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Status of the
European Green Crab in Oregon and Washington Estuaries
in 2012

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Executive Summary

Once a non-native species arrives and survives in an area, its long-term persistence depends on its recruitment success. If conditions are not favorable for recruitment it will ultimately disappear. 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 15 years. After the arrival of the strong founding year class of 1998, significant self-recruitment to the Oregon and Washington populations occurred only in 2003, 2005, 2006 and 2010. Warm winter water temperatures, high Pacific Decadal Oscillation and Multivariate ENSO (El Niño Southern Oscillation) Indices, late spring transitions and weak southward shelf currents in March and April are all correlated with the these strong year classes (Behrens Yamada and Kosro 2010). Cold winter water temperatures, low Pacific Decadal Oscillation Indices, early spring transitions and strong southward (and offshore) currents in March and April are linked to year class failure. 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. However, this could change if ocean conditions were to switch to a high PDO and strong El Niño patterns. 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.

Extensive surveys by Fisheries and Oceans Canada found green crabs in all the major inlets on the west coast of Vancouver Island, but so far none have been discovered in the inland sea between Vancouver Island and the mainland. Therefore, outreach efforts should continue to prevent the establishment of this invader in the inland waters via ballast water, shellfish transport or other human-mediated vectors.

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 2012

Date	**Talks / Activities**	**Location**
October 15, 2012	"Status of the European green crab in the Pacific Northwest" Presentation and field sampling exercise.	John Chapman's **"**Aquatic Biological Invasions class" (FW 421/521) **Hatfield Marin**e Science Center, ***Newport, Oregon***
April 9, 2012	"Status of the European green crab in the Pacific Northwest" Presentation and field sampling exercise.	Bi 450 class: Marine Biology, Hatfield Marine Science Center, ***Newport, Oregon***
March 2, 2012	"Predicting the success of marine species from ocean conditions" Talk presented with Bryan Black and Bill Peterson.	Oregon Chapter of the American Fisheries Society Meeting, ***Eugene, Oregon***

Date	**Recent Publications**	**Journal**
October 2010	Green crab (*Carcinus maenas*) assessment in Yaquina Bay, Oregon (October 18-21, 2010) and Green crab trapping calibration survey.	Abstract with Graham Gillespie and Katie Marko for PICES Rapid Assessment Survey
August 2010	"Claw morphology and feeding rates of introduced European green crab (*Carcinus maenas* L, 1758) and native Dungeness crabs (*Cancer magister* Dana, 1852)	Manuscript with Tim Davidson and Sarah Fisher published in Journal of Shellfish Research 29 (2):1-7.
May 2010	"Linking Ocean Conditions to Year Class Strength of the invasive European green crab, *Carcinus maenas*"	Manuscript with Mike Kosro published in Biological Invasions12:1791-1804. DOI 10.1007/s10530-009-9589-y

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. 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 yellow 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). 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). Since then, some localized recruitment has occurred in embayments from Coos Bay to the northern west coast of Vancouver Island. Year classes were more abundant following the warm winters and springs of 2003, 2005, 2006 and 2010 (Behrens Yamada & Gillespie 2008; Behrens Yamada & Kosro 2010).

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 <u>size/age structure</u> and relative <u>abundance</u> of green crabs in Oregon and Washington estuaries by using baited Fukui fish traps (Tables 2 and 4).
2. Collaborating with scientists from Oregon Department of Fish and Wildlife, Washington Department of Fish and Wildlife, and Fisheries and Oceans Canada as well as with shellfish growers and sports fishers in order to <u>compile all existing green crab data for the Pacific Northwest (Table 3).</u>
3. Estimating year-class strength of <u>0-age</u> (young-of-the-year) 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 early fall (Figure 2).
4. Comparing <u>patterns in the recruitment strength of 0-age crabs</u> over time and correlating them to ocean conditions: winter surface water temperatures, Pacific Decadal Oscillation Index for March, Day of Spring Transition and alongshore currents for March and April (Appendix 5).

