Status of the European Green Crab, *Carcinus maenas*, in Oregon and Washington coastal Estuaries in 2019

Sylvia Behrens Yamada yamadas@science.oregonstate.edu
Integrative Biology, Oregon State University
3062 NW Snowberry Place, Corvallis, OR 97330
541-760-1648

Shon Schooler shon.schooler@state.or.us
Renee Heller reheller@muhlenberg.edu
Luke Donaldson twixluke74@gmail.com
South Slough National Estuarine Research Reserve
Charleston, OR 97420

Graham T. Takacs Graham.T.Takacs@state.or.us
Oregon Department of Fish and Wildlife

Andrea Randall jaoskemmer@centurylink.net
PO Box 6, Chinook, Washington 98614

Chelsey Buffington Chelsey.Buffington@dfw.wa.gov
Washington Department of Fish and Wildlife

Adrianne Akmajian marine.ecologist@makah.com
Marine Ecologist, Makah Fisheries Management

For data on individual crabs see:

Yamada, S. B., Schooler, S., Heller, R., Donaldson, L., Takacs, G.T., Randall, A. & Buffington, C. (2020). Dataset for Status of the European Green Crab, Carcinus maenas, in Oregon and Washington coastal Estuaries in 2019 (Version 1) [Data set]. Oregon State University. https://doi.org/10.7267/028712995 or https://ir.library.oregonstate.edu/concern/datasets/028712995

Report prepared for:
Stephen H. Phillips, Program Manager
Aquatic Nuisance Species Project
Pacific States Marine Fisheries Commission
205 SE Spokane Street, Suite 100, Portland, Oregon 97202
503-595-3100; Fax: 503 595-3232
stephen_phillips@psmfc.org
http://www.psmfc.org

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, 2018 and 2019. 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; Behrens Yamada, Fisher and Kosro 2020 in review). Prior to 2015, green crabs were too rare (<0.2 per trap) to exert measurable effects on the native benthic community and on shellfish culture in Oregon and Washington. But after the 2015-2016 El Niño, we document the arrival of five strong year classes. Average catches steadily increased from 0.5 crabs per trap, in 2015 to around 3 crabs per trap in 2017 to 2019. The catches in the last 3 years are much higher than in any of the previous years, including 1998. Catches in some hot spots exceed 10 crabs per trap, a level at which measurable ecological impact can be expected (Grosholz et al. 2011). Since green crabs live for 6 years, these five consecutive year classes can produce larvae until 2025. 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 1950s for their numbers to build to a level at which they decimated the soft-shelled clam industry in Maine (Welch 1968). 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 their search for 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 2010

Date	Talks / Outreach Activities	Location
Feb. 28-March 2 2019	Set traps with Jamie Belinger and Shon Schooler of South Slough National Estuarine Research Reserve and gave talk on green crabs for a teacher's workshop.	North Bay Elementary School, Hauser, OR
April 6, 8, 2019	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
April 13, 2019	Set-up crab identification display with Marine Biology Students for Marine Science Day	Hatfield Marine Science Center, Newport, Oregon
April 25-27, 2019	Attended Pacific Estuarine Research Society Meeting, gave talk on status of the European Green Crab.	Fidalgo Bay Resort, Anacortes, WA
April 23, 2019	Wrote a manuscript with Jennifer Fisher and Mike Kosro: *Ocean ecosystem indicators forecast year class strength of the invasive European green crab in Oregon estuaries.* Commemorative issue, honoring William Peterson.	Submitted to Progress in Oceanography
June 30-July 1, 2019	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
July 27-28, 2019	Set traps and checked them with Jim Carlton's Bioinvasion Class (Bi408) students. Gave guest lecture on the invasion history, biology and status of the European Green crab in Oregon and Washington.	Oregon Institute of Marine Biology, Charleston, Oregon
Sept 18-19, 2019	Attended Pacific Coast Shellfish Growers Association/ National Shellfish Association meeting. Gave two talks: green crab range expansion in B. C. and status in Oregon.	Red Lion Inn, Janssen Beach, OR
October 9, 2019	Gave guest lecture on the invasion history, biology and status of the European Green crab to Scarlett Arbuckle's Marine Team Class (FW407)	Hatfield Marine Science Center, Newport, Oregon
Fall 2019	"Species on the Move" popular article on the European green crab in Oregon. Written by Nick Houtman, photos by Jen Pywelltory http://terra.oregonstate.edu/2019/10/species-on-the-move/	Terra, magazine of the OSU College of Science
November 21, 2019	Cam Parry of radio show "Hooked on Oregon" interviewed Sylvia Yamada about the new prevalence of green crabs in Coos Bay.	Radio KWRO, Charleston, Oregon

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 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 (Lafferty and 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, Oregon to around Bella Bella on 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, 2018 and 2019 (Behrens Yamada & Gillespie 2008; Behrens Yamada & Kosro 2010, Behrens Yamada et al. 2015).

Goals

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

1. Estimating the relative abundance and size/age structure of green crabs in Oregon and Washington estuaries during the summer by using baited Fukui fish 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 young-of-the-year, or 0-age green crabs at the end of their first growing season by setting minnow (crayfish) and pit-fall traps in the high intertidal zone at the end of summer and 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 winter water temperature and southern copepod anomality (Appendices 4 and 5). (For a complete list of correlations see Behrens Yamada et al. 2015).

Sampling Methods for Green Crabs

Our sampling effort in 2019 included one Washington and four Oregon estuaries: Willapa, Tillamook, Netarts, Yaquina and Coos Bay (Figure 1). Additional data for Makah Bay, Grays Harbor, Willapa Bay, and others were supplied by agency biologists, shellfish growers, and divers. All Oregon estuaries were sampled at least twice during the 2019 trapping season, with Coos Bay receiving additional sampling by biologists and interns from the South Slough National Estuarine Research Reserve. Willapa Bay was only sampled once at the Stackpole site for young-of-the-year crabs. In the Oregon estuaries, 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 12º-22º 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).

