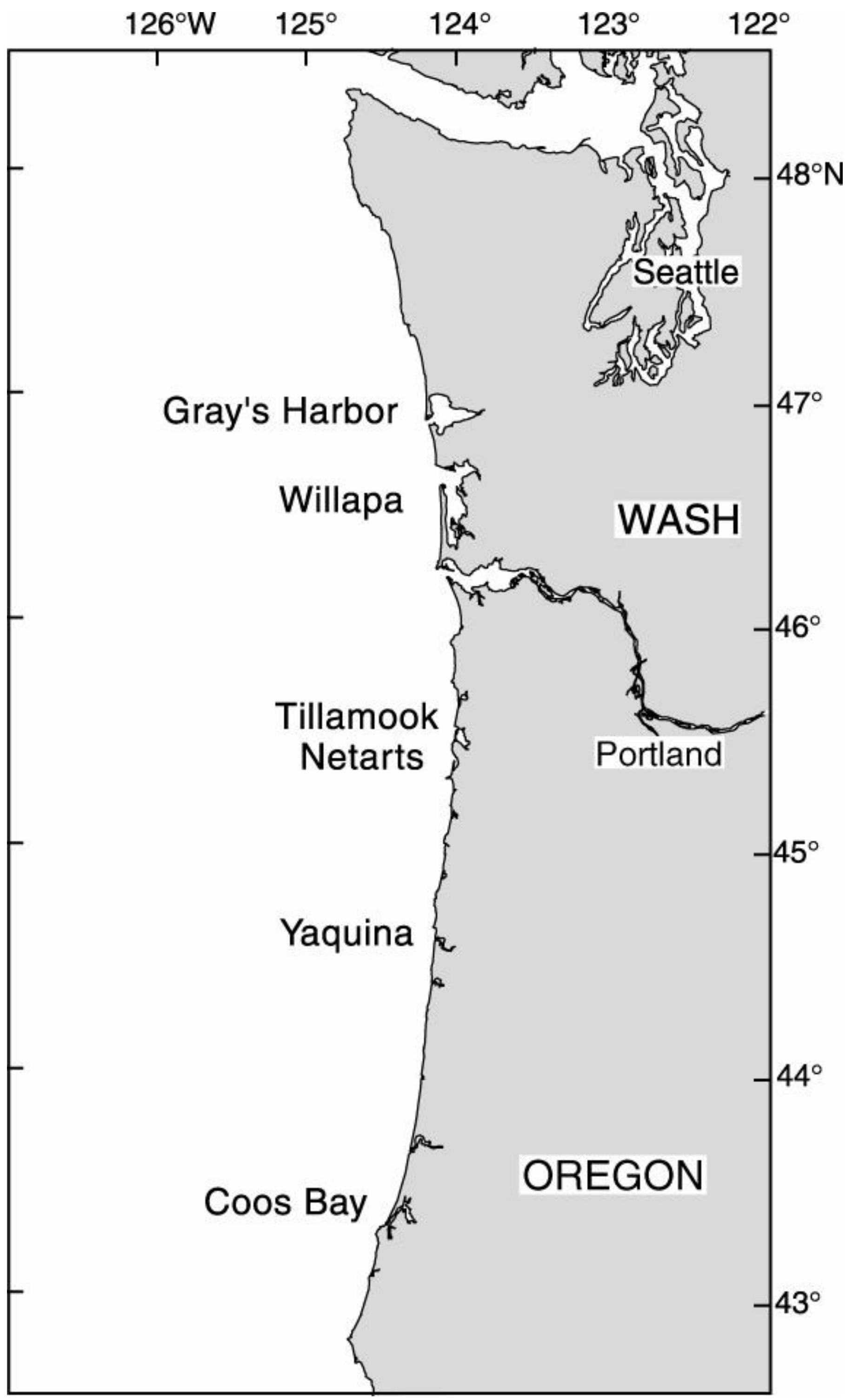
126°W
125°
124°
123°
122°
48°N
47°
46°
45°
44°
43°
Seattle
Gray's Harbor
Willapa
WASH
Tillamook
Netarts
Portland
Yaquina
Coos Bay
OREGON

Figure 1. Major sampling sites in Oregon and Washington coastal estuaries.
Data from the Makah, Nehalem, Alsea and Coquille estuaries were included in 2018 and 2018.

Table 2a. *Carcinus maenas* trapping results for study sites in Oregon and Washington coastal estuaries from 2002 to 2018. Number of crabs caught are given in the first line and (number of traps deployed) in second line. Data for Grays Harbor 2002 and Willapa Bay 2002-2003 and 2013 were kindly supplied by Washington Department of Fish and Wildlife. Supplemental data for Willapa Bay were supplied in 2004, by P. Sean McDonald and in 2016 by Washington Sea Grant- sponsored biologists: Sean McDonald, Emily Grason and Jeff Adams. Funding constraints did not allow us to sample Grays Harbor every year. Sightings for Grays Harbor were provided by Mark Ballo of Brady's Oysters, and for Willapa Bay, by Steve Shotwell of Elkhorn Oysters Company. Mary Sue Brancato from the Olympic Coast National Marine Sanctuary trapped for green crabs in Makah and Neah Bay from 2000 to 2003 and in 2007 and 2008, but did not catch any crabs. These early trapping efforts included both of these bays. *Trapping effort for Makah Bay is not included in the totals. See report by Akmajian and Halttunen 2019.

