Status of the European Green Crab, *Carcinus maenas*, in Oregon and Washington coastal Estuaries. Report for 2020 and 2021

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Shon Schooler is maintaining a data base on sex, size, weight etc. of individual crab caught in the five estuaries from 2002 to the present. He can be contacted at shon.schooler@state.or.us

Executive Summary

The European green crab (*Carcinus maenas*) has persisted in Oregon and Washington coastal estuaries since the late 1990s. A strong year class arrived in the Davidson Current during the 1998 El Niño, but numbers decreased and remained below 1 per trap per day until the arrival of the 2015-2016 El Niño. Ocean indices indicate that California was the predominate source of larvae prior to the 2015-2016 El Niño (Behrens Yamada &Kosro, Behrens Yamada, Peterson & Kosro, 2015). Since then, numbers have increased steadily to an average of around 6 crabs per trap per day for Yaquina and Coos estuaries, with maximums of up to 25- 28 per trap**.** Measurable ecological impact is predicted to occur around 10 per trap (Grosholz et al. 2011). Between the two El Niños recruitment of young green crabs to these estuaries was sporadic with many years of recruitment failure. But since 2015 recruitment has been good every year. Since green crabs live for 6 years, these recent strong year classes can produce larvae until 2027. Evidence suggests that the Davidson Current transporting larvae from California during the winter is no longer the only source of larvae for our coastal estuaries (Behrens Yamada, Fisher and Kosro 2021). Now that populations in Oregon, Washington and British Columbia have built up, we have evidence for local production and for larvae sources from a genetically distinct population on Vancouver Island (Alan Shanks and Carolyn Tepolt, personal communication). The current cooler ocean conditions could hold recruitment in check, but a return to high PDO and strong El Niño patterns would signal good recruitment and higher green crab densities.

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 European green crabs. It could serve as a model for the spread of other non-indigenous species with planktonic larvae.
2) To predict the arrival of strong year classes from ocean conditions and to alert managers and shellfish growers of possible increases in predation pressure from this invader.

Outreach Activities by Sylvia Behrens Yamada in 2021

Date	Talks / Outreach Activities in 2021	Location
January 14, 2021	Hatfield Marine Science Center Research Seminar: European Green crabs in Oregon: are they now established? Virtual seminar	Hatfield Marine Science Center, Newport, Oregon
April 5, 2021	Dr. Sally Hacker's Marine Biology Class (BI 450): European Green crabs in Oregon: are they now established? Virtual talk	Hatfield Marine Science Center, Newport, Oregon
April 22, 2021	Oregon State University Triad Club: Virtual talk,	Oregon State University Corvallis, Oregon
April 23 and 24, 2021	Two Virtual talks	Pacific Estuarine Research Society;
April 26, 2021	Itchung Cheung' Environmental Science 299 Class	Virtual via Hatfield Marine Science Center, Newport
June 2021	Sylvia Behrens Yamada, Graham E. Gillespie, Richard E. Thomson, Tammy C. Norgard 2021a. Ocean indicators predict range expansion of an introduced species: Invasion history of the European green crab *Carcinus maenas* on the North American Pacific Coast.	Published in J. of Shellfish Research, 40(2):399-413 (2021). https://doi.org/10.2983/035.040.0212 .
August 2021	Sylvia Behrens Yamada, Jennifer L. Fisher, P. Michael Kosro 2021b. Relationship between ocean ecosystem indicators and year class strength of the invasive European green crab (*Carcinus maenas*)	Published in Progress in Oceanography 196, August 2021, 102618 https://doi.org/10.1016/j.pocean.2021.102618
Submitted May 2021	Sylvia Behrens Yamada, Alan L. Shanks, Richard E. Thomson 202_. "Can the duration and timing of planktonic larvae contribute to invasion success?" A case study comparing range expansion in *Carcinus maenas* and *Pachygrapsus crassipes*".	Accepcted by Biological Invasions April 25, 2022
October 13-14, 2021	Green crab trapping demonstration for Stephanie Austin's Science class, Eddyville Charter School	Sally's Bend, Newport, Oregon
November 3, 2021	FW 426 – Coastal Ecology and Resource Management	Virtual talk to Scarlett Arbuckle's class at HMSC
December 1, 2021	Interview on the increase in abundance of European green crabs in Oregon. Oregon Department of State Lands	Jefferson Public Radio

Introduction

European green crabs (*Carcinus maenas)* made their way to the east coast of North America in sailing ships in the early 1800s (Say 1817). They arrived in San Francisco Bay during the 1980s, 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, on Haida Gwaii, and in the Salish Sea between Vancouver Island and the mainland (Behrens Yamada et al. 2021a; 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. 2010a). 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 (Lafferty and Kuris 1996, Jamieson et al. 1998, Behrens Yamada et al. 2010a).

On the West Coast, the northward range expansion and abundance of green crabs is linked to favorable ocean conditions for larval transport (Behrens Yamada et al. 2021a, 2021b). Warm temperatures and strong northward moving coastal currents, especially during El Niño events, are correlated with range expansions and the appearance of strong cohorts of young green crabs in Pacific NW estuaries (Behrens Yamada & Gillespie 2008; Behrens Yamada & Kosro 2010, Behrens Yamada et al. 2015, 2021a, 2021b).

Goals

Sampling of the estuaries during the Covid pandemic in Oregon estuaries was reduced, with the exception of Coos Bay (Shooler et al. 2021). The main focus for the other estuaries was to focus on documenting the recruitment of Age-0, or young-of-the-year (YOTY) crabs. We followed the abundance and size frequency distribution of young-of-the-year European green crab during their first growing season in four Oregon estuaries and Willapa Bay, Washington and simultaneously sampled all 5 estuaries during the same week in early fall. This was accomplished by setting crayfish (minnow) traps and pitfall traps in the high intertidal zone and measuring and counting YOTY crabs, typically measuring ≤ 50 mm in carapace width and weighing ≤ 30 g.