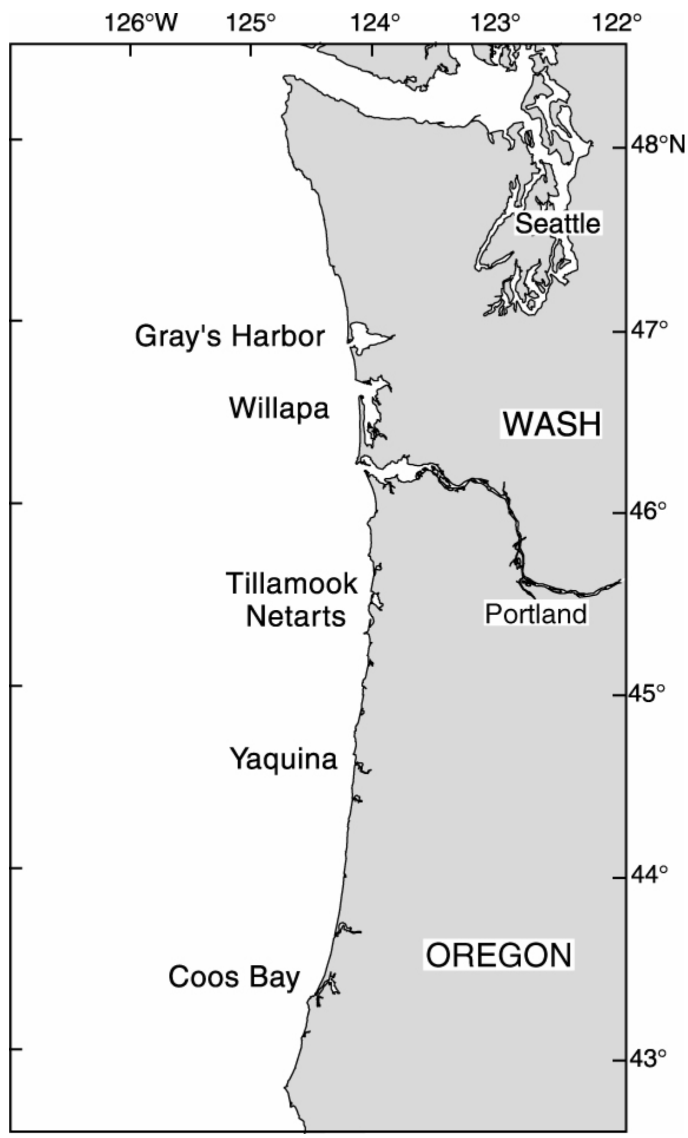


Figure 1. Major sampling sites in Oregon and Washington coastal estuaries.

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 minnow (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 ~ 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). 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 Oregon estuaries in 2019. These consist of commercial size fruit and vegetable tin cans used in commercial kitchens. The goal for using these smaller pitfall traps was to target very small crabs and to observe shifts in size frequency distributions over the summer months at Whiskey Creek Salmon Hatchery in Netarts Bay.

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 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
Pitfall Willapa	Water-filled 5-gallon bucket embedded into the sediment	31 cm diameter 37 cm high	High	All sizes
Pitfall Oregon	Large water-filled 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 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 Oregon sightings are tabulated in Appendix 2. Data on those caught during our trapping program can be found in accompanying file:

Yamada, S. B., Schooler, S., Heller, R., Donaldson, L., Takacs, G.T., Randall, A. & Buffington, C. (2020). Dataset for Status of the European Green Crab, Carcinus maenas, in Oregon and Washington coastal Estuaries in 2019 (Version 1) [Data set]. Oregon State University. https://doi.org/10.7267/028712995 or https://ir.library.oregonstate.edu/concern/datasets/028712995

Table 2a. *Carcinus maenas* trapping results for study sites in Oregon and Washington coastal estuaries from 2002 to 2019. 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 and Richard Wilson of Bay Center Farm. Mary Sue Brancato from the Olympic Coast National Marine Sanctuary trapped for green crabs in Makah and Neah Bay from 2000 to 2004 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 2020.

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	2019
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)	1397 (453)
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)	361 (110)
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)	140 (106)
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)	114 (53)
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)	38 (19)
Grays Harbor	5 (1203)	--	--	2 (94)	3 (175)	0 (30)	--	0 (20)	--	--	-	-	-	present	present	present	present	present
Makah Bay	0* (9)	0* (4)	0* (6)			0* (13)	0* (30)								present	34* (168)	922* (2245)	1056* (1879)
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 (922)	2305 (723)	2050 (741)

Table 2b. Relative abundance of *Carcinus maenas* for study sites in Oregon and Washington coastal estuaries. Number of crabs per trap was calculated from Table 2a. by multiplying 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 2020.

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***	***2019***
Coos Bay	5	7	13	4	8	**21**	**24**	6	2	7	19	7	1	**24**	**91**	**245**	**289**	**308**
Yaquina	15	6	3	13	**23**	**21**	15	12	8	7	13	11	5	**63**	**110**	**195**	**600**	**328**
Netarts	0	**25**	**31**	**49**	**57**	**34**	19	15	15	**24**	14	0	**27**	**83**	**81**	**157**	**292**	**132**
Tillamook	3	9	8	11	**28**	16	1	0	2	0	14	0	13	**40**	**102**	**133**	**159**	**215**
Nehalem																**59**	**21**	
Willapa	3.5	3	3	**25**	8	1	0	0	12	0	0	0	0	**40**	6	**43**	**65**	**200**
Grays Harbor	0.4	-	-	2	2	0	-	0	-	-	-	-	-	present	present	present	present	present
Makah Bay	0*	0*	0*			0*	0*								present	**(20)***	**(41)***	**(56)***
Total	3	6	6	18	16	15	17	7	6	8	15	7	10	**48**	**83**	**223**	**319**	**277**

Results

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

The relative abundance of green crabs trapped in Oregon and Willapa Bay, Washington in 2019 is tabulated in Appendix 1 and summarized in Table 2a and 2b. 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 in Oregon had dropped below 0.2 per trap (Table 2, Figure 2). Slight increases in catches reflect recruitment events in 2003, 2005, 2006, 2010 (Figure 3). Catches in Oregon increased to 0.5 in 2015, to 0.8 in 2016 and around to around 3.0 per trap in the next 3 years. The increase is directly attributed to the arrival of five strong year classes (Figure 3).