Estuary	***Number of crabs trapped over (number of traps deployed)***																
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Coos	9 (180)	14 (203)	18 (137)	9 (242)	22 (273)	52 (246)	65 (276)	18 (292)	6 (259)	18 (244)	41 (213)	12 (173)	3 (224)	26 (108)	445 (489)	1653 (676)	1280 (443)
Yaquina	26 (168)	63 (1084)	12 (461)	39 (290)	48 (211)	48 (231)	35 (227)	19 (162)	17 (211)	8 (110)	19 (149)	7 (65)	7 (147)	49 (78)	220 (200)	186 (95)	792 (132)
Netarts	0 (44)	11 (44)	12 (39)	52 (106)	47 (82)	35 (103)	17 (89)	13 (86)	14 (95)	19 (80)	5 (35)	0 (22)	31 (115)	49 (59)	62 (77)	77 (49)	187 (64)
Tillamook	2 (71)	6 (70)	4 (51)	12 (102)	41 (147)	15 (93)	1 (100)	0 (113)	2 (90)	0 (60)	5 (35)	0 (13)	20 (105)	28 (70)	66 (65)	65 (49)	92 (59)
Nehalem																13 (22)	3 (14)
Willapa	57 (1640)	13 (409)	6 (195)	113 (449)	19 (245)	4 (318)	0 (98)	0 (35)	2 (17)	0 (37)	0 (42)	0 (15)	0 (43)	8 (20)	7 (122)	9 (21)	13 (20)
Grays Harbor	5 (1203)	--	--	2 (94)	3 (175)	0 (30)	--	0 (20)	--	--	-	-	-	present	present	present	present
Makah Bay	0* (9)	0* (4)	0* (6)			0* (13)	0* (30)								present	34* (158)	922* (2245)
Total	99 (3306)	107 (1810)	52 (883)	228 (1283)	180 (1133)	154 (1021)	118 (692)	50 (708)	41 (672)	45 (530)	70 (453)	19 (288)	61 (634)	160 (335)	800 (963)	2003 (912)	2305 723

Table 2b. Relative abundance of *Carcinus maenas* for study sites in Oregon and Washington coastal estuaries. Number of crabs per trap calculated from Table 2a. was multiplied by 100 and expressed as number of crabs per 100 trap-days. *Makah Bay was not included in calculating the total. See report by Akmajian and Halttunen 2019.

Estuary	***Number of crabs trapped per 100 traps per day***																
	2002	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Coos Bay	5	7	13	4	8	**21**	**24**	6	2	7	19	7	1	**24**	**91**	**245**	**289**
Yaquina	15	6	3	13	**23**	**21**	15	12	8	7	13	11	5	**63**	**110**	**195**	**600**
Netarts	0	**25**	**31**	**49**	**57**	**34**	19	15	15	**24**	14	0	**27**	**83**	**81**	**157**	**292**
Tillamook	3	9	8	11	**28**	**16**	1	0	2	0	14	0	13	**40**	**102**	**133**	**159**
Nehalem																**59**	**21**
Willapa	3.5	3	3	**25**	8	1	0	0	12	0	0	0	0	**40**	6	**43**	**65**
Grays Harbor	0.4	-	-	**2**	2	0	-	0	-	-	-	-	-	present	present	present	present
Makah Bay	(0)*	(0)*	(0)*			(0)*	(0)*								present	(21)*	(41)*
Average	3	6	6	18	16	15	17	7	6	8	15	7	10	**48**	**83**	**223**	**319**

Results

***Carcinus maenas* Abundance in Oregon Estuaries**

The relative abundances of green crabs trapped in Oregon and Willapa Bay, Washington in 2018 are tabulated in Appendix 1 and summarized in Table 2. Catches of green crabs in Oregon and Washington estuaries decreased after the 1998 colonization event when catch per unit effort (CPUE) ranged from 0.3 to 1.9 green crabs per trap. Between 2002 and 2014 average catches had dropped below 0.5 per trap (Table 2, Figure 2). Slight increases in catches reflect recruitment events in 2003, 2005, 2006, 2010 (Figure 3). The steady increase in catches between 2015 and 2018 can be attributed to the arrival of four strong year classes (Figure 3).