The peaks of size frequency distributions can identify cohorts and shifts in size over time can be interpreted as growth. The abundance of YOTY green crabs in the fall can be correlated with inter annual variation in winter ocean temperature and currents patterns during their larval life. Larvae from the south are carried north by the warm Davison Current during the winter and crabs typically reach 30-53 mm in carapace width by the fall. Larvae from the north would arrive after spring transition when currents from the north would transport them southward. Young crabs originating from local and northern sources would thus be expected to be smaller in the fall than those arriving from the south. Our ultimate goal is to identify patterns in these size distributions between years and between estuaries and to eventually relate these patterns to possible larval sources. Since 2016 we have been preparing crab samples for genetic analysis and sending them to Carolyn Tepolt of Woods Hole Oceanographic Institute. So far, she has determined that larvae originating from a genetically distinct population on Vancouver Island (Sooke Basin) have seeded Makah Bay Willapa Bay in Washington and Tillamook Bay and Netarts Bay in Oregon.

Sampling Methods for Green Crabs

Sampling of *Carcinus maenas* during 2020 and 2021 focused on (YOTY) crabs from Willapa, Tillamook, Netarts, Yaquina and Coos Bay (Figure 1). All Oregon estuaries were sampled at least twice during the 2020 and 2021 trapping seasons, with Coos Bay receiving additional sampling by biologists and interns from the South Slough National Estuarine Research Reserve (Schooler et al 2021). Willapa Bay was only sampled once at the Stackpole site for YOTY crabs in the fall. We selected study sites within various habitat types and tidal levels. Since green crabs are 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 12°-22° C in the summer (Behrens Yamada and Davidson 2002). Green crabs are noticeably absent or rare 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).

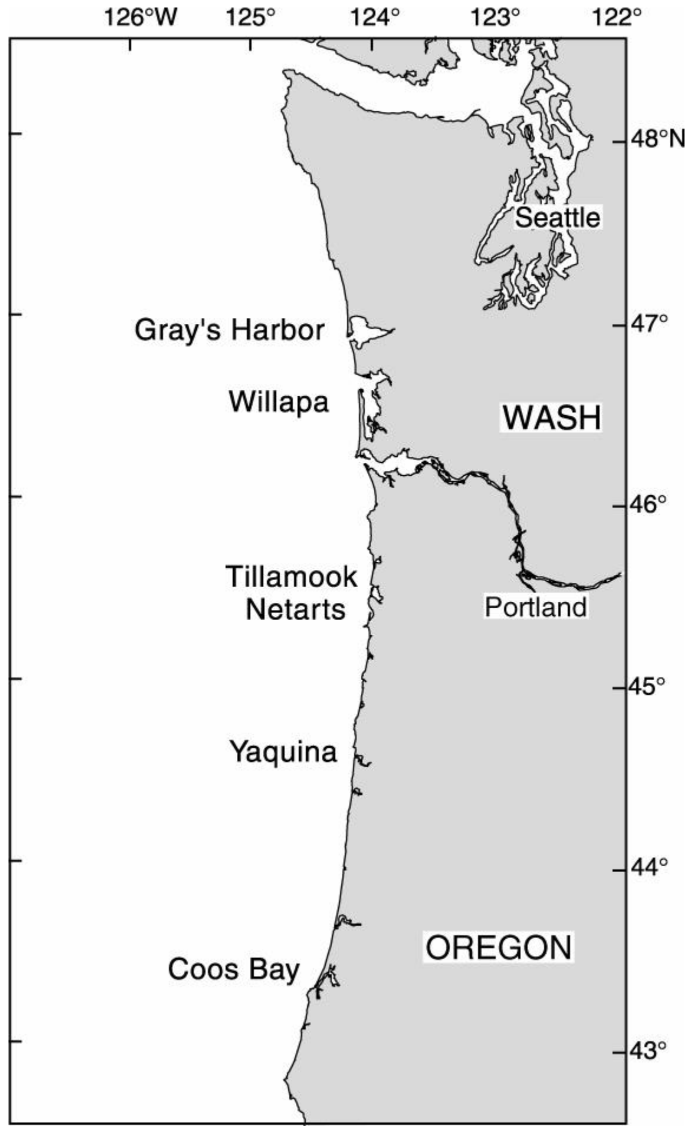


Figure 1. Major sampling sites in Oregon and Washington coastal estuaries.

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*. Traps differ in their sampling efficiency for different sizes of crabs (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 (minnow) traps with their small mesh size (0.5 cm) retain 0-age green crabs. Green crabs start entering these baited traps when they are ~ 25 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 and 2). In addition to these baited traps, we also set a few pitfall traps. The ones used in Willapa Bay are water-filled 5-gallon buckets buried into the sediment so that their rims are flush with the surface of the sediment. These traps thus catch any actively foraging crabs of any size. We tested a smaller version of pitfall trap in Netarts, Yaquina and Coos estuaries in 2019 and 2020. These consist of commercial size one gallon fruit or vegetable tin cans used in commercial kitchens. The goal for using these smaller pitfall traps was to target very small crabs. These traps were phased out in 2021 in Yaquina and Netarts because their catch rate was very low.

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 trap	Wire mesh (0.5 cm) cylinder with two openings expanded to 5 cm	21 cm diameter 37 cm long	Medium to high	25-70 mm
Pitfall trap, Willapa	Water-filled 5-gallon bucket embedded into the sediment	31 cm diameter 37 cm high	High	All sizes
Pitfall trap, Oregon	Large water-filled 1- gallon tin can embedded into the sediment	14.5 cm diameter 16.5 mm high	High	>6 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 ~24 hours later and identified and counted all crabs and other by-catch to species. The sex, carapace widths (CW) and molt stage (color of abdomen) of all green crabs were noted.

Green crabs were measured between the outside of their fifth anterio-lateral spines using digital calipers. Native crabs and other by-catch were counted and released while green crabs were removed from the ecosystem, frozen and donated to the Hatfield Marine Science Center aquarium for fish food.