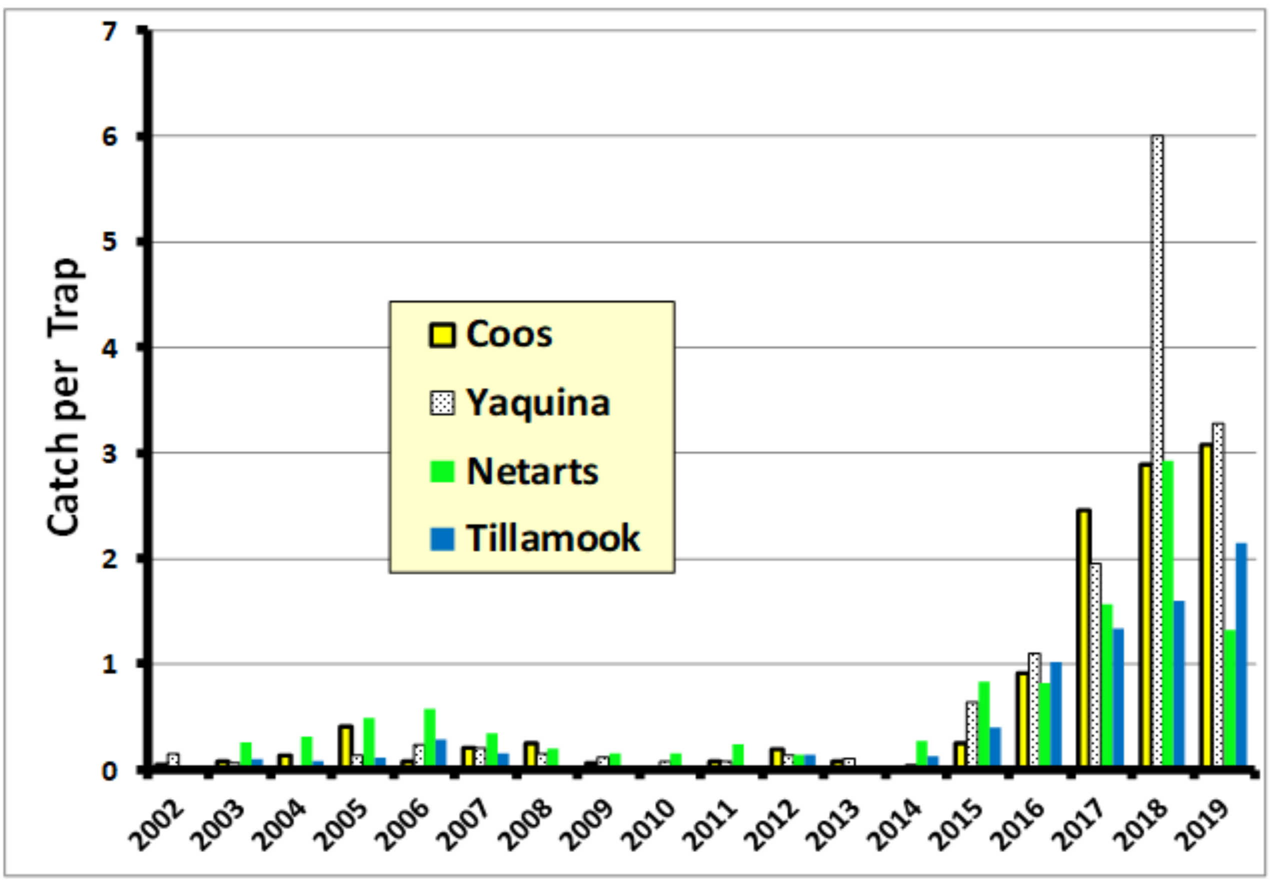


Figure 2. Relative abundance of *Carcinus maenas* in Oregon estuaries, expressed as average number per trap per day.

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

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. Note that winter water temperatures had to be above 10ºC 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 low, or no recruitment to the population, with the exception of moderately strong year classes in 2003, 2005, 2006 and 2010. From 2015 to 2019, five strong year classes recruited to all the estuaries, with catches of similar size or above to those of the 1998-year class (Figure 3).

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 the growth of crabs from 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 throughout 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. With the arrival of 5 strong, sequential year classes, it is no longer possible to accurately assign year classes because the size-frequency distributions overlap. However, we do know that all five year classes are still well represented because we recovered crabs ranging in size from <20 mm to over 90 mm in carapace width.

Recruitment of O-Age Crabs

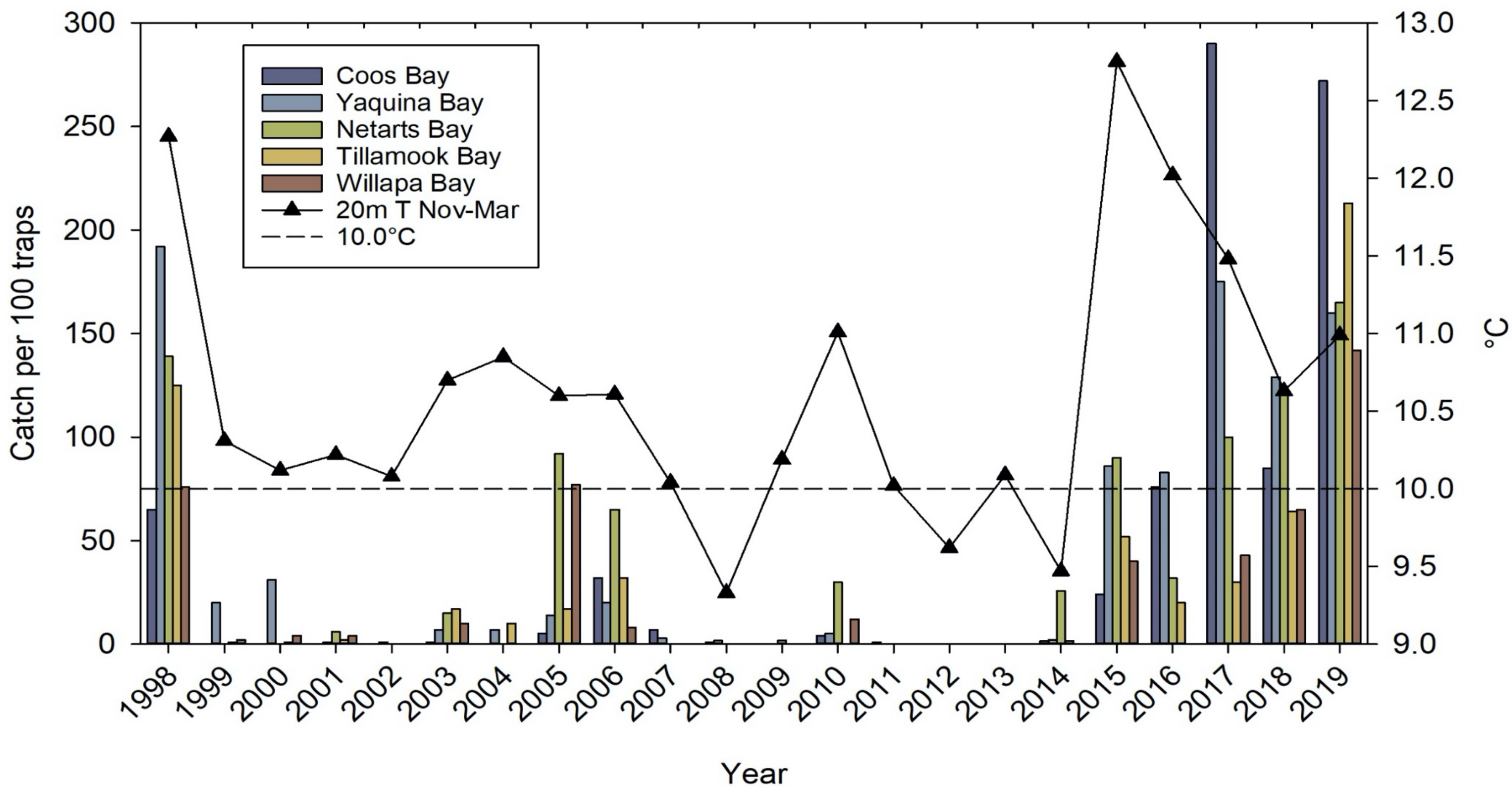


Figure 3. Relative Abundance of O-Age, or Young-of-the-Year, *Carcinus maenas* in coastal estuaries, expressed as average number per trap per day, superimposed with mean winter water temperature (November to March) off Newport OR. Note that few young green crabs recruit when mean winter water temperature is below 10°C.