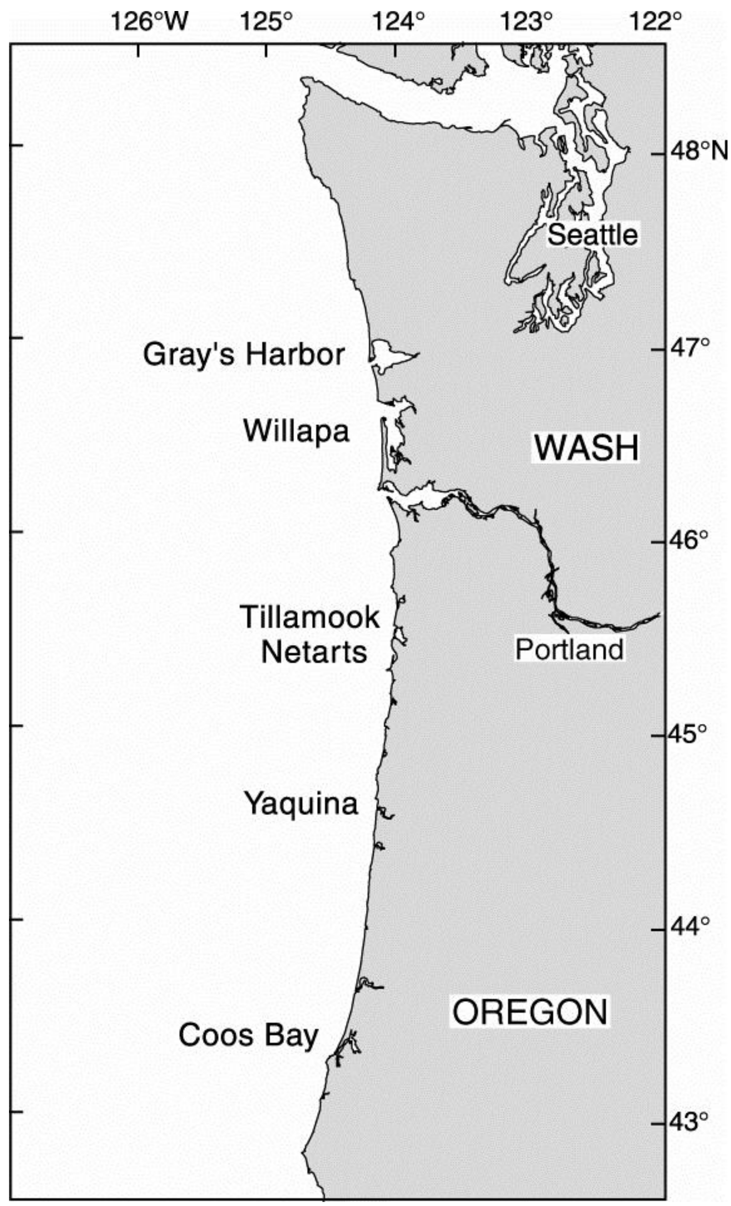


Figure 1. Major sampling sites in Oregon and Washington

Sampling Methods for Green Crabs

Our sampling effort in 2012 focused on one Washington and four Oregon estuaries: Willapa, Tillamook, Netarts, Yaquina and Coos Bay (Figure 1). All estuaries, were sampled at least twice during the 2012 trapping season (Appendix 2). 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 used three 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 minnow traps with their small mesh size (0.5 cm) retain 0-age green crabs. Green crabs start entering these baited traps when they are around 30 mm in carapace width. Pitfall traps are water-filled 5-gallon buckets buried into the sediment so that their rims are flush with the surface of the sediment. They thus trap actively foraging crabs of any size. Pitfall traps were only used at the Stackpole site in Willapa Bay. Typically, we would trap larger adult crabs in the mid to low intertidal and subtidal zones with folding Fukui fish traps and 0-age green crabs in the high intertidal with minnow and pit fall traps at the end of their first growing season (Appendix 2).