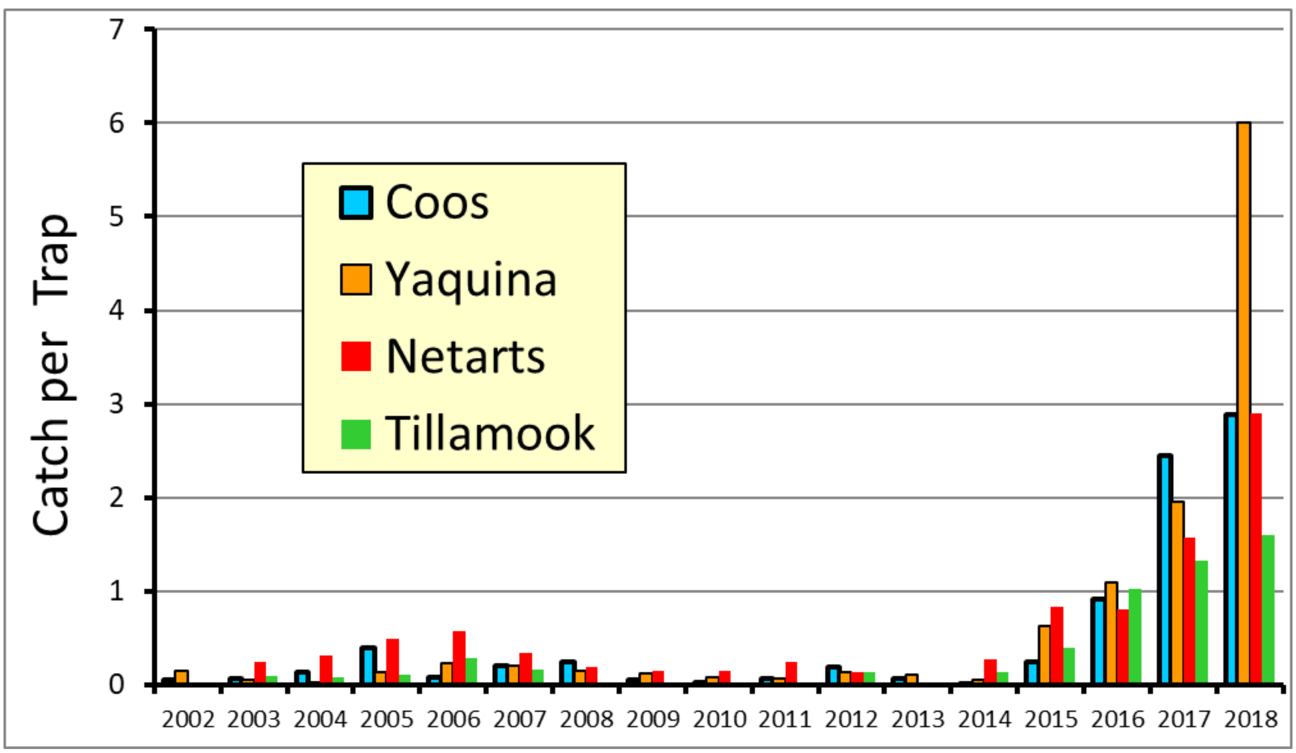

Figure 2. Average Number of *Carcinus maenas* caught per trap-day in Oregon estuaries from 2002 to 2018.

Recruitment strength of Young-of-the-Year <u>Carcinus maenas</u>

Young-of-the-year (YOTY), or 0-age, green crabs typically enter minnow traps once they reach ~30 mm in carapace width in late summer and fall. As can be seen from Figure 3 and Appendix 3, the appearance of 0-age green crabs is synchronous between estuaries. A good year, (or a poor year) in one estuary is a good (poor) year in all the others. In 1998, 0-age green crabs in Oregon and Washington averaged around 100 per 100 traps. The years between 1999 and 2014 exhibited low, or no recruitment to the population, with the exception of moderately strong year classes in 2003, 2005, 2006 and 2010. From 2015 to 2018, four strong year classes recruited to all the estuaries, with catches of similar size to those of the 1998 year class (Figure 3).

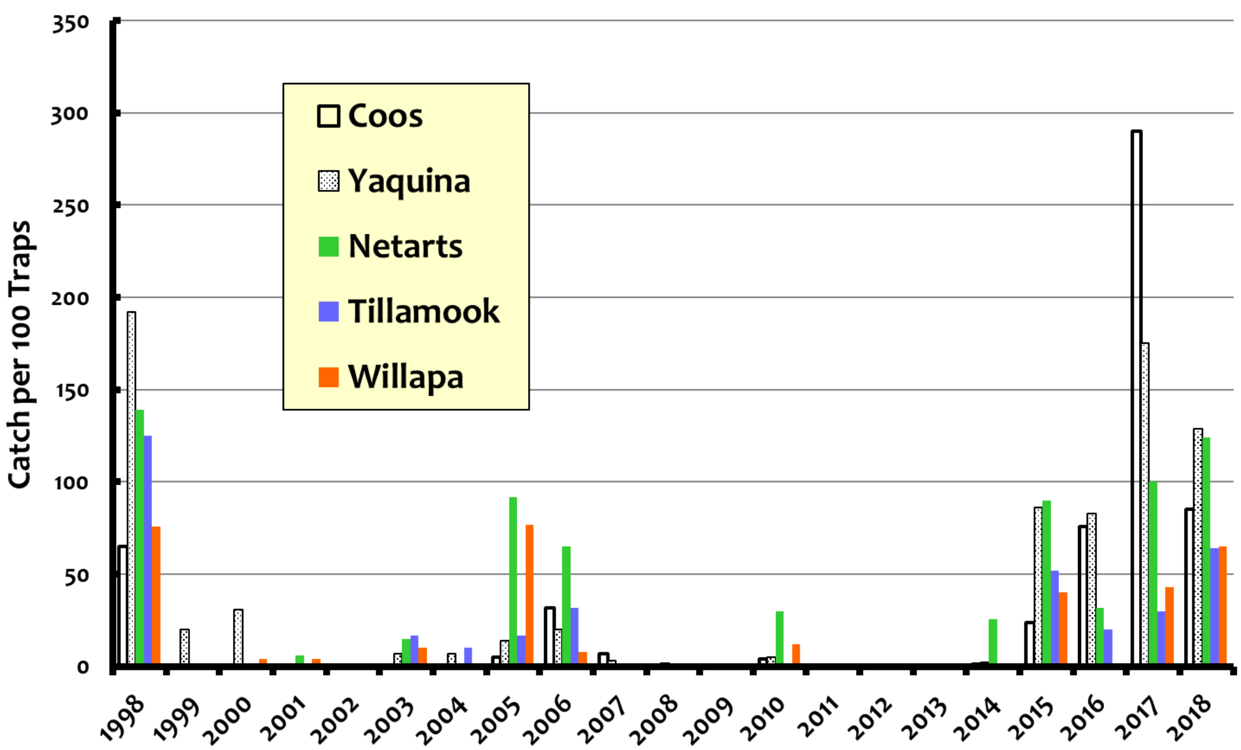

Figure 3. Average number of 0-age, or "Young-Of-The-Year" *Carcinus maenas* caught in the high marsh vegetation with crayfish traps at the end of the growing season. (PSMFC Data 2018)

Age Structure of <u>Carcinus maenas</u> in Oregon and Washington Estuaries

In previous years we were able to estimate the age structure of crabs based on a mark- recapture study, and from shifts in size frequency distributions over time (Behrens Yamada et al. 2005.) This was possible because typically only one strong year class appeared in the late summer-fall and it was easy to follow its size frequency distribution through the years. For example, during the summer, male crabs between 50- and 74-mm carapace width, and weighing less than 100 g, with green or yellow carapaces would represent the Age-1; crabs 75-84 mm and weighing >100 g, Age-2; and those >85 mm and weighing >150 mg, Age-3+. Crabs caught in the fall, ranging from 30 to 55 mm, were classified as Age 0. However, with the arrival of 4 strong, sequential year classes it is not possible to accurately separate the year classes because the size-frequency distributions overlap.