Ocean Conditions and Recruitment Strength of 0-age Carcinus maenas

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 past 22 years. After the arrival of the strong founding year class of 1998, significant recruitment to the Oregon and Washington populations occurred only in 2005, 2006, 2015, 2016, 2017, 2019 and 2019. Warm winter water temperatures, high Pacific Decadal Oscillation and Multivariate, ENSO (El Niño Southern Oscillation Indices), weak southward shelf currents in March and April are all correlated with these stronger year classes (Behrens Yamada and Kosro 2010, Behrens Yamada et al. 2015). 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. Biological indices used in salmon forecasting also predict green crab year class. These are 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). https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm . Up until recently, these ocean indices were excellent predictors of green crab year class strength. For example, larvae develop well when the winter surface temperature is warm, and currents from the south transport larvae from source populations in California, as indicated by a high southern copepod abundance. The correlations of these indices with green crab year class strength are still significant (Appendix 4 and 5), however the correlations are not as strong as they were 2 years ago. In other words, recruitment of young green crabs in 2018 and 2019 was higher than predicted from winter SST and the transport of water masses from the south.

Discussion

Over 2,000 European green crabs were caught in Oregon and Willapa Bay, Washington during the 2019 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. In addition to our trapping effort, 148 crabs were reported by Mark Ballo from his oyster plots in Grays Harbor, and

102 by Steve Shotwell, Dick Wilson, Andrea Randall and Zackery Forester from Willapa Bay (Buffington et al. 2020). That is the highest number of crabs ever reported by shellfish growers in these two bays. Since green crabs live up to 6 years, these crabs will supply larvae until 2025.

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). 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 habitats 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.

Prior to 2015 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 and 2019 more young green crabs were trapped than predicted, may be evidence for additional larval sources: 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). Densities in the coastal estuaries may now be large enough to represent breeding 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, Tillamook, and Netarts Bays. It is not known what the relative contribution of these additional larval sources is and how they might change with ocean conditions and global warming.

Green crabs, with an average of 3 per trap, are still rare and may not yet exert a measurable effect on the native benthic community and on shellfish culture in Oregon and Washington, but this could change in the next few years. If warm ocean conditions persist, green crabs could become established in in the Oregon and Washington coastal estuaries. 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 inland locations such as Hood Canal. While live green crabs have recently been discovered in the Washington Salish Sea (Grason et al. 2018, Behrens Yamada et al. 2017) it is not known if these individuals represent a breeding population. 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). Once green crabs get established in this inland sea, they could spread very quickly as many suitable habitats, devoid of larger crabs and other predators, exist in shallow, warm bays near freshwater outfalls.

Acknowledgements

We thank the staff and faculty of the Oregon Institute of Marine Biology for their hospitality while sampling in Coos Bay, and Chuck's Seafood of Charleston, Oregon for providing most of the bait. Mark Ballo reported sightings for Grays Harbor, Steve Shotwell and Richard Wilson for Willapa, and Mitch Vance for Yaquina. Alice Yeates, Liam Hunt, Thelonious Schooler, Ian Rodger, and Clementine Yeates helped sample in Coos Bay and students in the Marine Biology (Bi450) and Marine Invasions (FW421) classes, in Yaquina. Jennifer Fisher of NOAA Fisheries provided the ecosystem indicators for Appendices 4 and 5 and Figure 3. South Slough Estuarine Research Reserve provided housing, lab space, vehicle use, intern and volunteer coordination, while Friends of South Slough Reserve, Inc. provided internship stipends. The sampling efforts by Graham Takacs and Andrea Randall were supported by Oregon Department of Fish and Wildlife and Pacific States Marine Fisheries Commission respectively. Sylvia Yamada thanks the Pacific States Marine Fisheries Commission for travel support and the Oregon State University Valley Library for the use of a research room during preparation of this report.

Literature Cited

Akmajian, A. and L. Halttunen. 2020. European green crab trapping summary for the 2019 season. Makah Tribe Fisheries Management, Neah Bay, WA. 20 pp. marine.ecologist@makah.com

Behrens Yamada, S. J. Fisher, P.M. Kosro 2020. Ocean Ecosystem Indicators forecast year class strength in the invasive European green crab (*Carcinus maenas)*. Submitted to Progress in Oceanography.

Behrens Yamada, S, Thomson, RE, Gillespie, GE, Norgard, TC. 2017. Lifting Barriers to Range Expansion: The European green crab, *Carcinus maenas*, enters the Salish Sea. Journal of Shellfish Research 36(1)1-8.

Behrens Yamada, S, Peterson, W.T. Kosro, P.M. 2015. Biological and physical ocean indicators predict the success of an invasive crab, *Carcinus maenas*, in the northern California Current. Mar Ecol Prog Ser 537:175-189. https://doi.org/10.3354/meps11431

Behrens Yamada, S, T.M. Davidson and S. Fisher 2010. "Claw Morphology and Feeding Rates of introduced European green crabs (*Carcinus maenas)* and native Dungeness crabs (*Cancer magister)*". Journal of Shellfish Research 29(2):1-7.

Behrens Yamada, S and P.M. Kosro (2010). Linking ocean conditions to year class strength of the invasive European green crab, *Carcinus maenas*. Biological Invasions 12:1791-1804. DOI:10.1007/s10530-009-9589-y.

Behrens Yamada, S. and Gillespie, G. E. 2008. Will the European green crab (*Carcinus maenas*) persist in the Pacific Northwest? The Fifth International Conference on Marine Bioinvasions. International Council for the Exploration of the Sea, Journal of Marine Science, 65: 725-729. Doi:10.1093/icesjms/fsm191

Behrens Yamada, S,. B.R. Dumbauld, A. Kalin, C. Hunt, R. Figlar-Barnes and A. Randall 2005. Growth and persistence of a recent invader *Carcinus maenas* in estuaries of the Northeastern Pacific. Biological Invasions 7:309-321

Behrens Yamada, S. 2001. Global Invader: The European Green Crab. 123 pages. Oregon Sea Grant, Washington Sea Grant.

Behrens Yamada, S. and C. Hunt 2000. The arrival and spread of the European green crab, *Carcinus maenas,* in the Pacific Northwest. Dreissena! 11 (2): 1-7.

