Status of the European Green Crab, *Carcinus maenas*, in Oregon and Washington coastal Estuaries in 2017

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Accompanying Data Files:

1. *Green Crabs CW2017 Northern Estuaries.xlsx*, 2. *Green Crabs CW2017 Sorted Coos.xlsx*.

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Executive Summary

The European green crab (*Carcinus maenas*) has persisted in Oregon and Washington coastal estuaries since the late 1990's. After the arrival of a strong year class in 1998, significant recruitment to the populations occurred only in 2005, 2006, 2015, 2016 and 2017. Warm winter water temperatures, high Pacific Decadal Oscillation (PDO) and Multivariate ENSO (El Niño Southern Oscillation) Indices, weak southward shelf currents in March and April and a high abundance of southern copepods are all correlated with strong year classes and vice versa (Behrens Yamada Peterson and Kosro 2015). Prior to 2015, green crabs were too rare to exert measurable effects on the native benthic community and on shellfish culture in Oregon and Washington. Following the recent strong El Niño, however, we documented the arrival of three strong year classes in 2015, 2016 and 2017. Average catch rates in over the last three years steadily increased from 0.5 to 0.8 and to 1.9 crabs per trap. These catches are much higher than in any of the previous years, including 1998. Since green crabs live for 6 years, these three consecutive year classes will provide larvae until 2023. A switch to cooler ocean conditions in the coming years will result in poor recruitment, but a return to high PDO and strong El Niño patterns would signal good recruitment and higher green crab densities. For example, green crabs were first documented in New England in 1817, but it took warm ocean conditions during the 1950's for their numbers to build to a level at which they decimated the soft-shelled clam industry in Maine. With the recent warm trend on the East Coast, green crabs are again abundant. Not only are they preying on shellfish, they are also damaging valuable eelgrass habitat by ripping up the plants in search of food (Neckles 2015).

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

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

Professional and Outreach Activities by Sylvia Behrens Yamada in 2017

Date	Talks / Outreach Activities	Location
March 16-18, 2017	Attended Pacific Estuarine Research Society Meeting. Presented talk followed by a discussion: "Lifting Barriers to Range Expansion: "The European green crab, *Carcinus maenans*, enters the Salish Sea". Networked with students.	Southern Oregon Community College, North Bend, Oregon
March 20-21, 2017	Presented talk to the Oregon Invasive Species Council: Ocean Indicators Predict the Success of European Green crab.	Astoria, Oregon
April 2017	Manuscript "The European green crab, *Carcinus maenans*, enters the Salish Sea" with Richard Thomson, Graham Gillespie and Tammy Norgard was published	Journal of Shellfish Research
April 9-10, 2017	Set traps and checked them with Sally Hacker's Marine Biology (Bi 450) students. Gave guest lecture on the invasion history, biology and status of the European Green crab in Oregon and Washington.	Hatfield Marine Science Center, Newport, Oregon
May 3, 2017	Paige Browning, a reporter for KUOW interviewed me about our paper explaining the appearance of green crabs in the Salish Sea after the 2014-2016 el Niño and warm water "Blob" in the North Pacific.	KUOW news, Seattle,
May 11-13, 2017	Set traps with Bree Yednock, Erica Wilkinson, Ian Rodger, Kara Robbins and Ryan Scott of South Slough Estuarine Research Reserve.	Coos Bay, Oregon Institute of Marine Biology
June 30, 2017	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 6, 2017	Gave seminar to HMSC community on the invasion history and status of the European green crab in the Pacific Northwest.	Hatfield Marine Science Center, Newport, Oregon
Sept. 20, 2017	Gave talk on the status of the European green crab to the Pacific Coast Shellfish Growers/ National Shellfish Association meeting.	Welches, Oregon
October 28, 2017	Gave talk on the status of the invasive European green crab to the State of the Coast Conference	Florence, Oregon

Introduction

European green crabs (*Carcinus maenas)* made their way to the east coast of North America in sailing ships in the early 1800's (Say 1817). They arrived in San Francisco Bay during the 1980's, most likely via aerial shipment of Atlantic seafood or baitworms. From there, green crabs spread naturally via larvae carried in ocean currents, and by 2000, had dispersed as far north as Port Eliza on the northern west coast of Vancouver Island, British Columbia. Presently, green crabs are found around the Bella Bella area on the Central British Columbia coast. 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 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, McDonald and Armstrong 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 to the Central Coast of British Columbia. Year classes were more abundant following the warm winters and springs of 2003, 2005, 2006, 2010, 2015 and 2016. (Behrens Yamada & Gillespie 2008; Behrens Yamada & Kosro 2010, BehrensYamada et al. 2015).

Goals

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

1. Estimating the relative abundance and size/age structure of green crabs in Oregon and Washington estuaries during the summer by using baited Fukui fish traps (Tables 2 and 3).
2. Collaborating with scientists from Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, tribes, and Fisheries and Oceans Canada as well as with shellfish growers and sports fishers in order to compile all existing green crab data for the Pacific Northwest.
3. Estimating year-class strength of 0-age green crabs at the end of their first growing season by setting minnow and pit-fall traps in the high intertidal zone at the end of summer and fall (Figure 2, Appendix 3). These data will predict adult abundance in following years.
4. Comparing patterns in the recruitment strength of 0-age crabs over time and correlating them to ocean conditions such as the Pacific Decadal Oscillation Index for March and southern copepod anomality (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 2017 included one Washington and five Oregon estuaries: Willapa, Tillamook, Netarts, Nehalem, Yaquina and Coos Bay (Figure 1). Additional data for Makah Bay, Grays Harbor, Willapa Bay, Alsea and Coquille were supplied by agency biologist and shellfish growers. All Oregon estuaries were sampled at least twice during the 2017 trapping season, with Coos receiving additional sampling by biologists and interns from the South Slough National Estuarine Research Reserve and students from North Bend High School. Willapa was only sampled once for young-of-the-year crabs. In each estuary, we selected study sites within various habitat types and tidal levels. Since green crabs are rare and patchily distributed, we did not choose our sites randomly. Instead, we preferentially sampled sites that have harbored green crabs in the past such as tidal marshes, gradually sloping mudflats and tidal channels where salinities remain above 15 ‰ and water temperatures range between 12^{o}-22^{o} C in the summer (Behrens Yamada and Davidson 2002). Green crabs are noticeably absent from the cooler, more saline mouths of estuaries, which are dominated by the larger and more aggressive red rock crab, *Cancer productus*