Ocean Conditions and Recruitment Strength of 0-age <u>Carcinus maenas</u>

The European green crab (*Carcinus maenas*) has a six-year life span and has persisted at low densities in Oregon and Washington coastal estuaries for the many years. After the arrival of the strong founding year class of 1998, measurable recruitment to the Oregon and Washington populations occurred only in 2003, 2005, 2006, 2010, 2015, 2016, 2017 and 2018. Warm winter water temperatures, high Pacific Decadal Oscillation, ENSO (El Niño Southern Oscillation Indices), weak southward shelf currents in March and April are all correlated with these stronger year classes. Cold winter water temperatures, low Pacific Decadal Oscillation Indices, and strong southward (and offshore) currents in March and April are linked to year class failure. (Behrens Yamada and Kosro 2010). Recently, we found that biological indices, used in salmon forecasting, can also predict green crab year class strength:
https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm
Southern copepod anomaly, northern copepod anomaly, copepod community structure, and the day when the plankton community shifts from being dominated by southern species to, northern species (day of biological transition) are especially good predictors (Behrens Yamada, Peterson and Kosro

2015). We are presently working on a paper that adapts William Peterson's stoplight graph and principal component critical ecosystem indices to predict green crab year class strength from ocean indices experienced by their larvae during their planktonic development in the late winter to early spring (Behrens Yamada, Fisher and Kosro, in preparation).

Discussion

Over 2,000 European green crabs were caught in Oregon and Willapa Bay, Washington during the 2018 trapping season, yielding an average catch rate of 3.4 crabs per trap. This catch rate is of the same order of magnitude as that observed in 1998 after the 1997/1998 El Niño.

While green crabs in Oregon and Washington are still rare, they are thriving in some inlets on the west coast of Vancouver Island. Average catches of over 20 crabs per trap are not unusual (Behrens Yamada and Gillespie 2008 and Gillespie et al. 2015). While these densities are surprisingly high, it should be noted that these hot spots are confined to wave-protected shellfish beaches with freshwater outfall. Hunt and Behrens Yamada (2003), Jensen et al. (2007) and Claudio DiBacco (pers. com.) found that high densities of green crabs occur primarily in microhabitats where larger native crabs are rare or absent. In Oregon and Washington estuaries and in the inlets of the west coast of Vancouver Island, green crabs occur higher on the shore and in more marginal habitat than larger native crabs: *Metacarcinus magister* (Dungeness), *Cancer productus* (red rock), *Cancer antennarius* (brown rock crab) and *Cancer gracilis* (graceful crab). These larger native crabs are less tolerant of low salinity and high temperatures than green crabs and thus avoid these shallow, warm, low saline microhabitats. In the absence of competition and predation from these larger crabs, green appear to flourish.

Since green crabs live up to 6 years, a recruitment event is needed at least once every 6 years to keep the population from going extinct. Unfortunately, they have managed to persist (Figures 2, 3). While we have observed virtual recruitment failure in 2001, 2002, 2007, 2008, 2009, 2011, 2012 and 2013 the 2003, 2005, 2006, 2010, 2015, 2016, 2017 and 2018-year classes broke the cycle. The last four cohorts will keep producing larvae until 2024. While larvae can be transported north from established populations in Californian during favorable ocean conditions, there is also evidence for local production and transport of larvae from the north. During the winter of 2010 first instar zoea were sampled in plankton nets in Coos Bay (Alan Shanks, personal communication). However, it is not known what the relative contributions of these larval sources is and how it might change with ocean conditions and global warming. Carolyn Tepolt, a geneticist at the Woods Hole Oceanographic Institute, has evidence that larvae from a genetically distinct population on Vancouver Island have seeded estuaries to the south: Makah Bay, Tillamook and Netarts.

Right now, green crabs are still too rare to exert a measurable effect on the native benthic community and on shellfish culture in Oregon and Washington. The next few years are critical in determining whether green crabs can persist in Oregon and Washington coastal estuaries. Unfortunately, a weak El Niño is predicted for early 2019. (http://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/?enso_tab=enso-cpc_plume). Outreach efforts to educate the general public, boaters and shellfish growers about the dangers of transporting non-native Aquatic Nuisance Species (ANS) should continue. Such efforts could delay the spread of ANS in general, and could prevent the establishment of green crabs in the inland sea between Vancouver Island and the mainland, including Puget Sound and Hood Canal. While recently live green crabs have been discovered in the Washington Salish Sea (Grason et al. 2018, Behrens Yamada et al. 2017) these few individuals may not represent a breeding population. Once green crabs get established in this inland sea, they would spread very quickly as many suitable habitats, devoid of larger crabs and other predators, exist in shallow, warm bays near freshwater outfalls. Other non-native species such as the Japanese oyster, the manila clam and the purple varnish clam spread very rapidly throughout the inland sea as their larvae were retained and not carried out to sea during upwelling events (Behrens Yamada, et al 2017).

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Appendix 1. Relative abundance of crab species and sculpins (Numbers/trap/day) in Oregon and Washington coastal estuaries during 2018.