Behrens Yamada, S. and T. Davidson 2002. Status of the European Green Crab in Oregon Estuaries during the Summer of 2002. Report prepared for Pacific States Marine Fisheries Commission. https://ir.library.oregonstate.edu/concern/defaults/3n204356s

Buffington, Chelsey K. 2020. European Green Crab (*Carcinus maenas*): A comprehensive report for the state of Washington from the first detection in 1998 to 2018. Washington Department of Fish and Wildlife.

Buffington, Chelsey K. 2020. Status of European green crab, *Carcinus maenas*, for Washington State in 2019. Washington Department of Fish and Wildlife.

Carlton, J.T. and A.N. Cohen 2003. Episodic global dispersal in shallow water marine organisms: The case history of the European shore crabs *Carcinus maenas* and *C. aestuarii*. J. of Biogeography 30(12):1809-1820.

Cohen, A.N., J.T. Carlton, and M.C. Fountain, 1995. Introduction, dispersal and potential impacts of the green crab *Carcinus maenas* in San Francisco Bay, California. *Marine Biology*. 122:225-237

Crothers, J.H. 1968. The biology of the shore crab *Carcinus maenas* (L.). 2. The life of the adult crab. Field Studies 2:597-614.

Gillespie, G.E., Norgard, T.C., Anderson, E.D., Haggarty, D.R., and Phillips, A.C. 2015. Distribution and biological characteristics of European Green Crab, *Carcinus maenas*, in British Columbia, 2006 - 2013. Can. Tech. Rep. Fish. Aquat. Sci. 3120: viii + 88 p.

Gillespie, G. E., A. C. Phillips, D. L. Paltzat and T. W. Therriault 2007. Surveys for European green crab, *Carcinus maenas*, in British Columbia-2006. Canadian Technical Report of Fisheries and Aquatic Sciences 2700

Grason EW, McDonald PS, Adams J, Little K, Apple JK, Pleus A (2018) Citizen science program detects range expansion of the globally invasive European green Crab in Washington State (USA). Management of Biological Invasions 9:1)39-47 DOI: https://doi.org/10.3391/mbi.2018.9.1.04

Grosholz, E., Lovell, S., Besedin, E., Katz, M., 2011. Modeling the impacts of the of the European green crab on commercial shellfisheries. Ecological Applications. Vol.21(3):915-924.

Hunt, C.E. and S. Behrens Yamada 2003. Biotic resistance experienced by an invasive crustacean in a temperate estuary. Biological Invasions 5 (1) 33-43. 1989-2000.

Jamieson, G.S., E.D. Grosholtz, D.A. Armstrong and R.W. Elner 1998. Potential ecological implications for the introduction of the European green crab, *Carcinus maenas*, (Linnaeus), to British Columbia, Canada and Washington, USA. Journal of Natural History 32:1587-1598.

Jensen, G.C., P.S. McDonald, and D.A. Armstrong. 2002. East meets west: competitive interactions between green crab, *Carcinus maenas* and *Hemigrapsus* spp. Marine Ecology Progress Series 225:251-262.

Jensen, G.C., P.S. McDonald, and D.A. Armstrong. 2007. Biotic resistance to green crab, *Carcinus maenas*, in California bays. Marine Biology 151:2231-2243

Lafferty, K. and A. Kuris 1996. Biological control of marine pests. Ecology 77: 1989-2000.

McDonald, P.S., G.C. Jensen and D.A. Armstrong. 2001. The competitive and predatory impacts of the nonindigenous crab *Carcinus maenas* (L) on early benthic phase Dungeness crab *Cancer magister* Dana. Journal of Experimental Marine Biology and Ecology 258(1):39-54.

Neckles, H.A.2015. Loss of eelgrass in Casco Bay, Maine, linked to green crab disturbance. Northeastern Naturalist 22(3):478-500.

Say, T. 1817. An account of the Crustaceans of the United States. Journal of the Academy of Natural Sciences of Philadelphia 1:57-63.

Welch, W.R. 1968. Changes in abundance of the green crab, *Carcinus maenas* (L.) in relation to recent temperature changes. Fisheries Bulletin 67:337-345.

Zeng, C., P. Abello, and E. Naylor 1999. Endogenous tidal and semilunar moulting rhythms in early juvenile shore crabs *Carcinus maenas*: implications for adaptations to a high intertidal habitat. Marine Ecology Progress Series 191: 257-266.

Appendix 1. Relative abundance of crab species and sculpins (Numbers/trap/day) in Oregon and Washington coastal estuaries during 2019. Asterisk * indicates that March 1 data were not included in calculating annual CPUE because water temperature was too low for crabs to feed.

Coos Bay

Site	Date	Trap Type	Zone	# green crabs	Mean CPUE (Catch/trap/day) *Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	# Traps
Kentuck *N 43.421390 W 124.192000*	3/1/2019*	Pitfall		(1)*	0	0.25	0.25	0.00	0.00	0.00	0.00	(4)*
	3/1/2019*	Minnow		(1)*	0	0.09	0.18	0.00	0.00	0.00	0.00	(11)*
	7/23/2019	Fukui		2	na	0.33	0.00	0.00	5.33	na	0.00	6
	7/23/2019	Minnow		7	na	1.17	0.00	0.00	0.17	na	0.00	6
	7/26/2019	Minnow		18	na	1.80	0.20	0.00	0.00	0.00	0.00	10
	7/26/2019	Pitfall		8	na	0.80	0.80	0.00	0.00	0.00	na	10
	7/29/2019	Pitfall		3	na	0.30	0.20	0.00	0.00	0.00	0.00	10
	10/2/2019	Minnow		16	na	2.67	0.00	0.00	0.33	0.00	0.00	6
Russell Point *N 43.433050 W 124.220481*	3/1/2019*	Fukui	*Pools under 101 bridge*	(1)*	0.25	0.75	0.00	0.00	0.00	0.00	0.00	(4)*
Schooler Slough *N 43.315900 W 124.310700*	10/4/2019	Minnow		2	0.33	0.17	0.00	0.00	0.00	0.00	0.00	6
Transpacific Lane South N 43.442850 W 124.223000	3/1/2019*	Fukui		(0)*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	(10)*
	6/21/2019	Fukui		20	3.33	0.00	0.00	15.50	0.00	0.00	0.17	6
	7/19/2019	Fukui		0	0.00	0.17	0.00	1.00	0.00	0.00	0.00	6
	7/19/2019	Minnow		1	0.17	3.00	0.00	0.67	0.00	0.00	0.50	6
	8/16/2019	Fukui		15	2.50	0.00	0.00	41.17	0.00	0.00	0.00	6
Coos History Museum	6/20/2019	Fukui		41	6.83	0.00	0.00	0.00	0.00	0.00	0.00	6
	7/3/2019	Fukui		75	15.00	0.00	0.00	0.00	0.00	0.00	0.40	5
	7/4/2019	Fukui		7	1.40	0.00	0.00	0.00	0.00	0.00	0.20	5
	7/9/2019	Fukui		90	18.00	0.00	0.00	0.00	0.00	0.00	0.40	5