(Hunt and Behrens Yamada 2003). Since *C. maenas* larvae settle high on the shore (Zeng et al. 1999), and crabs move into deeper water as they age (Crothers 1968), we adapted our collecting methods and locations to effectively sample all age classes of *C. maenas.* Since traps differ in their sampling efficiency for different sizes of crabs, we mainly used two trap types (Table 1). Folding Fukui fish traps, with their wide slit-like openings, work well for adult crabs larger than 40 mm carapace width (CW), while crayfish traps with their small mesh size (0.5 cm) retain 0-age green crabs. Green crabs start entering these baited traps when they are around 30 mm in carapace width. Typically, we would trap larger adult crabs in the mid to low intertidal zones with folding Fukui fish traps and 0-age green crabs in the high intertidal vegetation with crayfish traps at the end of their first growing season (Appendix 1).

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

Trap Type	**Description**	**Dimensions**	**Tidal Height**	**Size Selectivity**
Fukui Fish trap	Plastic mesh (2 cm) with two slit openings (45 cm)	63 x 46 x 23 cm	Low to subtidal	>40 mm
Frabill Minnow trap	Wire mesh (0.5 cm) cylinder with two openings expanded to 5 cm	21 cm diameter 37 cm long	Medium to high	30-70 m

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 reported sightings are tabulated in Appendix 2, and those caught during our trapping program in two Excel files:

1. Green Crabs CW2017 Northern Estuaries.xlsx, *2. Green Crabs CW2017 Sorted Coos.xlsx.*

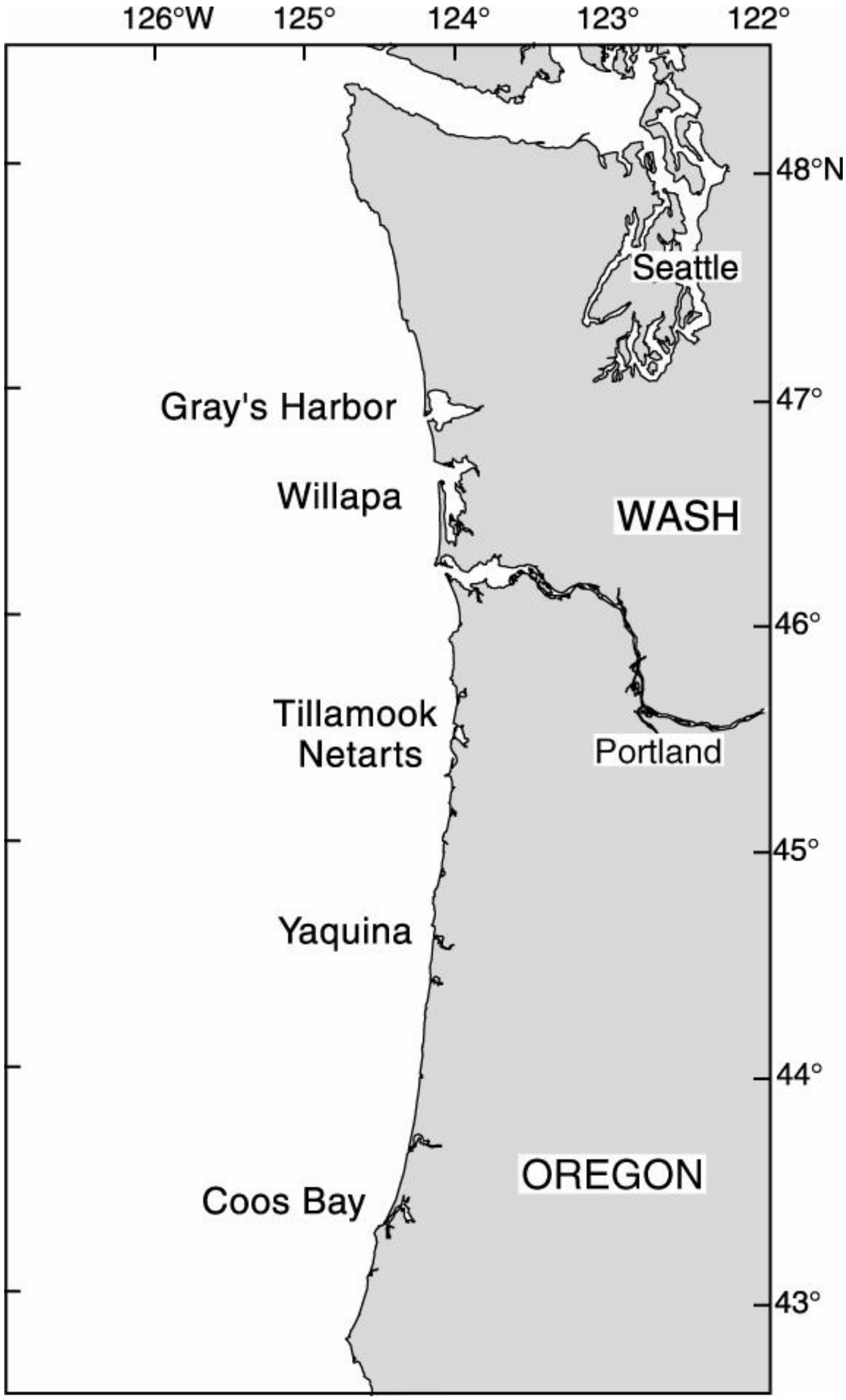

Figure 1. Major sampling sites in Oregon and Washington coastal estuaries.
Data from the Makah, Nehalem, Alsea and Coquille estuaries were added in 2017.