Coos Bay **Mean CPUE (Catch/trap/day)**

Site	Date	Trap Type	Zone	# *green*	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	Number Traps
Kentuck	5/3/18	minnow	Scirpus	11	1.1	1.1					0.6	10
N 43º 25.299'	9/26/18	minnow	Scipus/mudflat	27	0.675	0.03		0.003	2.45		0.225	40
W 124º 11.522'												
Big Cedar	6/30/2018	Fukui	mudflat	9	0.90	29.40	0.00	0.10	0.00	0.00	2.90	10
Big Cedar	7/6/2018	Fukui	mudflat	10	1.00	37.90	0.00	0.00	0.00	0.00	3.90	10
Big Cedar	7/20/2018	Fukui	mudflat	5	0.50	22.00	0.00	0.10	0.00	0.00	0.40	10
Big Cedar	8/5/2018	Fukui	mudflat	7	0.70	18.70	0.00	0.00	0.00	0.00	1.50	10
BLM Boat Ramp	7/12/2018	Fukui	mudflat	0	0.00	0.00	0.00	2.57	0.14	2.00	0.43	7
Coos History Museum	7/24/2018	Fukui	mudflat	209	23.22	0.00	0.00	0.00	0.00	0.22	0.33	9
Coos History Museum	7/26/2018	Fukui	mudflat	133	14.78	0.00	0.00	0.11	0.00	0.11	0.33	9
East Side Boat Ramp	7/25/2018	Fukui	mudflat	39	3.90	0.00	0.00	0.90	0.00	0.00	0.20	10
Hinch Bridge	6/30/2018	Fukui	mudflat	0	0.00	2.70	0.00	0.00	0.00	0.00	4.20	10
Hinch Bridge	7/6/2018	Fukui	mudflat	1	0.10	3.50	0.00	0.00	0.10	0.00	0.90	10
Hinch Bridge	7/20/2018	Fukui	mudflat	0	0.00	1.33	0.00	0.22	0.11	0.00	3.44	9
Hinch Bridge	8/5/2018	Fukui	mudflat	0	0.00	2.20	0.00	0.00	0.00	0.00	1.60	10
Indian Point 1	6/29/2018	Fukui	mudflat	33	3.30	0.40	0.00	3.70	0.30	0.00	4.90	10
Indian Point 1	7/5/2018	Fukui	mudflat	12	1.20	0.30	0.00	4.40	1.00	0.00	1.40	10
Indian Point 1	7/19/2018	Fukui	mudflat	28	2.80	0.10	0.00	7.90	7.30	0.00	0.30	10
Indian Point 1	8/4/2018	Fukui	mudflat	14	1.40	0.10	0.00	3.60	4.90	1.50	1.00	10
Indian Point 2	6/29/2018	Fukui	mudflat	0	0.00	0.00	0.00	0.90	0.00	1.90	0.50	10
Indian Point 2	7/5/2018	Fukui	mudflat	4	0.40	0.00	0.00	2.10	0.60	0.60	2.10	10
Indian Point 2	7/19/2018	Fukui	mudflat	8	0.80	0.00	0.00	2.50	0.10	2.00	0.10	10
Indian Point 2	8/4/2018	Fukui	mudflat	22	2.20	0.00	0.00	1.30	0.20	4.00	0.60	10
Isthmus Slough	7/12/2018	Fukui	mudflat	109	12.11	0.00	0.00	0.00	0.00	0.00	0.33	9
Joe Ney Slough	6/22/2018	Fukui	mudflat	30	3.00	4.60	0.00	0.00	0.00	0.00	2.10	10
Joe Ney Slough	6/28/2018	Fukui	mudflat	14	1.40	1.30	0.00	0.00	0.00	0.00	1.70	10
Joe Ney Slough	7/4/2018	Fukui	mudflat	41	4.10	3.60	0.00	0.00	0.00	0.00	2.00	10
Joe Ney Slough	7/18/2018	Fukui	mudflat	40	4.00	4.40	0.00	0.20	0.00	0.00	1.10	10
Joe Ney Slough	8/3/2018	Fukui	mudflat	70	7.00	3.30	0.00	0.70	0.40	0.00	1.10	10

Metcalf Marsh	6/27/2018	Fukui	mudflat	50	5.56	0.33	0.00	1.11	0.00	0.00	2.00	9
Metcalf Marsh	7/3/2018	Fukui	mudflat	47	4.70	0.70	0.00	0.30	2.20	0.00	4.60	10
Metcalf Marsh	7/17/2018	Fukui	mudflat	20	2.00	0.00	0.00	4.60	2.00	0.10	1.10	10
Metcalf Marsh	8/2/2018	Fukui	mudflat	15	1.50	0.00	0.00	1.00	8.80	0.00	2.80	10
Transpacific Ln. South	7/12/2018	Fukui	mudflat	22	4.40	0.20	0.00	0.20	0.40	0.00	0.20	5
Valino	6/28/2018	Fukui	mudflat	3	0.30	0.10	0.00	11.30	0.00	0.00	0.20	10
Valino	7/4/2018	Fukui	mudflat	2	0.20	0.40	0.00	5.80	0.40	0.00	0.90	10
Valino	7/18/2018	Fukui	mudflat	1	0.10	0.10	0.00	8.70	0.40	0.50	0.20	10
Valino	8/3/2018	Fukui	mudflat	1	0.10	0.20	0.00	8.80	1.50	0.90	0.50	10
Wilanch Creek	7/13/2018	Fukui	mudflat	42	4.20	0.10	0.00	0.10	0.00	0.00	0.80	10
Transpacific Lane South	5/2/18	Fukui	*Mid*	47	4.7							10
	5/2/18	Fukui	Mid	52	5.2			1.1				10
N 43º 26'34" W 124º 13'23"	5/2/18	Fukui	mid	31	3.1							10
Transpacific North	5/3/18	Fukui	*Mid*	45	4.5							10
Under 101 bridge	5/2/18	Fukui	*pools*	26	4.3							6
N 43º 25'58"												
W 124º 13'15"												
Total Number				1280								443