N 43.375060 W 124.212000	7/10/2019	Fukui		8	1.60	0.00	0.00	0.00	0.00	0.00	0.20	5
	7/17/2019	Minnow		19	3.17	0.00	0.00	0.00	0.00	0.00	0.83	6
	7/17/2019	Fukui		15	2.50	0.00	0.00	0.00	0.00	0.00	0.17	6
	8/2/2019	Fukui		144	24.00	0.17	0.00	0.00	0.00	0.00	0.00	6
	8/14/2019	Fukui		128	21.33	0.00	0.00	0.00	0.00	0.00	0.00	6
	8/14/2019	Minnow		40	8.00	0.00	0.00	0.00	0.00	0.00	0.00	5
	10/3/2019	Minnow		47	7.83	0.00	0.00	0.00	0.00	0.00	0.17	6
Day Creek N 43.315620 W 1 24.312455	7/23/2019	Minnow		4	0.80	1.80	0.00	0.00	0.00	0.00	0.00	5
Empire Docks N 43.393000 W 124.280000	6/21/2019	Fukui		3	0.50	0.00	0.00	3.00	0.17	0.83	1.67	6
	7/2/2019	Fukui		1	0.10	0.00	0.00	17.20	0.00	0.30	0.10	10
	7/3/2019	Fukui		6	0.60	0.00	0.00	13.00	0.60	0.10	0.00	10
	7/4/2019	Fukui		3	0.30	0.00	0.00	5.50	0.20	0.50	0.10	10
	7/9/2019	Fukui		3	0.43	0.00	0.00	20.00	0.00	2.57	0.43	7
	7/10/2019	Fukui		1	0.14	0.00	0.00	8.29	0.00	0.29	0.43	7
	7/19/2019	Fukui		1	0.17	0.00	0.00	5.67	0.50	4.00	0.33	6
	7/19/2019	Minnow		0	0.00	0.00	0.00	0.00	1.67	0.00	0.83	6
	8/1/2019	Fukui		1	0.17	0.17	0.00	0.00	0.00	0.00	0.00	6
	8/2/2019	Fukui		2	0.40	0.00	0.00	0.00	0.00	0.00	0.00	5
	8/16/2019	Fukui		0	0.00	0.00	0.00	1.50	2.33	0.33	0.00	6
Hinch Bridge N 43.276272 W 124.319689	6/18/2019	Fukui		0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6
	7/16/2019	Fukui		0	0.00	0.17	0.00	0.00	0.00	0.00	0.00	6
	8/13/2019	Fukui		1	0.17	2.83	0.00	0.00	0.66	0.00	0.33	6
Indian Point 1 N 43.328360 W 124.321000	7/16/2019	Pitfall		1	0.33	6.33	0.00	0.00	0.00	0.00	0.00	3
	10/4/2019	Minnow		20	3.33	0.33	0.00	0.00	0.00	0.00	0.00	6
Indian Point 2 N 243.333042 W 124.315089	6/19/2019	Fukui		8	1.33	0.00	0.00	2.50	0.00	0.33	0.17	6
	7/18/2019	Fukui		10	1.67	0.00	0.00	17.67	0.00	0.83	0.00	6
	7/18/2019	Minnow		1	0.17	0.00	0.00	0.17	0.00	0.00	0.00	6
	7/18/2019	Pitfall		0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3

	8/15/2019	Fukui		3	0.50	0.00	0.00	13.83	0.00	0.00	0.00	6
	6/20/2019	Fukui		98	16.33	0.00	0.00	0.67	0.00	0.00	0.33	6
	7/17/2019	Fukui		64	10.67	0.00	0.00	0.17	0.17	0.00	0.00	6
Isthmus Slough	7/17/2019	Minnow		23	3.83	0.00	0.00	0.17	0.00	0.00	0.67	6
N 43.356350	8/14/2019	Fukui		93	15.50	0.00	0.00	0.00	0.00	0.00	0.00	6
W 124.193000	8/14/2019	Minnow		60	10.00	0.00	0.00	0.00	0.00	0.00	0.00	6
	10/3/2019	Minnow		17	2.83	0.00	0.00	0.00	0.00	0.00	0.00	6
	10/4/2019	Minnow		18	3.00	0.00	0.00	0.17	0.00	0.00	0.00	6
	6/18/2019	Fukui		28	4.67	0.00	0.00	21.67	0.00	0.00	0.00	6
	7/16/2019	Fukui		51	8.50	1.50	0.00	25.00	0.00	0.00	0.00	6
Joe Ney Slough	7/16/2019	Minnow		6	1.20	2.40	0.00	0.00	0.00	0.00	0.00	5
N 43.339290	7/23/2019	Fukui		46	7.67	4.33	0.00	30.00	na	0.00	0.00	6
W 124.310000	7/30/2019	Fukui		27	4.50	4.83	0.00	0.00	0.00	0.00	0.00	6
	7/31/2019	Fukui		8	1.33	1.17	0.00	0.00	0.00	0.00	0.00	6
	8/13/2019	Fukui		21	3.50	0.83	0.00	10.00	0.00	0.00	0.00	6
	4/18/2019	Fukui		5	0.50	0.00	0.00	24.80	0.00	0.20	0.00	10
Valino Island	6/19/2019	Fukui		11	2.20	0.00	0.00	41.00	0.00	0.00	0.00	5
N 43.315140	7/18/2019	Fukui		1	0.17	0.00	0.00	10.00	0.00	0.00	0.00	6
W 124.321000	7/18/2019	Minnow		0	0.00	0.00	0.00	0.17	0.00	0.00	0.00	6
	8/15/2019	Fukui		0	0.00	0.67	0.00	32.67	0.00	0.00	0.00	3
Medcalf Marsh	6/19/2019	Fukui		8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6
N 43.333930	7/18/2019	Fukui		5	3.33	0.00	0.00	15.50	0.00	0.00	0.17	6
W 124.327000	7/18/2019	Minnow		8	0.00	0.17	0.00	1.00	0.00	0.00	0.00	6
	8/15/2019	Fukui		9	0.17	3.00	0.00	0.67	0.00	0.00	0.50	6
Charleston Boat	7/25/2019	Minnow		0	0.00	0.20	0.00	0.00	0.00	0.00	0.10	10
Basin	7/25/2019	Fukui		11	1.83	0.00	0.00	0.00	na	na	na	6
N 43.347281	7/26/2019	Minnow		0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11
W 124.323273	9/28/2019	Minnow		3	0.50	0.17	0.00	0.00	0.00	0.00	0.00	6
	9/28/2019	Fukui		1	0.17	0.00	0.00	0.00	0.00	3.17	0.00	6