Table 2. Relative Green Crab abundances (# crabs per 100 trap-days) for study sites in Oregon and Washington coastal estuaries. Data for Grays Harbor 2002 and Willapa Bay 2002-2003 and 2013 were kindly supplied by Washington Department of Fish and Wildlife. Supplemental data for Willapa Bay were supplied in 2004, by P. Sean McDonald and in 2016 by Washington Sea Grant-sponsored biologists: Sean McDonald, Emily Grason and Jeff Adams. Funding constraints did not allow us to sample Grays Harbor every year. Sightings for Grays Harbor were provided by Mark Ballo of Brady's Oysters, and for Willapa Bay, by Steve Shotwell of Elkhorn Oysters Company. Mary Sue Brancato from the Olympic Coast National Marine Sanctuary trapped green crabs in Makah and Neah Bay from 2000 to 2003 and in 2007 and 2008, but did not catch any crabs. Asterisk indicates that trapping results include those from near-by Neah Bay and were not used in CPUE calculations.

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
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)
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)
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)
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)
Nehalem																13 (22)
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)
Grays Harbor	5 (1203)	--	--	2 (94)	3 (175)	0 (30)	--	0 (20)	--	--	-	-	-	present	present	present
Makah Bay	0* (9)	0* (4)	0* (6)			0* (13)	0* (30)								present	34 (158)
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)	2037 (1070)

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***
Coos Bay	5	7	13	4	8	**21**	**24**	6	2	7	19	7	1	**24**	**91**	**245**
Yaquina	15	6	3	13	**23**	**21**	15	12	8	7	13	11	5	**63**	**110**	**195**
Netarts	0	**25**	**31**	**49**	**57**	**34**	19	15	15	**24**	14	0	**27**	**83**	**81**	**157**
Tillamook	3	9	8	11	**28**	**16**	1	0	2	0	14	0	13	**40**	**102**	**133**
Nehalem																**59**
Willapa	3.5	3	3	**25**	8	1	0	0	12	0	0	0	0	**40**	6	**43**
Grays Harbor	0.4	-	-	**2**	2	0	-	0	-	-	-	-	-	present	present	present
Makah Bay	0*	0*	0*			0*	0*								present	21
Total	3	6	6	18	16	15	17	7	6	8	15	7	10	**48**	**83**	**190**

Results

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

The relative abundances of green crabs trapped in Oregon and Washington coastal estuaries in 2017 are tabulated in Appendix 1 and summarized in Table 2. Catches of green crabs in Oregon and Washington estuaries decreased after the 1998 colonization event when catch per unit effort (CPUE) ranged from 28 to 192 green crabs per 100 traps. Between 2002 and 2014 average catches had dropped below 20 per 100 traps (Table 2). Slight increases in catches reflect recruitment events in 2003, 2005, 2006, 2010 (Figure 2). The steady increase in catches between 2015 and 2017 can be attributed to the arrival of three strong 0-age year classes. Abundance of green crabs in 2017 decreased with latitude, with Coos Bay harboring the highest densities (Table 2).