Results

***Carcinus maenas* Abundance in the Pacific Northwest coastal estuaries**

The relative abundance of green crabs trapped in Oregon and Willapa Bay, Washington in for 2020 and 2021 are tabulated in Appendices 1 and 2 and summarized in Tables 2 and 3. Catches of green crabs in the estuaries decreased after the arrival of the 1997/1998 El Niño cohort. Between 2002 and 2014 average catches dropped below 1 per trap (Figure 2). Slight increases in catches reflect recruitment events in 2003, 2005, 2006, 2010 (Figure 3). Catches increased steadily after the 2015-2016 El Niño (Figure 2). These increases are directly attributed to the arrival of seven strong year classes (Figure 3). Catches in Fukui traps in Coos and Yaquina estuary in 2021 averaged around 6 per trap, slightly higher than those in three coastal Washington estuaries (Table 3).

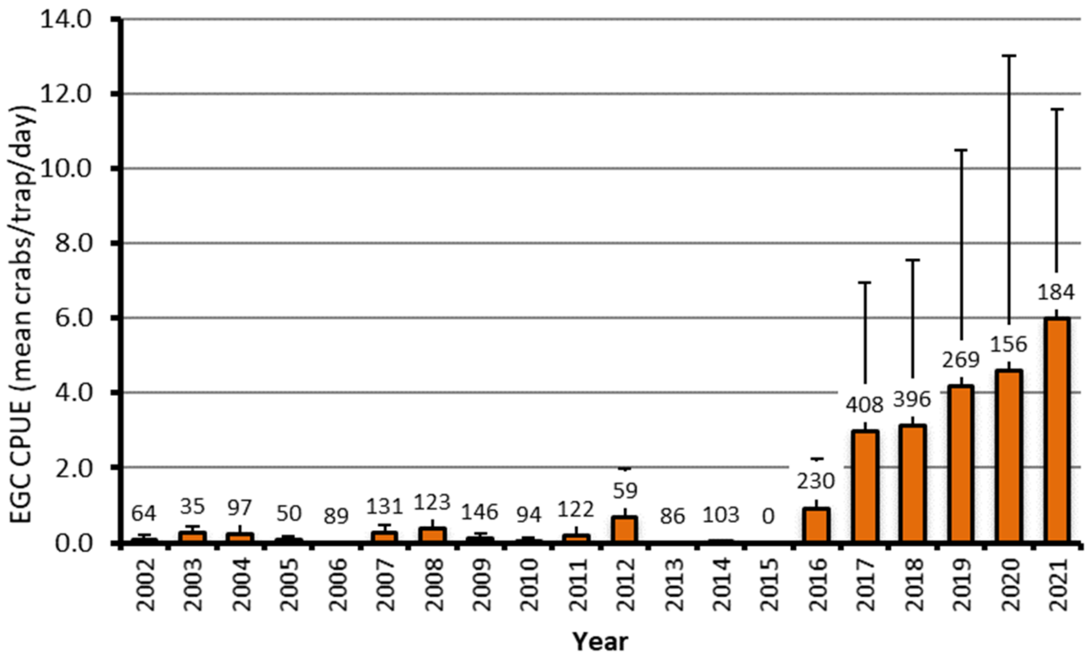


Figure 2. Relative abundance of adult *Carcinus maenas* captured in Fukui fish traps in Coos Bay estuary, expressed as average number per trap per day. Numbers above bars indicate # of traps. No Fukui traps were deployed in 2015. Other estuaries exhibited similar patterns.

Table 2. Comparison of *Carcinus maenas* trapping results for study sites in Oregon estuaries and Willapa Bay in 2020 and 2021 using crayfish and 5-gallon pitfall traps.

Estuary	**2020**			**2021**		
	# green crabs	# traps	*Catch per trap per day*	# green crabs	# traps	*Catch per trap per day*
Coos, Crayfish traps	99	24	4.13	239	122	1.96
Yaquina, Crayfish traps	131	98	1.34	190	215	0.88
Netarts, Crayfish traps	58	61	0.95	54	75	0.72
Tillamook, crayfish traps	86	54	1.59	70	75	0.93
Willapa, crayfish traps	21	12	1.75	16	10	1.6
Willapa, 5-gal pitfall traps	12	8	1.5	22	7	3.14
Total / average CPUE	407	257	1.58	591	504	1.17

Table 3 Catch per unit effort of *Carcinus maenas* trapping results for Oregon and Washington coastal estuaries in 2021 using mainly Fukui traps. Note that these data may not in their final form and do not include those crabs removed by hand. Since different trap types and methods were used, these data are not stricty comparable. Asterisks indicate data courtesy of Washington Department of Fish and Wildlife, Washington Sea Grant Crab Team, growers, and various partners (listed in the Acknowledgements) and compiled by Alex Stote.

Estuary	**2021**			
	# green crabs	# traps	*Average Catch per trap per day*	*Maximum Catch per trap per day*
Coos Fukui fish traps	1164	184	6.32	28
Yaquina Fukui fish traps	162	28	5.79	25
Willapa Bay, Shrimp, Fukui, crayfish traps	9007	2,520	3.57*	40
Grays Harbor, Shrimp, Fukui fish traps	2885	1381	2.09*	37
Makah Bay Shrimp traps	1,321	345	3.83	46