Yaquina Bay **Mean CPUE (Catch/trap/day)**

Site	Date	Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	Number Traps
Sally's Bend A	7/18/10	Fukui		67	11.1							6
	7/19/18	Fukui		68	11.6							6
	7/19/18	Fukui		67	11.1							6
N 44º 37.699'	8/30/18	Fukui		60	12							5
W124º 01.482'	8/31/18	Fukui		57	11.4							5
	9/1/18	Fukui		61	12.2							5

	8/27/18	Fukui		18	3							3
	8/28/18	Fukui		23	7.7							3
	11/17/2018	Minnow	*Upper vegetation*	28	1.87			0.13			0.2	15
HMSC Pumphouse *N 44º 37.408'* *W124º 02.576'*	4/9/2018	Fukui	mid	31	3.88	0.25		0.23				8
	6/6/18	Fukui	*mid*	84	10.5			0..25	0.25		9.13	8
Oregon Coast Aquarium Mudflat *N 44º 37.108'* *W124º 02.165'*	4/9/2018	Fukui	Tidal channel	15	1.88	0.25		0.25				8
	6/6/2018	Fukui	Tidal Cannel	99	12.3	1.13					1.6	8
	11/17/2018	Fukkui	Tidal Cahnnel	5	5			1	6			1
	4/9/2018	Minnow	Upper vegetation	3	0.3	1.7						10
	6/6/2018	Minnow	*Upper vegetation*	22	2.2	1.1					0.7	10
	8/29/2018	Minnow	*Upper vegetation*	20	2				0.25			10
	11/17/2018	Minnow	*Upper vegetation*	1	0.07	0.33						15
Total Number				792								132

Tillamook Bay

Mean CPUE (Catch/trap/day)

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	Number Traps
View Point *N 45º 32.623'* *W 123º 54.183'*												
	5/20/18	Fukui		8	2	0.25						4
	6/13/18	Fukui		20	3.33	0.17	0.33	0.5	0.17			6
	6/20/18	Fukui		13	2.17						0.17	6
	6/28/18	Fukui		12	2	0.33					0.17	6
	7/11/18	Fukui		10	2	1.4	1.2					5
	7/17/18	Fukui		15	1.5							10
Tillamook Spit B *N 45º 30.456'* *W 123º 56.615'*	9/11/18	Minnow		3	0.27	0.73					1.90	11
Pitcher Point	9/11/18	minnow		11	1.0	*1.27*					2	11

N 45º 30.365’ W 123º 56.508’												
Total Number				92	1.56							59

Netarts Bay **Mean CPUE (Catch/trap/day)**

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	Number Traps
Intersection *N 45º 24.865’ W 123º 56.064’*	5/16/18	Fukui		2	0.5	0.25	0.25	1.75				4
	5/23/18	Fukui		1	0.25	0.5		1.25				4
	6/2/18	Fukui		7	1.75			12.75	2			4
	6/12/18	Fukui		14	2.33			14	3		0.16	6
	6/29/18	Fukui		16	3.2			0.8		0.2		5
	7/6/18	Fukui		47	9.4	0.4		4			1.8	5
	7/12/18	Fukui		49	9.8	0.8	1.4	10.8	5.4		1.2	5
	7/19/18	Fukui		25	2.5	0.7	0.6	9.4	3.1	0.1	0.4	10
Whiskey Creek Salmon Hatchery *N 45º 23.670’ W 123º 56.214‘*	9/11/18	Minnow	*High marsh*	26	1.24	1.14					1.52	21
Total Number				187	2.92							64

Nehalem **Mean CPUE (Catch/trap/day)**

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	Number Traps
Nehalem State Park	5/21/18	Fukui		1	0.25	0.25		2				4
N45.7059	5/30/18	Fukui		1	0.25			3.25				4
W123.9329	6/19/18	Fukui		1	0.17			7.5	2.2			6
Total Numbers				3	0.21							14

Willapa Bay					**Mean CPUE (Catch/trap/day)**							
Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	Number Traps
Stackpole *N 46º 35.848'* *W 124º 02.195'*		Minnow	Edge vegetation	9	0.69	2.0	0	0.3	0.46	0	0.74	13
		Pit-fall	Edge and open mudflat	4	0.57	0.73	0	3.34	0	0	0	7
Total Number				13	0.65							20

Appendix 2. *Carcinus maenas*. Sightings of green crabs from Oregon and Washington coastal Estuaries in 2018. These were reported by agency personnel, shellfish growers and the general public. Crabs were assigned to year classes based on the size and condition attained by tagged crabs of known age (Behrens Yamada et al. 2005). Crabs that are green have molted recently, while red crabs have not molted for a long time, in some case well over a year. Missing limbs are numbered in sequence: R1= Right claw; R5= last leg on right side, L1= left claw, L5=last leg on left side. For trapping results see Excel Files: ***Green_Crab_Data_2018.csv*** For more detailed sightings for Willapa Bay and Grays Harbor see Buffington et al. 2019.

Estuary	Site	Date	Sex	Carapace Width (mm)	Weight (g)	color	Year class	Missing limbs	comments	Collector
Chetco	At mouth	12/22/18	M	72		orange			Sports gear	Scott Groth, ODFW
Coquille	dock/Old Town Bandon	2/4/2018	M	53.8		green	2017			Dustin Risner, ODFW
Coquille	dock/Old Town Bandon	2/4/2018	M	64.3		Green-red	2016/2017			Dustin Risner, ODFW
Coos	Charleston Bridge		U	~30			2017			Tony DAndrea, ODFW
Alsea	Public dock	5/18/18	M	80		Yellow-orange	2015/2016		Sports catch /mated pair	Mitch Vance, ODFW
Alsea	Public dock	5/18/18	F	51		Yellow-orange	2017	L1.2	Molted to 62 mm by 5/21 / mated pair	Mitch Vance, ODFW
ALsea	Public dock	6/3/18	M	92.8		Yellow-tan	2015		Sport trap	Elizabeth Perotti, ODFW
Alsea	Public Dock	6/11/18	M	80		Yellow-white	2015/2016		L1/ barnacles	Elizabeth Perotti, ODFW
Alsea	Public dock	6/11/18	M	71		Yellow-white	2016		barnacles	Elizabeth Perotti, ODFW
Alsea	Public dock	8/9/18	M	76		Orange	2016			Mitch Vance ODFW
Alsea	Public dock	8/9/18	M	55		Yellow	2017			Mitch Vance ODFW
Alsea	Public dock	8/9/18	F	58		Olive green	2017			Mitch Vance ODFW
Alsea	Public dock	8/9/18	F	56		orange	2017			Mitch Vance ODFW
Yaquina	Sawyer's Landing	6/12	F	83		Orange/pink				Nathaniel Lewis, EPA