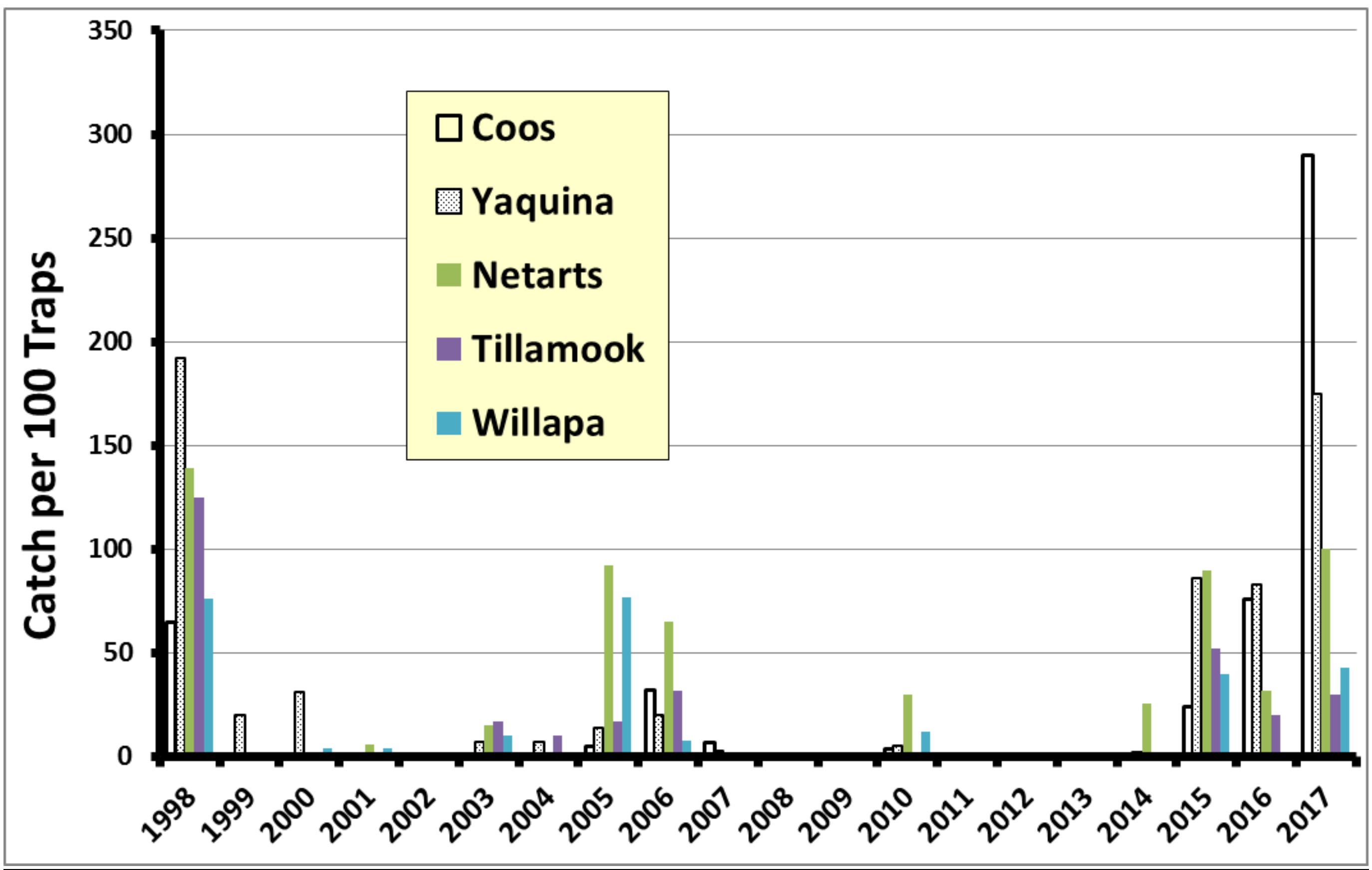

Figure 2. Relative Year Class Strength of 0-age *Carcinus maenas* in Oregon and Washington estuaries. *(Files/Papers/Papers/Ocean Conditions/Data files 2017recruits)*

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

Young-of-the-year (YOTY), or 0-age, green crabs typically enter minnow traps once they reach 30 mm in carapace width in late summer and fall. As can be seen from Figure 2 and Appendix 3, the appearance of 0-age green crabs is synchronous between estuaries. A good year, (or a poor year) in one estuary is a good (poor) year in all the others. In 1998, 0-age green crabs in Oregon and Washington averaged around 100 per 100 traps. Catches in subsequent years remained below this level. However, in the fall of 2017, we caught between 30 and 290 young green crabs per 100 traps, making 2017 the best recruitment year ever (Figure 2). Catches of 0-age crabs tended decrease with latitude, with Coos Bay reporting the higher recruitment.

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

From previous mark and recapture studies, and from shifts in size frequency distributions over time (Behrens Yamada et al. 2005), we estimated the age of green crabs retrieved from Oregon and Washington estuaries in 2017. We assigned crabs to age classes based on their size and coloration (Table 3, and Excel Files: *<u>Green Crabs CW2017 Northern Estuaries.xlsx</u>*, and *<u>Green Crabs CW2017 Sorted Coos.xlsx</u>*.). For example, during the summer, male crabs between 50 and 75 mm carapace width and weighing less than 100 g, with green or yellow carapaces would represent the 2016-year class; crabs 74-84 mm and weighing >100 g the 2015-year class; and those >84 mm and weighing >150 mg, the 2014-year class. Crabs caught in the fall of 2017, ranging from 30 to 55 mm, were assigned to the 2017-year class.

Year class assignment became more difficult in 2017 for two reasons. The 2015 and 2016-year classes did not separate out clearly into distinct peaks along carapace width and weight gradients as was the case in previous years. Likewise, 0-age crabs were only sampled in 6 estuaries in the fall, while most of the intense trapping of adult crabs occurred in Coos Bay during the middle of the summer. For these reasons we feel that the 2017-year class is underestimated and that the relative sizes of the 2015 and 2016-year class estimates is only approximate. In 2017 we detected four year classes with the 2014 year class being the lease abundant. (Table 3).

Table 3. Estimated age structure of *Carcinus maenas* retrieved from Oregon and Washington estuaries in 2017. Totals for each estuary include crabs caught using standard trapping protocol (Table 2), as well as those retrieved by other methods. Mark Ballo kindly provided sightings for Grays Harbor and Steve Shotwell for Willapa Bay. An asterisk indicates that 0-age crabs were not targeted.

Estuary	2017	2016	2015	2014	Total
Coquille	*	1	3		4
Coos Bay	*91*	1033	512	55	1691
Alsea	*	2	1		3
Yaquina	70	75	32	16	193
Netarts	33	2	35	7	77
Tillamook	10	17	30	8	65
Nehalem	*	11	2		13
Willapa	12		2		14
Grays Harbor	4	7	2	1	14
Makah Bay	16	18			34
Total	236	1166	619	87	2108
Percent	11.2	55.3	29.4	4.1	100

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 20 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 and 2017. 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). Pacific Oscillation index for March turned out to be one of the better predictor of year class strength, explaining 68% of the annual variation (Appendix 4). 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. Recently, we found that biological indices, used in salmon forecasting, can also predict green crab year class strength:
https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/index.cfm . Southern copepod

anomaly, northern copepod anomaly, copepod community structure, and the day when the plankton community shifts from being dominated by southern species to, northern species (day of biological transition) are especially good predictors (Behrens Yamada, Peterson and Kosro 2015; Appendix 5).

Discussion

Over 2,000 European green crabs were caught in Oregon and Washington coastal estuaries, yielding an average catch rate of 1.9 crabs per trap. This catch rate is of the same order of magnitude and twice as high as the one observed in 1998 after the 1997/1998 El Niño.

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

Since green crabs live up to 6 years, a recruitment event is needed at least once every 6 years to keep the population from going extinct. Unfortunately, they have managed to persist (Figure 2). While we have observed virtual recruitment failure in 2007, 2008, 2009, 2011, 2012 and 2013 the 2010, 2015, 2016 and 2017-year classes broke the cycle. The last three cohorts will be a potential larval source until 2023. While larvae can be transported north from established populations in Californian during favorable ocean conditions, there is also evidence for local production. During the winter of 2010 first instar zoea were sampled in plankton nets in Coos Bay (Alan Shanks, personal communication). However, it is not known what the relative contribution of these larval sources is and how it might change with ocean conditions and global warming.

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

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Appendix 1. Relative abundance of crab species and sculpins (Numbers/trap/day) in Oregon and Washington coastal estuaries during 2017.