Recruitment strength of Young-of-the-Year Carcinus maenas

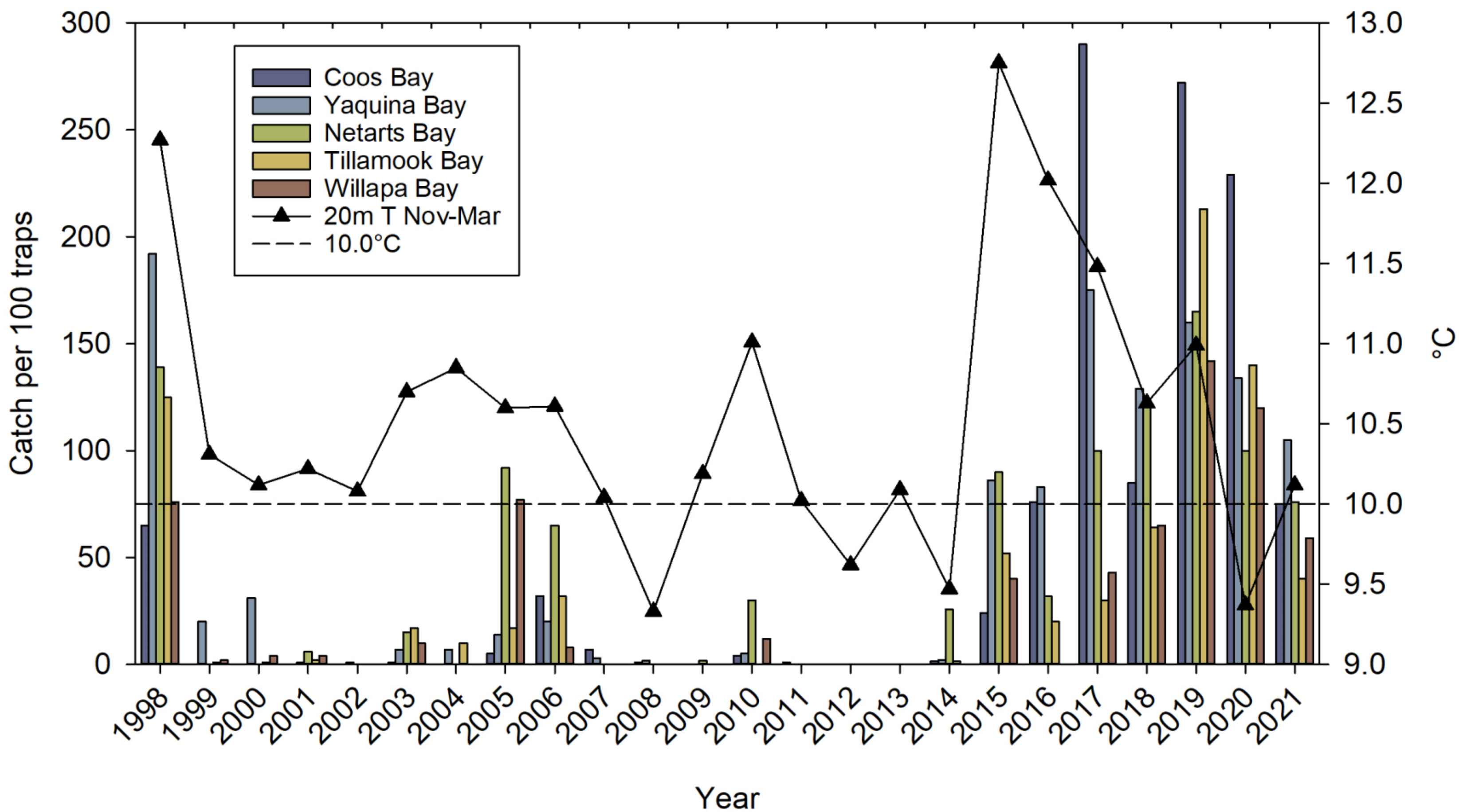
Young-of-the-year (YOTY), or 0-age, green crabs typically enter crayfish traps once they reach ~25 mm in carapace width in late summer and fall. As can be seen from Figure 3 and Appendix 3, the appearance of 0-age green crabs is synchronous between estuaries. A good year, (or a poor year) in one estuary is a good (poor) year in all the others. Note that winter water temperatures had to be above 10°C for a new year class to enter the population. In 1998, 0-age green crabs in Oregon and Washington coastal estuaries averaged around 100 per 100 traps. The years between 1999 and 2014 exhibited sporadic recruitment to the population, including years of recruitment failure and moderately recruitment in 2003, 2005, 2006 and 2010. From 2015 to 2021, strong year classes recruited to all the estuaries, with catches of similar size to those of the 1998-year class (Figure 3). Note that in 2020 and 2021 recruitment was good despite cool winter sea surface water temperature.

Age Structure of Carcinus maenas in Oregon and Washington Estuaries

Prior to 2017 we were able to estimate the age structure of crabs in the estuaries, based on their growth from a mark- recapture study, and from shifts in size frequency distributions over time (Behrens Yamada et al. 2005, 2021a.) This was possible because typically only one strong year class appeared every few years and it was easy to follow its size frequency distribution over time. 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 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 that were ≤50 mm, and weighing <30 g were classified as Age-0. With the arrival of 7 strong, sequential year classes, it is no longer possible to accurately assign year classes because the size-frequency distributions overlap. Since green crabs live for 6 years (Behrens Yamada et al. 2005), year classes 2016-2021 would have been present in the population in 2021.

Recruitment of O-Age Crabs

Figure 3. Relative Abundance of O-Age, or Young-of-the-Year, *Carcinus maenas* in coastal estuaries, expressed as average number per 100 trap per day. Superimposed is the mean winter surface water temperature (November to March) off Newport OR (NOAA Fisheries ocean ecosystem indicators for 2021). The stippled line indicates the critical water temperature of 10°C below which larvae cannot develop. Note that years 2020 and 2021 have higher recruitment than predicted by winter surface water temperature.