Total Number				1400-3*								482-29*

Yaquina Bay

Site	Date	Trap Type	Zone	# green crabs	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'*	09/24/2019	minnow	high	34	1.7	0.5	0	0	0	0	0	20
Sally's Bend C N 44° 37.419' W124° 01.463'	09/11/2019	Fukui	mid	41	10.25	0	0	0	0	0	0	4
	09/12/2019	Fukui		39	9.75	0	0	0	0	0	0	4
	09/12/2019	Fukui		24	4.8	0	0	0	0	0	0	5
	09/13/2019	Fukui		21	4.2	1	0	0	0	0	0	5
HMSC Pumphouse *N 44° 37.408' W124° 02.576'*	04/08/2019	Fukui	mid	20	2.0	0.3	0	0	0	0	2.3	10
	07/01/2019	Fukui	Mid	23	4.6	0	0	0.4	0	0	3.0	5
Oregon Coast Aquarium Mudflat *N 44° 37.108' W124° 02.165'*	04/08/2019	Fukui	mid	38	4.75	0	0	0.88	0	0	0.75	8
	07/01/2019	Fukui	mid	45	11.25	0.25	0	0	0	0	0.75	4
	08/22/2019	Fukui	Mid	36	12	0	0	1	0	0	1.3	3
	04/08/2019	minnow	High	5	0.45	1.54	0	0	1.73	0	0	11
	07/01/2019	minnow	high	14	2.33	0.33	0	0	0	0	0.33	6
	08/22/2019	minnow	High	9	3	0	0	1	0	0	0	3
	09/24/2019	minnow	high	30	1.5	0.25	0	0.15	0	0	0.25	20
	04/08/2019	pitfall	high	1	0.25	1.50	0	0	0	0	0	4
	07/01/2019	pitfall	high	11	1.83	0	0	0	0	0	0	6
	08/22/2019	pitfall	high	2	0.33	0	0	0	0	0	0	6
	09/24/2019	pitfall	high	2	0.33	0	0	0	0	0		6
Total Number				361								110

Tillamook Bay

	Mean CPUE (Catch/trap/day)	

Site		Trap Type	Zone	# green crabs	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	# Traps
View Point *N 45° 32.623'* *W 123° 54.183'*	7/12/2019	Fukui	mid	6	1.5	1.25	0.25	18.5	3.75	0.25	1.75	4
	9/18/2019	Fukui	mid	41	8.2	0	0	18.2	0	0	0.2	5
Tillamook Spit B *N 45° 30.456'* *W 123° 56.615'*	6/12/2019	Fukui	Mid	0	0	2	0	0.2	0	0	0.2	5
	6/12/2019	Minnow	high	0	0	15	0.25	0	0	0	2	4
	10/1/2019	minnow	High	28	2.8	0	0	0	0	0	0.6	10
	10/1/2019	minnow	high	23	2.3	0.4	0	0	0	0	0.3	10
	6/12/2019	pitfall	high	1	0.2	18.6	0	0	0	0	0	5
Pitcher Point *N 45° 30.365'* *W 123° 56.508'*	10/1/2019	minnow	high	15	1.5	0.4	0	0	0	0	0.5	10
Total Number				114								53

Netarts Bay

					Mean CPUE (Catch/trap/day)							# Traps
Site		Trap Type	Zone	# green crabs	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	
Intersection *N 45° 24.865'* *W 123° 56.064'*	6/12/2019	Fukui	Mid	20	4	0.6		1.4			1.4	5
	8/22/2019	Fukui	Mid	57	11.4	1.00		17.00	1.20		5.00	5
Whiskey Creek Salmon Hatchery *N 45° 23.670'* *W 123° 56.214'*	6/12/2019	minnow	*high*	1	0.17	4.83	0.17					6
	7/12/2019	minnow	*high*	0	4.8	1	0.5				1	5
	8/22/2019	minnow	*high*	9	1.80	1.40			1.80		1.60	5
	9/18/2019	minnow	*high*	6	1.20		5.80		1.20			5
	10/1/2019	minnow	*high*	18	1.64	3.09					0.36	11
	10/15/2019	minnow	*high*	4	0.36	4.18	0.91					11
	6/12/2019	pitfall	*high*	1	0.2	9.2						5
	7/11/2019	Pitfall	*High*	3	0.5	5.83	0.67					6

	7/12/2019	pitfall	*high*	1	0.17	6.33						6
	8/21/2019	pitfall	*High*	3	0.50	0.67						6
	8/22/2019	pitfall	*high*	3	0.5	0.33			0.33			6
	9/17/2019	pitfall	*high*	4	0.67		3.17		0.67			6
	9/18/2019	Pitfall	*high*	4	0.67	0.17	1.17		0.50			6
	10/15/2019	Pitfall	*high*	3	0.50	2.50						6
	10/16/2019	pitfall	*high*	4	0.67	3.00	0.17					6
Total Number				140								106

Willapa Bay					**Mean CPUE (Catch/trap/day)**							# Traps
Site		Trap Type	Zone	# green crabs	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	
Stackpole *N 46° 35.848'* *W 124° 02.195'*	10/01/2019	Minnow	Edge vegetation	18	1.50	0.2	9	0.3	0	0	0.8	12
	10/01/2019	Pit-fall	Edge and open mudflat	20	2.86	0	0	0.7	0	0	0	7
Total Number				38								19

Appendix 2. *Carcinus maenas.* Sightings of green crabs from Oregon coastal estuaries in 2019. 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 Oregon and Willapa Bay trapping results and Willapa Bay and Grays's Harbor sightings by shellfish growers, see: Yamada, S. B., et al. 2020, Dataset for Status of the European Green Crab, *Carcinus maenas,* in Oregon and Washington coastal Estuaries in 2019 (Version 1) [Data set]. Oregon State University. https://doi.org/10.7267/tt44pt057 The green crab sightings by shellfish growers in Willapa Bay and Grays Harbor were compiled by Buffington et al.2020b and also included in Yamada, S. B., et al. (2020). Dataset for Status of the European Green Crab, *Carcinus maenas,* in Oregon and Washington coastal Estuaries in 2019 (Version 1) [Data set]. Oregon State University. https://doi.org/10.7267/tt44pt057