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

Site	Date	Trap Type	Zone	# *green*	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	Number Traps
Kentuck *N 43º 25.299'* *W 124º 11.522'*	7/8/2017	Fish		36	3.27	6.8	0	0	0	0	1.36	11
	7/9/2017	Fish		23	2.1	7.45	0	0.09	0	0	1.9	11
	7/10/2017	Fish		11	1.33	7	0	0.17	0	0	1.3	12
	7/11/2017	Fish		13	1.08	6.58	0	1.33	0	0	0.42	12
	7/12/2017	Fish		14	1.17	5.83	o	1.4	0	0	0.92	12
	7/13/2017	Fish		9	0.75	4.75	0	1.67	0	0	0.5	12
	7/8/2017	minnow		1	0.17	2.5	0	0	0	0	1.17	6
	7/9/2017	minnow		2	0.3	3.83	0	0	0	0	0.36	6
	7/10/2017	minnow		2	0.33	6.3	0	0	0	0	0	6
	7/11/2017	minnow		0	0	4.8	0	0	0	0	0.5	6
	7/12/2017	minnow		0	0	2.83	0	0	0	0	0.5	6
	7/13/2017	minnow		0	0	0.28	0	0	0	0	0.33	6
	9/12/2017	minnow		83	3.32	0.44	0	0.08	0	0	0.16	25
Transpacific Lane South *N 43º 26'34"* *W 124º 13'23"*	5/13/2017	Fish	*Below rip-rap*	10	1.0	0.2	0	2.2	0	0	0.8	10
	5/13/2017	Fish	*Below rip-rap*	33	3.3	0	0	0.6	0	0	0.1	10
	5/13/2017	Fish	*Below rip-rap*	48	4.8	0.4	0	1.8	0	0	0.1	10
	7/22/2017	Fish		36	3	0.75	0	6.8	0	0	0.67	12
	7/22/2017	minnow		4	0.67	4.7	0	0	0.17	0	0.33	6
Under 101 bridge *N 43º 25'58"* *W 124º 13'15"*	5/13/2017	Fish	*Pools*	39	7.8	0	0	0.2	0	0	0.4	5
	5/14/2017	Fish	*Pools*	31	6.2	0	0	0	0	0	0	5
	7/23/2017	Fish		57	4.75	0.58	0	5.25	0	0	1.91	12
	7/23/2017	minnow		6	1	0.17	0	0	0	0	0.67	6
Coos History Museum	6/27/2017	Fish		154	12.83	0.08	0	0.17	0	0	1	12
	7/27/2017	Fish		194	16.2	0.08	0	3.5	0.08	0.08	0.92	12
	6/27/2017	minnow		6	1	1.67	1	0.33	0	0	0.83	6
	7/27/2017	minnow		7	1.17	4	0	0	0	0	0.5	6

Isthmus Slough	6/26/2017	Fish		145	12.08	0	0	3.08	0	0	0.17	12
	7/26/2017	Fish		181	15.08	0.67	0	1	0	0	0.42	12
	6/26/2017	Minnow		10	2	0	0	0	0	0	0	6
	7/26/2017	minnow		9	1.5	1.17	0	0	0	0	1	6
Millicoma Boat Ramp	6/25/2017	Fish		107	8.92	0	0	4.92	0	0	1.42	12
	7/25/2017	Fish		94	7.8	0.33	0	3.3	0.58	0	0.25	12
	6/25/2017	minnow		10	1.67	0.17	0	0	0	0	0.5	6
	7/25/2017	minnow		3	0.5	0.67	0	0.17	0	0	0.5	6
	9/15/2017	minnow		6	1.20	0.1	0	0	0	0	0.4	5
Willanch Creek	6/24/2017	Fish		17	1.7	1	0	1	0	0	4	10
	7/24/2017	Fish		73	6.08	0.92	0	0	0	0	0.66	12
	6/24/2017	minnow		5	0.83	3.83	0	0	0	0	1.5	6
	7/24/2017	minnow		2	0.33	3	0	0	0	0	0.5	6
Hayne's Inlet *N 43º 27' 01"* *W 124º 13'28"*	5/14/2017	Fish	*Below vegetation*	6	0.6	0.8	0	1.0	0	0	0.1	10
Memorial Hyw101	5/14/2017	Fish	*Below Memorial*	15	1.5	0.5	0	0.4	0	0	0.3	10
South Slough sites		Fish and minnow		151	0.50	2.71	0.5	1.62	0	0.01	0.47	302
Total Number				1653								676

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

Site	Date	Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	Number Traps
Johnson Slough *N 44º 34.692'* *W123º 59.333'*	9/23/2017	minnow	*edge of vegetation*	34	3.4	0	0	0	0	0	0.3	10

Sally's Bend A	9/23/2017	minnow	*edge of vegetation*	38	2.33	0.67	0	0	0	0	1	15
N 44º 37.699' *W124º 01.482'*												
HMSC Pumphouse *N 44º 37.408'*	4/9/2017	Fish		3	0.38	0.25	0	0.5		0.5	0	8
W124º 02.576'	6/1/2017	Fish		5	1.0	present	0	2	0	present	0	5
	6/30/2017	Fish		38	4.2	0.67	0	3.2	1.11	1.55	1	9
	4/9/2017	Fish		10	1.43	0.29	0	1.57	0	0.14	0	7
Oregon Coast	6/30/2017	Fish		42	7	0.33	0	0	0	0	1.33	6
Aquarium Mudflat	4/9/2017	minnow		5	0.5	2.8	2.0	0	0	0	0	10
N 44º 37.108'	6/30/2017	minnow		3	0.4	3.3	0	0	0	0	0.3	10
W124º 02.165'	9/23/2017	minnow		7	0.47	0.33	0	0	0	0	0.67	15
Total Number				186								95

Tillamook Bay

Mean CPUE (Catch/trap/day)

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	Number Traps
View Point	5/26/2017	Fish			4.4			*1*	*0.2*			5
N 45º 32.623'	6/23/2017	Fish			2.5			0.75				4
W 123º 54.183'	7/21/2017	Fish			2.4			0.8			0.4	5
	8/24/2017	Fish			2			1.8			0.8	5
Tillamook Spit B	9/25//2017	minnow	*Scirpus*		0.2	0.13					0.2	10
N 45º 30.456' *W 123º 56.615'*	10/7/2017	minnow	*Scirpus*		0.5	1.1					0.3	10
Pitcher Point	9/25/2017	minnow	*Scirpus*		0.4	2.9					0.1	10
N 45º 30.365' *W 123º 56.508'*												
Total Number					65							49