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

The European green crab has persisted in Oregon and Washington coastal estuaries for the past 24 years. From the arrival of the strong founding year class of 1998 to 2015, significant recruitment to the Oregon and Washington populations occurred only after warm winters such as in 2003, 2005, 2006 and 2010 (Figure 3). Regressions of year class strength of young green crabs against winter sea surface temperature and against southern copepod anomaly, (a proxy for northward transport of water masses) showed R^2 values of 0.61 and 0.69 respectively. This suggests that larvae were carried north from California in the warm Davidson Current (Behrens Yamada and Kosro 2010, Behrens Yamada et al. 2015 and top graphs in Figures 4 and 5). The predictive power of these ocean indicators, however, is much lower when the recent years 2016-2021 are included in the analysis (Behrens Yamada et al. 2021b). The correlations of these indices with green crab year class strength are still significant (bottom graphs of Figures 4 and 5), but the percent of variability explained by regression is halved. In other words, recruitment of young green crabs in 2018, 2019, 2020 and 2021 was higher than predicted from winter ocean surface water temperature and from the transport of water masses (and larvae) from the south.

<u>Discussion</u>

While green crabs in Oregon and Washington are increasing in abundance, they are not as abundant as in some of the inlets on the west coast of Vancouver Island, where average catches of over 20 crabs per trap is not unusual (Behrens Yamada and Gillespie 2008; Gillespie et al. 2015, Katie Gale, personal com.). 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 where larger adult 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 habitats than larger adult 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

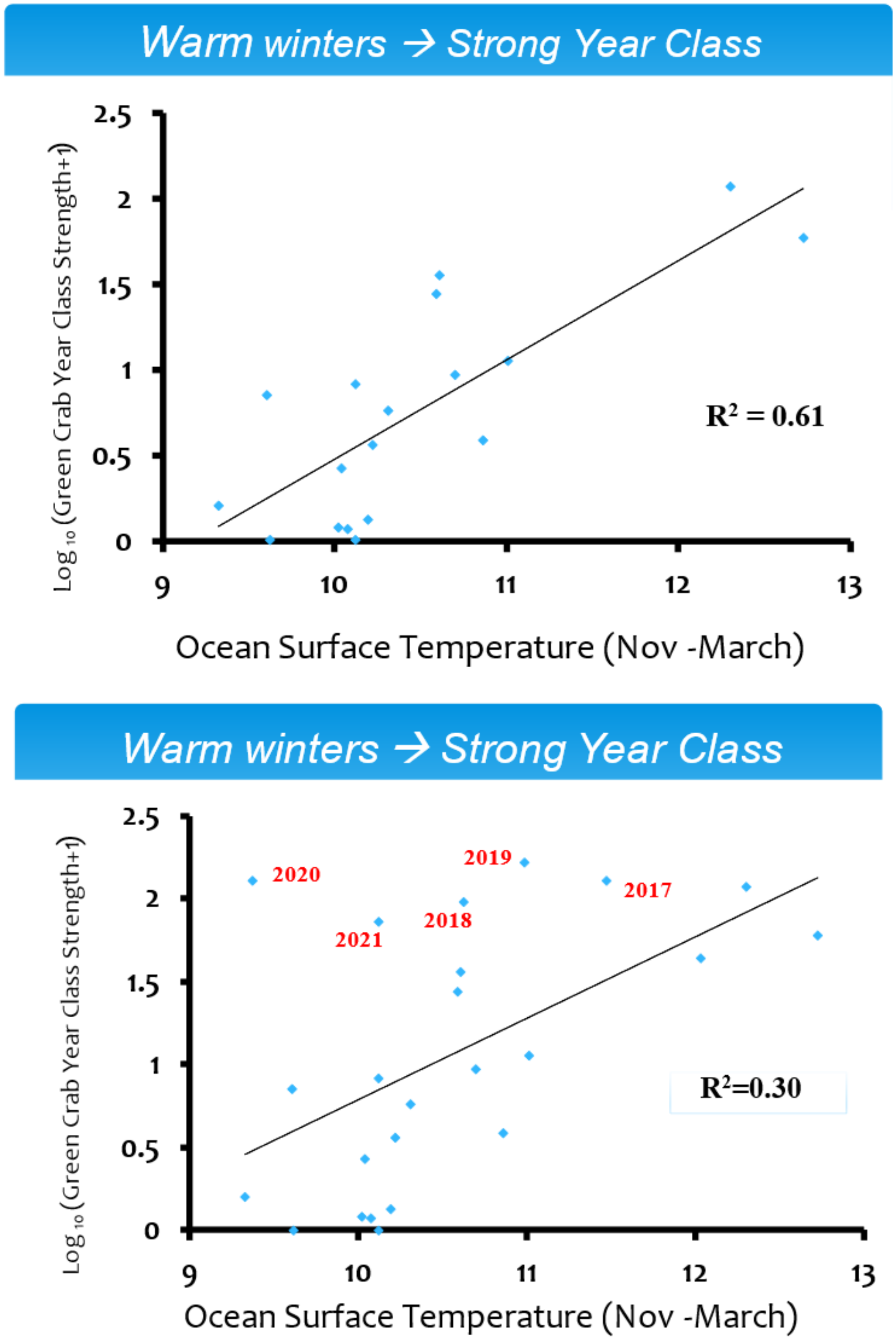
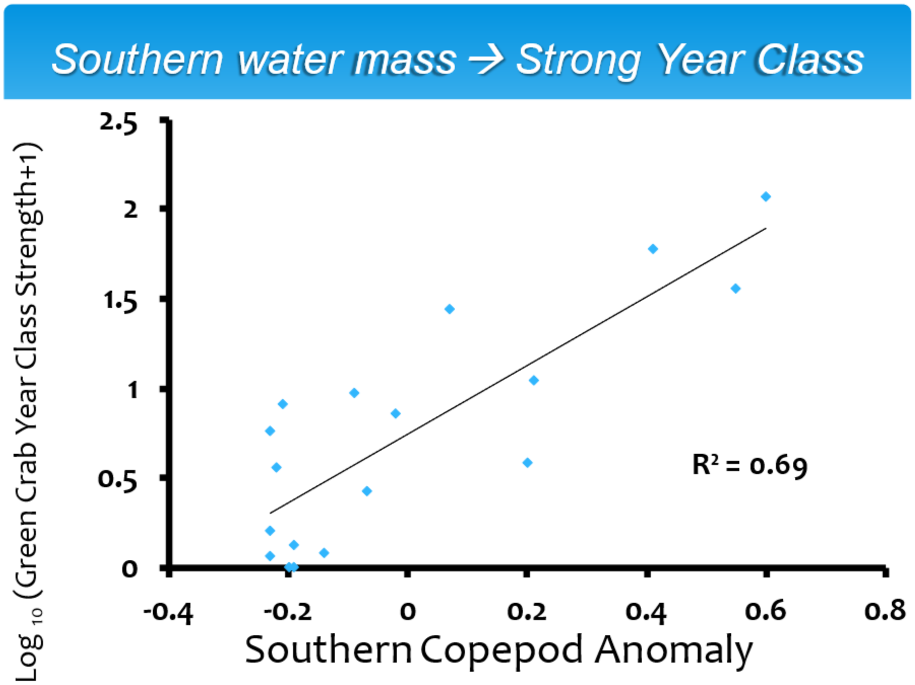