Estuary	Site	Date	Sex	Carapace Width (mm)	Weight (g)	color	Estimated Year class	Missing limbs	comments	collector
Winchester Bay		3/25/2019	F	~60 mm		orange	2018	R1	Caught while seining	Jason Brandt ODFW
Siuslaw N 44.015211 W 124.130581	West of Harbor Vista Park, North side Siuslaw River in "crab hole"	1/5/2019	M	84			2017			Andrew Day
		1/12/2019	M	~90		Yellow-orange	2015,2016	R1	Large barnacles	Andrew Day
		1/13/2019	M	83	91.7	Yellow-green	2017	R1	Large Barnacles on claw, belly and back	Andrew Day
		2/10/19	F	72	108.9	yellow	2017			Andrew Day
	Public docks, Mo's	2/27/19	M	77		yellow	2017		barnacles	Spots catch/ODFW
	Pulbic docks, Mo's	2/17/19	M	80		orange	2016		barnacles	Sports catch/ODFW
Siletz	Mudflat by mouth	7/24/2019	?	?			2018, 2017		Lots of molts	Sylvia Yamada
Siletz	Under bridge	8/14/2019	?	?					2 large crabs	June Mohler
Salmon	Mouth of Bay	5/ 20/2019	F	57		Green	2018		~ 5 crabs in 10 ft area	Gile Kendal gaileke@oregonstate.edu
Salmon	Mouth of Bay	5/20/2019	M	78		red	2017	barnacles		Gile Kendal gaileke@oregonstate.edu
Netarts		10/27/2019	M	?	?	Yellow-orange				Brian Turner

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.

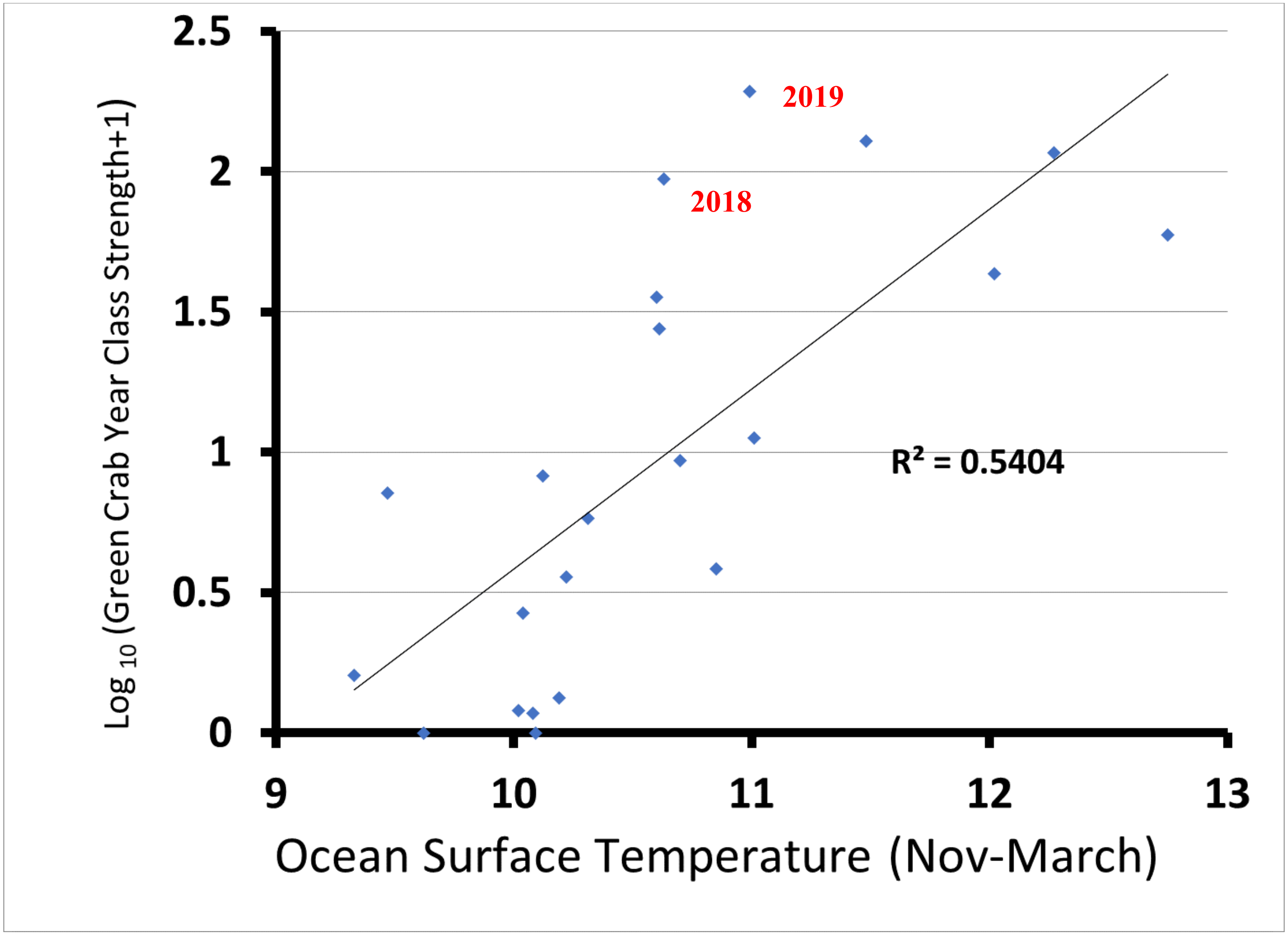
Year Class	**Estuary**	**# Months <10ºC**	**Mean Winter Temp. ºC**	**N**	**CPUE Pitfall traps**	**CPUE Minnow traps**	**Mean Carapace Width (mm)**	**SD**	**Range**
2002	Coos	4	9.6	0		0.00			
2003		**0**	**10.9**	1		0.01	59.4		
2004		**1**	**10.4**	0		0.00			
2005		**2**	**10.3**	2		0.05	45.0		44-46
2006		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
2019				98		**2.75**	46.0	5.5	32-53
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				65		**1.63**	38.3	6.3	25-54
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
2019				18		**1.64**	41.4	8.7	27-55
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				65		**2.17**	44.06	5.5	30-55
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
2019				27		**1.42**	45.5	5.6	33-52
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			
2010							Not sampled		
2011							Not sampled		
2012							Not sampled		
2013							Not sampled		
2014							Not sampled		
2015							Not sampled		
2016							Not sampled		
2017							Not sampled		
2018							Not sampled		
2019							Not sampled		
2017	Makah Bay			16			45.6	9.6	24-57
2018									
2019									

Appendix 4. *Carcinus maenas* year class strength as a function of winter sea surface temperature. Average catch data for the five estuaries were averaged, log-transformed and regressed against November to March SST. The regression explains 54% of the inter-annual variability in year class strength. Without the last 2 years, it explained 64%.



Appendix 5. *Carcinus maenas* year class strength as a function Southern Copepod Anomaly (a proxy for southern water sources). The regression explains 51% of the inter-annual variation. Without the last 2 years, it explained 72%.