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

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	Number Traps
Boat Ramp												
Intersection	5/25/2017	Fish			3.8	0.2	0.2	10.4	3.4			5
N 45° 24.865'	6/22/2017	Fish			2.4			2.5	0.2	0.4		5
W 123° 56.064'	7/22/2017	Fish-			1.2			4.6	0.2	0.2		5
	9/6/2017	Fish			1.75			8	0.5			4
Whiskey Creek	9/25/2017	minnow	*edge vegetation*		1.0	2	0.25				0.1	20
Salmon Hatchery	10/5/2017	minnow			1.2	1.6						5
N 45° 23.670'												
W 123° 56.214'												
North of Nevor Shellfish	10/5/2017	minnow			1.4	2					0.2	5
Total Number					77							49

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

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	Number Traps
Nehalem State Park	5/28/2017	Fish			1.5							4
N45.7059	6/26/2017	Fish			1.25			7	0.25			4
W123.9329	7/23/2017	Fish			0	1		5.8	1.4		0.2	5
	9/8/2017	Fish			0.5	0.25	0	1.25	0.5			4
Total Numbers					13							22

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

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpins	Number Traps
Stackpole	9/22/2017	minnow	edge vegetation		0.6	0.4	0	1.2	0.2	0	0.7	15

N 46º 35.848' *W 124º 02.195'*		Pit-fall	edge and open mudflat		0	0.7	0.17	2.5	0	0	0	6
Total Number					9							21

Makah Bay

Mean CPUE (Catch/trap/day)

Site		Trap Type	Zone		*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Cancer productus*	Sculpin	Number Traps
Wa'atch Point	10/5/2017	Fish	Mid to High		0							2
		Minnow			0							1
	10/6/2017	Fish			0.5							2
		Minnow			0							1
Tsoo-Yess River	10/5/2017	Fish	River mouth mud flat/ sloughs		0.67							3
		Minnow			1.3							3
	10/6/2017	Fish			0.33							3
		Minnow			1.3							3
Wa'atch River	10/5/2017	Fish	Side sloughs/ channels		0.32							34
		Minnow			0.11							36
	10/6/2017	Fish			0.15							33
		Minnow			0.05							37
Total Number					34							158

Appendix 2. *Carcinus maenas*. Sightings of green crabs from Oregon and Washington coastal Estuaries in 2017. Crabs were assigned to year classes based on the size and condition attained by tagged crabs of known age (Behrens Yamada et al. 2005). Crabs that are green have molted recently, while red crabs have not molted for a long time, in some case well over a year. Missing limbs are numbered in sequence: R1= Right claw; R5= last leg on right side, L1= left claw, L5=last leg on left side. For trapping results see Excel Files:

1. *Green Crabs CW2017 Northern Estuaries.xlsx* and 2. *Green Crabs CW2017 Sorted Coos.xlsx*

Estuary	Site	Date	Sex	Carapace Width (mm)	Weight (g)	color	Year class	Missing limbs	comments
Coquille	Public dock	5/ 27/2017	M	68.75	65.2	Tan	2016		Kristal Talbot/ODFW
Coquille	Public dock	5/27/2017	M	76.9	87.5	Tan/yellow	2015		Kristal Talbot/ODFW
Coquille	Public dock	5/ 27/2017	F	62.87	51.6	Orange	2016		Kristal Talbot/ODFW
Coquille	Public dock	5/ 27/2017	F	51.87	29.9	orange	2016		Kristal Talbot/ODFW
Alsea	2 miles from mouth	6/7//17	M	61		green	2016		Mitch Vance/ODFW
Alsea	2 miles from mouth	7/15/2017	M	72		Orange/barnacles	2015		Mitch Vance/ODFW
Alsea	2 miles from mouth	7/15/2017	F	48		Yellow-orange	2016		Mitch Vance/ODFW
Yaquina	Sawyers	6/23/2017	M	74		orange	2015		Mitch Vance/ODFW
Yaquina	Port Dock 5	7/3/2017	?	2			2017		John Chapman
Yaquina	Sawyers Landing	12/9/2016	M	82		Orange/barnacles	2015		ODFW
Yaquina	Sawyers Landing	12/9/2016	M	84		Orange/barnacles	2015		ODFW
Yaquina	Sawyers Landing	12/9/2016	M	69		Light orange	2015		ODFW
Yaquina	Sawyers Landing	12/9/2016	M	86		Green	2015		ODFW
Yaquina	Sawyers Landing	12/9/2016	M	80		Green	2015		ODFW
Yaquina	Sawyers Landing	12/9/2016	M	79		Green	2015		ODFW
Yaquina	Sawyers Landing	12/9/2016	M	82		Orange and black	2015		ODFW
Yaquina	Sawyers Landing	12/9/2016	M	72		Orange/black/barn acles	2015		ODFW
Willapa Bay	Elkhorn Oyster Co.	Spring	M	74.5		Yellow-orange	2015	Among seed bags	Steve Shotwell
Willapa Bay	Elkhorn Oyster Co	Spring	M	76.2		Yellow-orange	2015	Among seed bags	Steve Shotwell
Willapa Bay	Elkhorn Oyster Co.	September	M	44.5			2017	Harvest bed	Steve Shotwell
Willapa Bay	Elkhorn Oyster Co.	September	M	45.7			2017	Harvest bed	Steve Shotwell

Willapa Bay	Elkhorn Oyster Co.	12/20/2017	M	53.8			2017	Harvest bed	Steve Shotwell
Grays Harbor	Brady's Oysters	May 2017	F	60		Red orange	2016	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	May 2017	F	61		Dull orange	2016	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	June 2017	F	47		Bright orange	2016	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	June 2017	F	60		Red-orange	2016	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	6/19/ 2017	M	77		Bright orange	2015	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	July 2017	M	72		Bright orange	2016	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	August 2017	M	92		Bright orange	2014	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	10/30/2017	F	65		orange	2016	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	11/14/2017	M	60		Green/very soft	2017	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	11/14/2017	M	55		Green/very soft	2017	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	11/14/2017	?	55		Green/very soft	2017	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	12/1/2017	M	92		Yellow-orange	2015	Among oyster bags	Mark Ballo
Grays Harbor	Brady's Oysters	12/1/2017	F	57.1		Green	2017	Among oyster bags	Mar k Ballo
Grays Harbor	Brady's Oysters	12/1/2017	F	73		green	2016	Among oyster bags	Mark Ballo