Figure 4. Regression of Carcinus maenas year class strength at the end of their first growing season against ocean surface temperature off Newport during the previous winter. From 1998-2015 (top) the R,^{2} or % of interannual variability explained by regression, was 61%. The addition of recent years brought the R^2 down to 30%.



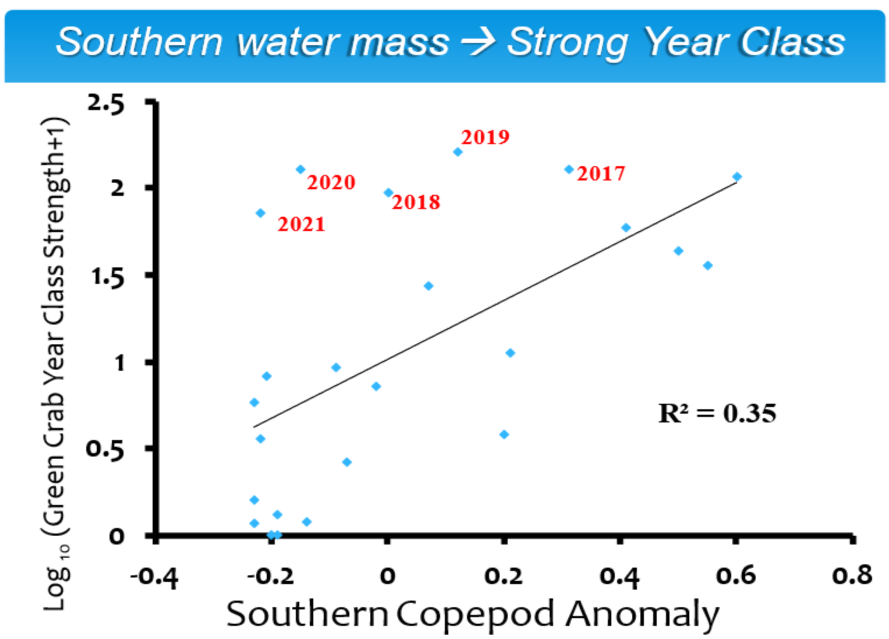


Figure 5. Regressions of *Carcinus maenas* year class strength at the end of their first growing season against southern copepod anomaly (a proxy for southern water sources). From 1998-2015 (top) the R,^{2} or % of interannual variability explained by regression, was 69%. The addition of recent years brought the R^2 down to 35 %.

microhabitats. In the absence of competition and predation from these larger crabs, green crabs appear to flourish.

Prior to 2016 the ocean indices suggested that green crab larvae were transported north from established populations in California during favorable ocean conditions. The observation that in 2018, 2019, 2020 and 2021 more young green crabs were trapped than predicted, may be evidence for additional larval sources from local production, and transport of larvae from the north. During 2010 first instar zoea were sampled in plankton nets at Jordan cove in Coos Bay in January, February and March (Shanks 2011). These early larvae had to be locally produced. Densities of green crabs in the coastal estuaries may now be large enough to represent self-sustaining populations. 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, Willapa, Tillamook, and Netarts Bays. It is not known what the relative contribution of these two additional larval sources is and how that might change with ocean conditions and global warming.

Green crabs, with an average of 6 per trap in two Oregon estuaries, and between 2 and 4, in three Washington coastal estuaries are starting to have an effect on shellfish culture by preying on small clams and seed oysters (Larissa Pfleeger & Andrea Randall, personal communications). There are at least four entities that are conducting large scale independent trapping efforts in Washington: Makah Fisheries Management in Makah Bay, Pacific Seafoods in Grays Harbor, and Shoalwater Bay Indian Tribe and Pacific County Vegetation Management in Willapa Bay. All four groups have already begun their 2022 removal trapping efforts, and the Shoalwater Bay Tribe continued trapping through last winter into this year. Our goal for 2022 is to compile all these sampling efforts into a regional report.

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 locations which, at present, have no green crabs, such as Hood Canal. While green crabs have been discovered at various locations the Washington Salish Sea (Grason et al. 2018, Behrens Yamada et al. 2017, 2021a) it is not known if this species will establish itself there. Intense trapping efforts are ongoing to reduce the breeding populations in high water retention habitats such as bays and lagoons. Most of the trapping effort in the summer of 2022 will be directed at Lummi Nation Sea Pond, an artificial aquaculture lagoon surrounded by a 3-mile dike. Nearly 86,000 green crabs were removed in 2021 with a relative abundance of 4 per trap (Bobbie Buzzell, personal com.).

Acknowledgements

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We are especially grateful to shellfish growers, including Bay Center Farms, Brady's Oysters, Taylor Shellfish, and Elkhorn Oyster Company, for sharing their green crab sightings with us, especially during the years when the crabs were still rare. In Washington, independent removal trapping efforts were completed by the Shoalwater Bay Indian Tribe and Pacific County Vegetation Management (Willapa Bay) and Pacific Seafoods (Grays Harbor) in 2021, and those numbers are included in the data reported here.