Yaquina	Sawyer's Landing	6/12	F	72		orange				Nathaniel Lewis, EPA
Yaquina	HMSC/EPA	6/12	M	47		Yellow-green	2017			Nathaniel Lewis, EPA
Nehalem	Jetty fishery	4/23/2018	M	78		green	2016		Sports catch	J.Lawonn; ODFW
Nehalem	Jetty fishery	4/23/2018	M	60		Yellow-orange	2016		Sports catch	J.Lawonn; ODFW
Willapa Bay	½ mile N of Goose Pt. N 46° 33.227 W 124° 59.976	4/24/ 2018	M	40.7		Light yellow			On Concrete pier by nursery	Richard Wilson Bay Center Farms
Willapa Bay	½ mile N of Goose Pt.	4/28/2018	F	38.4		Orange-green			On Concrete pier by nursery	Richard Wilson Bay Center Farms
Willapa Bay	Between Stoney Point and Wilson	5/4/2018	F	44.5		Orange with EGGS			From oyster bed	Richard Wilson Bay Center Farms
Willapa Bay	Neham	8/21/18	M	74			2017			Zachary Forster WDFW
Willapa Bay	Neham	7/10/18	F	48			2018			Zachary Forster WDFW
Willapa Bay	Grassy Island	7/10/18	F	68			2017		Dredged -subtidal	Zachary Forster WDFW
Grays Harbor	Brady's Oysters	March 2018	M	28		Orange-yellow	Late 2017			Mark Ballo
Grays Harbor	Brady's Oysters	April 25	M	60		Light green	2017			Mark Ballo
Grays Harbor	Brady's Oysters	April 25	M	58		Yellow-orange	2017			Mark Ballo
Grays Harbor	Brady's Oysters	May 8	F	50		Orange	2017	Eggs	Seed pallet	Mark Ballo
Grays Harbor	Brady's Oysters	May 8	F	50		Orange	2017	eggs	Seed pallet	Mark Ballo
Grays Harbor	Brady's Oysters	May 8	F	49		Orange	2017		Seed pallet	Mark Ballo
Grays Harbor	Brady's Oysters	May 8	M	55		Green	2017		Seed pallet	Mark Ballo
Grays Harbor	Brady's Oysters	May 8	F	30		Yellow-orange	2017		Seed pallet	Mark Ballo
Grays Harbor	Brady's Oysters	May 8	M	81		orange	2015 /2016		Seed pallet	Mark Ballo
Grays Harbor	Brady's Oysters	May 23	F	44		orange	2017		Harvest basket	Mark Ballo
Grays Harbor	Brady's Oysters	May 26	F	50		orange	2017		See pallet	Mark Ballo
Grays Harbor	Brady's Oysters	May 26	F	58		orange	2017		Seed pallet	Mark Ballo
Grays Harbor	Brady's Oyster	June 6	F	50		orange	2017		Harvested oysters	Mark Ballo
Grays Harbor	Brady's Oyster	June 7	F	61		orange	2016		Harvested oysters	Mark Ballo
Grays Harbor	Brady's Oysters	June 15	F	77		orange	2015/2016	eggs	1.5 ft level	Mark Ballo
Grays Harbor	Brady's Oysters	June 19	M	90		Beige	2015			Mark Ballo
Grays Harbor	Brady's Oysters	June 27	F	45		Green	2017		Harvest basket	Mark Ballo

Grays Harbor	Brady’s Oysters	June 27	F	55		Orange	2017		Harvest basket	Mark Ballo
Grays Harbor	Brady’s Oysters	July 12	F	55		Orange	2017			Mark Ballo
Grays Harbor	Brady’s Oysters	July 12	M	63		green	2017			Mark Ballo
Grays Harbor	Brady’s Oysters	Sept 26	M	97		orange	2015			Mark Ballo
Grays Harbor	Brady’s Oysters	Sept 26	M	79		orange	2016			Mark Ballo
Grays Harbor	Brady’s Oysters	Oct 9	M	80		Yellow-beige	2016			Mark Ballo
Grays Harbor	Brady’s Oysters	Oct 23	M	80		orange	2016			Mark Ballo
Grays Harbor	Brady’s Oysters	Oct 23	F	60		orange	2017			Mark Ballo
Grays Harbor	Brady’s Oysters	Oct 28	F	60		Orange	2017		Seed holding area	Mark Ballo
Grays Harbor	Brady’s Oysters	Dec 31	F	67			2016.2017	eggs		Mark Ballo

Appendix 3. Relative abundance (CPUE) and size of young-of-the-year *Carcinus maenas* at the end of their first growing season in Oregon and Washington estuaries. Crabs were typically caught between mid-August to early October. Catch per unit effort (CPUE) is reported as number of crabs per trap per day. N=number of young crabs sampled; SD=Standard Deviation, Water temperatures for December-March for the Hatfield Marine Science Center Pump Dock in Yaquina Bay were provided by David Specht of the Newport EPA; those for Willapa Bay, by Jan Newton and Judah Goldberg of the DOE.