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

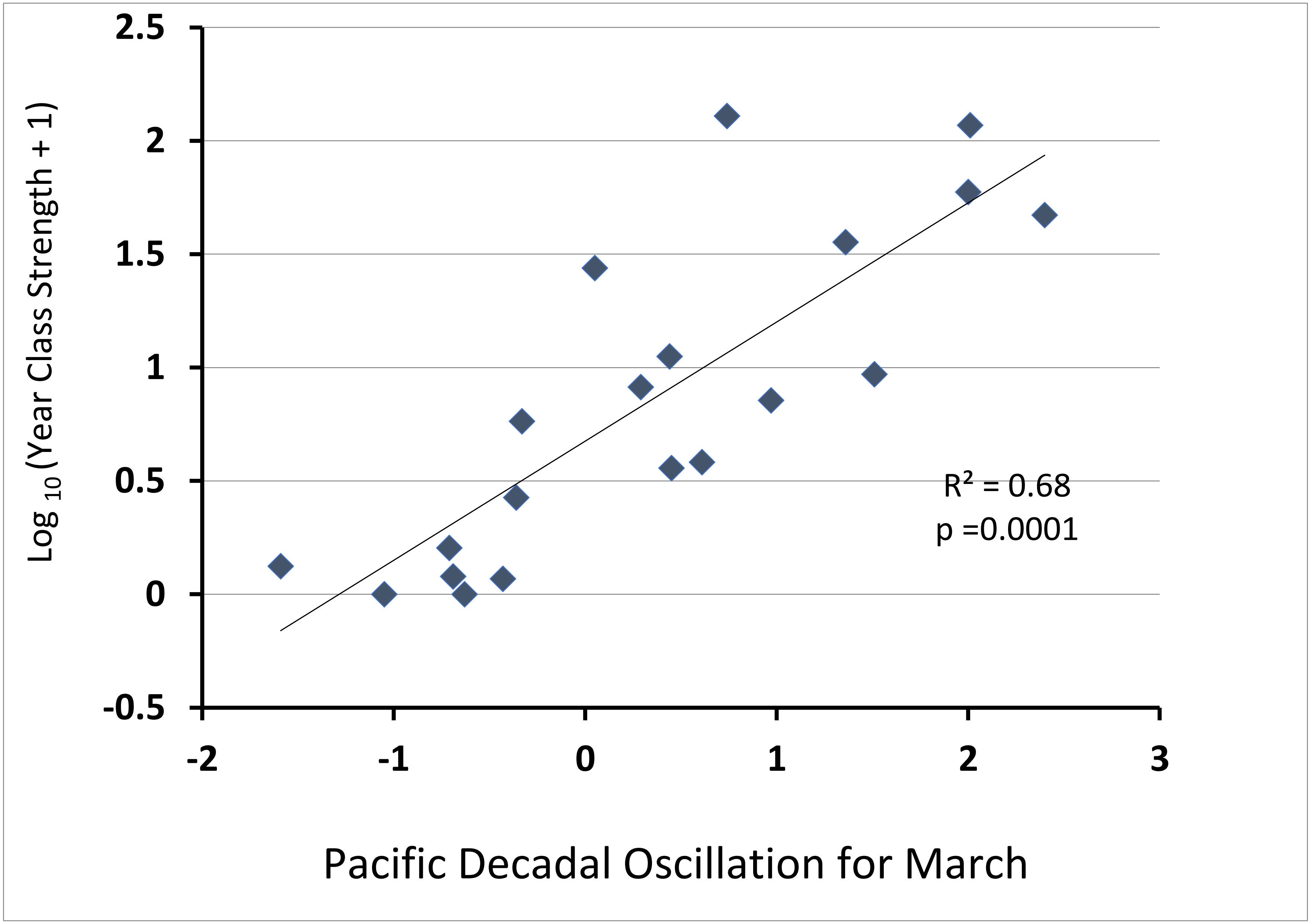
Year Class	Estuary	# Months <10ºC	Mean Winter Temp. ºC	N	CPUE Pitfall traps	CPUE Minnow traps	Mean Carapace Width (mm)	SD	Range
2002	Coos	4	9.6	0		0.00			
2003		**0**	**10.9**	1		0.01	59.4		
2004		**1**	**10.4**	0		0.00			
2005		**2**	**10.3**	2		0.05	45.0		44-46
2006		2	9.9	17		**0.32**	43.5	4.6	36-52
2007		3	9.8	5		0.08	45.4	4.0	43-52
2008		5	8.8	1		0.01	47.0		
2009		4	9.0	0		0.00			
2010		**1**	**10.0**	2		0.04	40.7		40-41
2011		1	9.8	1		0.01	35.5		
2012		4	8.7	0		0.00			
2013		3	9.6			Not Sampled			
2014				2		0.015	46.5		45-47
2015				26		**0.24**	47.9	4.9	32-54
2016				52		**0.76**	37.1	4.9	26-52
2017				87		**2.90**	35.7	5.4	22-52
1998	Yaquina	**0**	**11.2**	201		**5.00**	46.9	5.0	32-60
1999		4	8.8	13	**0.20**		38.0	5.0	30-47
2000		3	9.7	14		**0.31**	37.5	5.0	30-45
2001		3	9.6	Not sampled					
2002		4	9.4	1		0.01	38.9		
2003		**0**	**11.0**	9		0.07	44.9	5.5	41-59
2004		**3**	**10.1**	4		0.07	35.3	5.1	32-43
2005		**2**	**10.1**	21	**0.75**	0.14	41.0	8.4	28-46
2006		3	9.8	18		**0.20**	42.6	5.9	34-51