Carolyn Tepolt is doing genetic analysis of crab samples from all the coastal estuaries. We appreciate suggestions by Larissa Pfleeger for improving this report. Pacific States Marine Fisheries Commission covered the cost of travel and a part-time student helper for SBY. Shon Schooler is maintaining master data sheets on sex, size and weight of individual crab caught in the 5 estuaries. He can be contacted at shon.schooler@state.or.us

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Appendix 1. Relative abundance of crab species and sculpins (Numbers/trap/day) in Oregon and Washington coastal estuaries during **2020**.

Yaquina Bay

Site	Date	Trap Type	Zone	# *Carcinus maenas*	Mean CPUE (Catch/trap/day) *Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	# Traps
Sally's Bend A *N 44° 37.699' W124° 01.482'*	7/08/2020	crayfish	high	4	0.44	1	0	0	0	0	0.78	9
	9/04/2020	crayfish	high	27	1.8	0.2	0	0	0	0	0.133	15
	9/20/2020	crayfish	high	18	1.8	0	0	0	0	0	0.3	10
	9/20/2020	crayfish	high	20	2.0	0	0	0	0	0	0.5	10
Oregon Coast Aquarium Mudflat *N 44° 37.108' W124° 02.165'*	7/08/2020	crayfish	High	14	1.55	0.11	0	0	0	0	0.22	9
	9/04/2020	crayfish	high	8	0.73	0.09	0	0	0	0	0	11
	9/20/2020	crayfish	High	6	1.0	0	0	0	0	0	0.17	6
	9/20/2020	crayfish	high	24	2.4	0.1	0	0	0	0	0.1	10
			TOTAL crayfish	121	1.51							80
	7/08/2020	pitfall	high	2	0.33	0	0	0	0	0	0	6
	9/04/2020	pitfall	high	4	0.67	0.17	0	0	0	0	0	6
	9/20/2020	Pitfall	high	4	0.67	0	0	0	0	0	0	6
Total Number				131	1.34							98

Tillamook Bay

Site	Date	Trap Type	Zone	# *Carcinus maenas*	Mean CPUE (Catch/trap/day) *Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	# Traps
Pitcher Point *N 45° 30.365' W 123° 56.508'*	7/30/2020	crayfish	high	9	0.9	2.6	0	0	0	0	1.5	10
	9/17/2020	crayfish	high	21	2.1	0.8	0	0	0	0	1.1	10
	9/18/2020	crayfish	high	10	1.0	0	0	0	0	0	0.5	10

Tillamook Spit A *N 45º 30.456'* *W 123º 56.615'*	7/30/2020	crayfish	high	11	1.38	1.13	0	0	0	0	0.13	8
	9/17/2020	crayfish	high	24	2.4	0.3	0	0	0	0	1.0	10
	9/17/2020	crayfish	high	11	1.83	0.33	0	0	0	0	.83	6
Total Number				86	1.59							54

Netarts Bay

Site		Trap Type	Zone	# *Carcinus maenas*	Mean CPUE (Catch/trap/day) *Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	# Traps
Boat Ramp Marsh N 45.4306 W 123.9473	9/18/2020	crayfish	high	10	1.0	0	0	0	0	0	0.4	10
Whiskey Creek Salmon Hatchery *N 45º 23.670'* *W 123º 56.214'*	7/30/2020	crayfish	high	7	0.7	0.3	0	0.1	0	0	0.3	10
	7/31/2020	crayfish	high	7	0.47	0.47	0.13	0	0	0	1.07	15
	9/17/2020	crayfish	high	11	1.1	1.6	0	0	0	0	0.4	10
	9/18/2020	crayfish	high	23	1.44	1.81	0	0	0	0	0.38	16
			TOTAL crayfish	58	0.95							61
	7/30/2020	pitfall	high	1	0.2	2.6	0	0	0	0	0	5
	7/31/2020	pitfall	high	1	0.2	2.0	0	0	0	0	0	5
	9/17/2020	pitfall	high	2	0.4	3.0	0	0	0	0	0	5
	9/18/2020	pitfall	high	5	1.0	1.6	0	0	0	0	1	5
Total Number				67	0.83							81

Willapa Bay

Site		Trap Type	Zone	# *Carcinus maenas*	Mean CPUE (Catch/trap/day) *Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	# Traps

Stackpole *N 46º 35.848'* *W 124º 02.195'*	9/18/2020	crayfish	high	21	1.75	0.66	0	1.09	0	0	0.16	12
	9/18/2020	5-gallon pitfall	high	12	1.5	0.5	0	0.1	0	0	0	8
Total Number				33	1.65							20

Appendix 2. Relative abundance of crab species and sculpins (Numbers/trap/day) in Oregon and Washington coastal estuaries during 2021.

Yaquina Bay					**Mean CPUE (Catch/trap/day)**							# Traps
Site	Date	Trap Type	Zone	# *Carcinus maenas*	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	
Johnson Slough *N 44º 34.692'* *W123º 59.333'*	3/25/2021	crayfish	*high*	0	0	0	0	0	0	0	0	9
Sally's Bend A *N 44º 37.699'* *W124º 01.482'*	3/25/2021	crayfish	high	4	0.25	1.0	0	0	0	0	0	16
	5/11/2021	crayfish	high	18	1.8	1.0	0	0	0	0	0.2	10
	5/11//2021	crayfish	high	30	3.0	2.9	0	0	0	0	1.1	10
	6/15/2021	crayfish	high	7	0.7	0.1	0	0	0	0	0.8	10
	6/15/2021	crayfish	high	13	1.3	4.55	0	0	0	0	0.8	10
	7/12/2021	crayfish	high	13	0.65	2.2	0	0	0	0	1.49	20
	9/22/2021	crayfish	high	22	1.10	0.5	0.05	0	0	0	0.5	20
	10/14/2021	crayfish	high	6	0.6	2.9	0	0	0	0	0.9	10
Sally's Bend C N 44º 37.419' W124º 01.463'	6/26-29	Fukui	Mid	<132>	5.5	0.08	0	0	0	0	5.25	<24>
	7/12/2021	Fukui	mid	<30>	7.5	0	0	0.5	0	0	6.25	<4>
Oregon Coast Aquarium Mudflat	3/25/2021	crayfish	high	2	0.10	2.30	0	0	0	0	0	20
	5/11/2021	crayfish	high	7	0.7	1.5	0	0	0	0	0	10
	5/11/2021	crayfish	high	9	0.9	0.7	0	0	0	0	0.1	10