Year Class	Estuary	# Months <10ºC	Mean Winter Temp. ºC	N	CPUE Pitfall traps	CPUE Minnow traps	Mean Carapace Width (mm)	SD	Range
2002	Coos	4	9.6	0		0.00			
2003		**0**	**10.9**	1		0.01	59.4		
2004		**1**	**10.4**	0		0.00			
2005		**2**	**10.3**	2		0.05	45.0		44-46
2006		2	9.9	17		**0.32**	43.5	4.6	36-52
2007		3	9.8	5		0.08	45.4	4.0	43-52
2008		5	8.8	1		0.01	47.0		
2009		4	9.0	0		0.00			
2010		**1**	**10.0**	2		0.04	40.7		40-41
2011		1	9.8	1		0.01	35.5		
2012		4	8.7	0		0.00			
2013		3	9.6			Not Sampled			
2014				2		0.015	46.5		45-47
2015				26		**0.24**	47.9	4.9	32-54
2016				52		**0.76**	37.1	4.9	26-52
2017				87		**2.90**	35.7	5.4	22-52
2018				24		**0.85**	35.8	8.8	23-51
1998	Yaquina	**0**	**11.2**	201		**5.00**	46.9	5.0	32-60
1999		4	8.8	13	**0.20**		38.0	5.0	30-47
2000		3	9.7	14		**0.31**	37.5	5.0	30-45
2001		3	9.6	Not sampled					
2002		4	9.4	1		0.01	38.9		
2003		**0**	**11.0**	9		0.07	44.9	5.5	41-59
2004		**3**	**10.1**	4		0.07	35.3	5.1	32-43
2005		**2**	**10.1**	21	**0.75**	0.14	41.0	8.4	28-46

2006		3	9.8	18		**0.20**	42.6	5.9	34-51
2007		3	9.5	3		0.03	44.4	7.0	36-49
2008		5	8.4	1		0.02	44.3		
2009		5	8.9	0		0.00			
2010		**1**	**10.1**	8	0.05	0.05	40.8	6.7	30-50
2011		4	9.3	0		0.00			
2012		4	8.7	0		0.00			
2013			9.6	0		0.00			
2014			9.2	2		0.02	45.9		42-49.5
2015				43		**0.86**	44.6	4.8	35-54
2016				30		**0.83**	36.9	7.4	26-53
2017				70		**1.75**	39.1	11.8	17-56
2018				37		**1.29**	46.4	7.2	16-54
2002	Netarts			0		0.00			
2003				6		0.15	49.4	3.7	45-55
2004				0		0.00			
2005				25		**0.92**	42.9	5.3	30-53
2006				21		**0.65**	38.6	5.3	29-50
2007				0		0.00			
2008				0		0.00			
2009				1		0.02	47.7		
2010				6		**0.30**	44.7	5.6	37-51
2011				0		0.00			
2012				0		0.00			
2013				0		0.00			
2014				18		0.257	43.6	3.9	33-50
2015				36		**0.90**	46.3	5.4	38-56
2016				16		**0.32**	34.5	5.2	24-44
2017				33		**1.00**	36.7	5.4	25-50
2018				23		**1.24**	33.6	6.5	23-50
2002	Tillamook			0		0.00			
2003				5		0.17	50.0	3.1	46-55
2004				2		0.10	41.0		37-45

2005				10		0.17	47.8	4.5	42-56
2006				31		**0.32**	40.7	4.4	31-51
2007				0		0.00			
2008				0		0.00			
2009				0		0.00			
2010				0		0.00			
2011				0		0.00			
2012				0		0.00			
2013				0		0.00			
2014				1		0.015			
2015				26		**0.52**	49.2	4.1	44-60
2016				8		**0.20**	45.3	5.3	36-52
2017				11		**0.30**	45.2	7.9	27-57
2018				12		**0.64**	40.1	4.2	35-50
1998	Willapa	3	8.9	47	**0.778**	**0.74**	45.9	4.0	37-55
1999		4	7.6	3	0.023	0.00	38.2	7.5	32-47
2000		4	8.0	9	0.046	0.03	43.4	12.0	19-58
2001		5	8.0	7	0.046	0.02	51.3	2.7	48-56
2002		4	7.6	0	0.00	0.00			
2003		3	9.0	10	0.167	0.00	48.3	5.1	43-59
2004		5	8.6		Not sampled				
2005		3	9.0	106	**0.37**	**1.17**	46.1	3.3	34-52
2006		5	8.3	5	0.04	0.13	42.5	5.1	35-49
2007		5	8.4est	0	0.00	0.00			
2008		5	7.7est	0	0.00	0.00			
2009		5	7.2	0	0.00	0.00			
2010		3	8.9	2	**0.40**	0.00	43.8		43- 44
2011		5	7.8	0	0.00	0.00			
2012		5	7.7	0	0.00	0.00			
2013		5	8.1	0	0.00	0.00			
2014				0	0.00	0.00			
2015				8	**1.00**	0.20	43.1	4.5	35-47
2016					0	0			

2017				9	0	**0.43**	41.3	6.1	32-50
2018				10		**0.64**	46.5	7.8	37-56
1998	Grays Harbor			3		**1.00**	45.3	5.0	40-50
1999				24		0.02	37.4	7.7	34-51
2000				3		0.01	41.3	6.5	35-48
2001				1		0.01	47.9		
2002				0		0.00			
2003							Not sampled		
2004							Not sampled		
2005				2		0.03	47.3		44-50
2006				1		0.02	49.0		
2007				0		0.00			
2008							Not sampled		
2009				0		0.00	Not sampled		
2010							Not sampled		
2011							Not sampled		
2012							Not sampled		
2013							Not sampled		
2014							Not sampled		
2015							Not sampled		
2016							Not sampled		
2017							56.8	2.0	55-60
2018									
2017	Makah Bay			16			45.6	9.6	24-57
2018									