2007		3	9.5	3		0.03	44.4	7.0	36-49
2008		5	8.4	1		0.02	44.3		
2009		5	8.9	0		0.00			
2010		**1**	**10.1**	8	0.05	0.05	40.8	6.7	30-50
2011		4	9.3	0		0.00			
2012		4	8.7	0		0.00			
2013			9.6	0		0.00			
2014			9.2	2		0.02	45.9		42-49.5
2015				43		**0.86**	44.6	4.8	35-54
2016				30		**0.83**	36.9	7.4	26-53
2017				70		**1.75**	39.1	11.8	17-56
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		**1.10**	36.7	5.4	25-50
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			

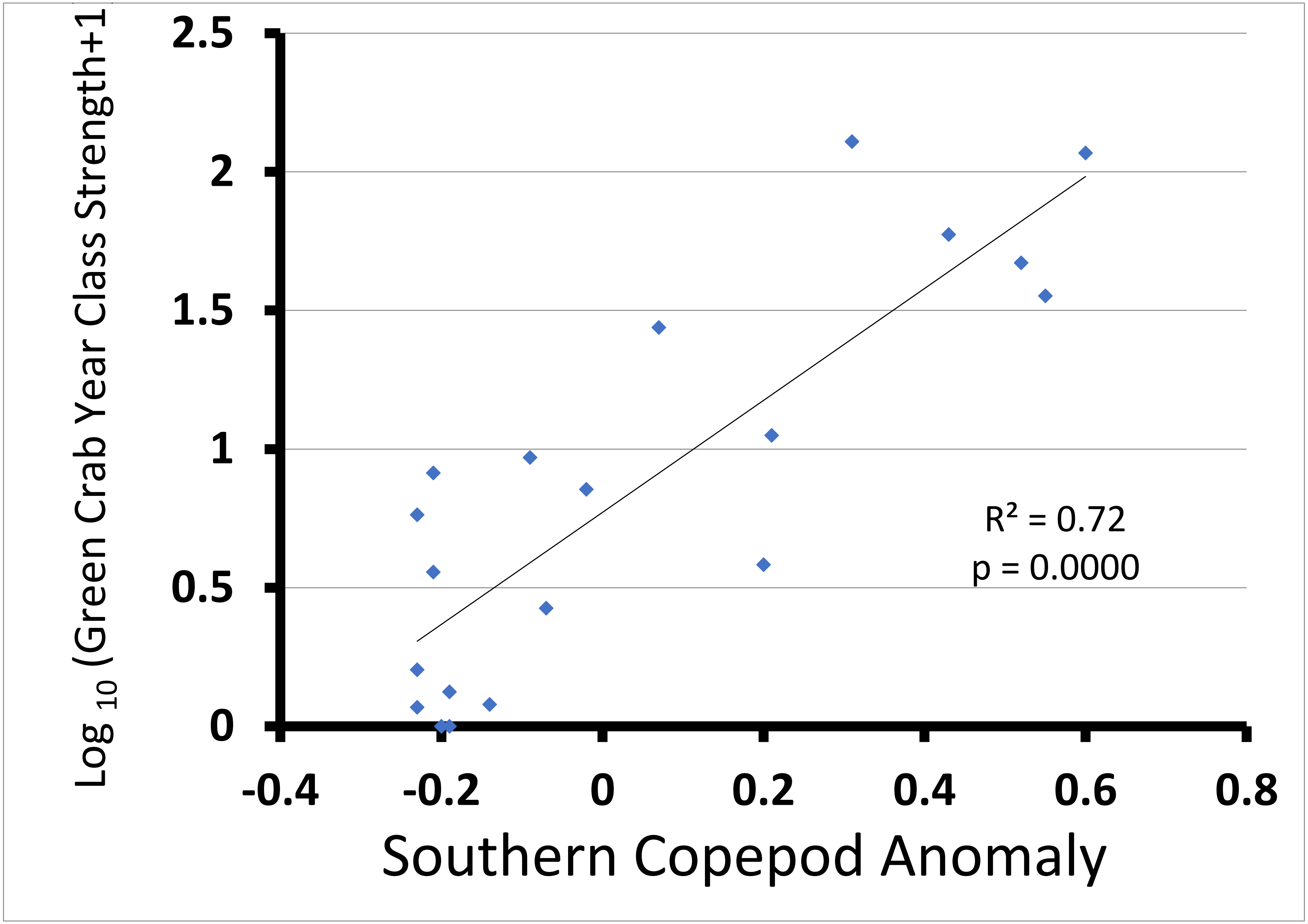
2008				0		0.00			
2009				0		0.00			
2010				0		0.00			
2011				0		0.00			
2012				0		0.00			
2013				0		0.00			
2014				1		0.015			
2015				26		**0.52**	49.2	4.1	44-60
2016				8		**0.20**	45.3	5.3	36-52
2017				11		**0.37**	45.2	7.9	27-57
1998	Willapa	3	8.9	47	**0.778**	**0.74**	45.9	4.0	37-55
1999		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	**0.60**	41.3	6.1	32-50
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			
2003							Not sampled		
2004							Not sampled		
2005				2		0.03	47.3		44-50
2006				1		0.02	49.0		
2007				0		0.00			
2008							Not sampled		
2009				0		0.00	Not sampled		
2010							Not sampled		
2011							Not sampled		
2012							Not sampled		
2013							Not sampled		
2014							Not sampled		
2015							Not sampled		
2016							Not sampled		
2017							56.8	2.0	55-60
2017	Makah Bay						45.6	9.6	24-57

Appendix 4. *Carcinus maenas* year class strength as a function of Pacific Decadal Oscillation for March. Average catch data for the five to six estuaries were log -transformed and regressed against Pacific Decadal Oscillation Index for March. The regression is significant at $p < 0.01$ and explains 68% of the inter-annual variability in year class strength. (This figure is an up-date of Figure 2b in Behrens Yamada, Peterson and Kosro 2015**.)**



Appendix 5. *Carcinus maenas* year class strength as a function Southern Copepod Anomaly (a proxy for southern water sources).


Log 10 (Green Crab Year Class Strength+1
2.5
2
1.5
1
0.5
0
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Southern Copepod Anomaly
R² = 0.72
p = 0.0000