N 44º 37.108' *W124º 02.165'*	6/15/2021	crayfish	high	22	1.1	1.6	0	0	0	0	0.15	20
	7/12/2021	crayfish	high	17	0.85	1.65	0	0	0	0	0.55	20
	9/22/2021	crayfish	high	26	1.3	0.2	0	0	0	0	0,3	20
	3/25/2021	pitfall	high	<0>	0	1.83	0	0	0	0	0	<6>
	5/11/2021	ptfall	high	<3>	0.74	0	0	0	0	0	0	<4>
	6/15/2021	pitfall	high	<2>	0.67	4.0	0	0	0	0	0	<3>
	3/25/2021	Fukui	mid	<17>	8.5	0	0	1.0	0	0	0.5	<2>
	5/11/2021	Fukui	mid	<53)	25.5	0	0	0	0	0	0.5	<2>
Total, crayfish only				190	0.88							215

Tillamook Bay

Site	Date	Trap Type	Zone	# *Carcinus maenas*	Mean CPUE (Catch/trap/day) *Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	# Traps
Pitcher Point *N 45º 30.365'* *W 123º 56.508'*	5/2/2021	crayfish	high	10	1.0	2.9	0	0	0	0	2.1	10
	7/26/2021	crayfish	high	13	1.3	1.0	0	0	0	0	0.8	10
	9/9/2021	crayfish	high	13	1.3	0.5	0	0	0	0	0.4	10
Tillamook Spit A *N 45º 30.456'* *W 123º 56.615'*	5/2/2021	crayfish	high	2	0.2	1.0	0	0	0	0	1.8	10
	5/2/2021	crayfish	high	1	0.2	0.8	0	0	0	0	3.6	5
	7/26/2021	crayfish	high	14	1.4	0.2	0	0	0	0	0.5	10
	7/26/2021	crayfish	high	6	1.2	0	0	0	0	0	0.3	5
	9/9/2021	Crayfish	High	7	0.7	0.2	0	0	0	0	0.2	10
	9/9/2021	crayfish	*high*	4	0.8	1.0	0	0	0	0	1.0	5
Total Number				70	0.93							75

Netarts Bay

Site		Trap Type	Zone	# *Carcinus maenas*	Mean CPUE (Catch/trap/day) *Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	# Traps

Whiskey Creek Salmon Hatchery *N 45º 23.670'* *W 123º 56.214'*	5/2/2021	crayfish	high	2	0.4	0.4	0	0	0	0	0.2	5
	5/2/2021	crayfish	high	1	0.1	1.0	0	0	0	0	0.6	10
	7/26/2021	crayfish	high	2	0.2	1.4	0.3	0	0	0	0.5	10
	7/26/2021	crayfish	high	0	1.4	0	0	0	0	0	0.4	5
	9/9/2021	crayfish	high	6	0.6	1.4	0	0	0	0	0	10
Boat Ramp Marsh N 45.4306 W 123.9473	5/2/2021	crayfish	high	4	0.4	1.2	0	0	0	0	0.3	10
	7/26/2021	crayfish	high	19	1.9	0.2	0	0	0	0	0.5	10
	9/9/2021	crayfish	high	20	1.33	0.2	0	0	0	0	0.67	15
Total Number				54	0.72							75

Willapa Bay					**Mean CPUE (Catch/trap/day)**							
Site		Trap Type	Zone	# *Carcinus maenas*	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister >50 mm*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	# Traps
Stackpole *N 46º 35.848'* *W 124º 02.195'*	9/23/3031	Crayfish	High	16	1.6	0.5	0	0.1	0	0	0.2	10
	9/23/2021	5-gallon pitfall	high	22	3.14	1.0	0	0.14	0	0	0	7
Total Number				38	2.24							17

Appendix 3. Relative abundance (CPUE) and size of young-of-the-year (YOTY) *Carcinus maenas* at the end of their first growing season in Oregon and Washington estuaries. YOTY crabs are ≤ 50 mm in carapace width and weigh ≤30. Crabs were sampled within the same week of September or early October. Catch per unit effort (CPUE) is reported as number of crabs per trap per day. N=number of YOTY 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
2019				75		**2.08**	45.0	4.5	32-50
2020				45		**1.88**	47.6	3.0	37-50
2021				53		**0.75**	45.8	3.5	31-50
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		42-50
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
2019				64		**1.60**	38.0	6.0	25-51
2020				51		**1.42**	41.9	5.1	31-50
2021				42		**1.05**	39.4	4.9	29-48
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
2019				15		**1.36**	38.9	7.2	27-50
2020				45		**1.14**	34.2	8.5	11-50
2021				19		**0.76**	35.9	3.9	31-50
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
2019				56		**1.90**	42.7	4.7	30-50
2020				51		**1.42**	43.7	4.8	23-51
2021				10		**0.40**	46.8	3.2	40-50
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	0			
2017				9	0	**0.43**	41.3	6.1	32-50
2018				10		**0.64**	46.5	7.8	37-56
2019				22		**1.16**	44.2	5.4	33-50
2020				9		**0.45**	40.4	5.9	30-47
2021				10		**0.59**	46.0	4.3	36-50
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	40.		
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			