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
Folding Fukui Fish Trap	Plastic mesh (2 cm) with two slit openings (45 cm)	63 x 46 x 23 cm	Subtidal to mid-intertidal	>40 mm
Minnow/ Crayfish	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
Pit fall	Water-filled 5-gallon bucket embedded into the sediment	31 cm diameter 37 cm high	High	All sizes

On gravel shores, we added rocks to the minnow 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 (Appendix 3). 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 and destroyed.

Table 2. Relative Green Crab abundances (# per 100 trap-days) for study sites in Oregon and Washington estuaries. Data for Grays Harbor 2002 and Willapa Bay 2002-2003 were kindly supplied by Washington Department of Fish and Wildlife and those for Willapa Bay in 2004, by P. Sean McDonald. Funding constraints did not allow us to sample Grays Harbor every year. Asterisk indicates that most of the crabs came from repeatedly trappings of known "hot-spot", thus inflating abundance estimates.

Estuary	Number of crabs trapped over (number of traps deployed)										
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Coos Bay	9 (180)	14 (203)	18 (137)	9 (242)	22 (273)	52 (246)	65 (276)	18 (292)	6 (259)	18* (244)	41* (213)
Yaquina	26 (168)	63 (1084)	12 (461)	39 (290)	48 (211)	48 (231)	35 (227)	19 (162)	17 (211)	8 (110)	19 (149)
Netarts	0 (44)	11 (44)	12 (39)	52 (106)	47 (82)	35 (103)	17 (89)	13 (86)	14 (95)	19* (80)	5 (35)
Tillamook	2 (71)	6 (70)	4 (51)	12 (102)	41 (147)	15 (93)	1 (100)	0 (113)	2 (90)	0 (60)	5 (35)
Willapa	57 (1640)	13 (409)	6 (195)	113 (449)	19 (245)	4 (318)	0 (98)	0 (35)	2 (17)	0 (37)	0 (42)
Grays Harbor	5 (1203)	--	--	2 (94)	3 (175)	0 (30)	--	0 (20)	--	--	-
Total	99 (3306)	107 (1810)	52 (883)	228 (1283)	180 (1133)	154 (1021)	118 (692)	50 (708)	41 (672)	45 (530)	70 (453)

Estuary	Number of crabs trapped per 100 traps per day										
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Coos Bay	5	7	13	4	8	**21**	**24**	6	2	7*	**19***
Yaquina	**15**	6	3	13	**23**	**21**	**15**	12	8	7	13
Netarts	0	**25**	**31**	**49**	**57**	**34**	**19**	**15**	**15**	**24***	14
Tillamook	3	9	8	11	**28**	**16**	1	0	2	0	14
Willapa	3.5	3	3	**25**	8	1	0	0	12	0	0
Grays Harbor	0.4	--	--	2	2	0	--	0	--	--	--
Total	3	6	6	18	16	15	17	7	6	8	15

Table 3. ***Carcinus maenas*** **catch rates (crabs per 100 trap-days) by embayment in the Pacific Northwest, 1997–2012.** "P" indicates confirmed presence from public reports. British Columbia data were supplied by Graham Gillespie of the Department of Fisheries and Oceans Canada. Asterisk indicates that most of the crabs came from repeatedly trapping known "hot-spots", thus inflating abundance estimates.

	Number of *Carcinus maenas* per 100 trap-days															
Embayment	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Gale Passage											0				6	112
Fish Egg Lake											0				6	0
Quatsino Sound											34			62		
Winter Harbor											**1254**			105		
Klaskino											183			21		
KyuquotSound, BC						P			P	53	38			**1027**		
Amai Inlet														**1388**		
Mary Basin											33					
Tlupana Inlet											3					
Sydney Inlet											150					
Nootka/Esperanza				P	P	P	P		5	38	25		69	15		
Queen Cove										124			117	39		
Clayoqout Snd. BC				P						22	**872**			26		
Pretty Girl Cove										142	196			50		
Barkley Sound. BC			P						P	170	**818**	**1632**	**731**	**530**	**1614**	**3029**
Pipestem Inlet										226	**872**	**2619**	**1369**	**501**	**1946**	**3029**
Esquimalt BC			P													
Sooke																407
Roche Cove																**2100**
Grays Harbor, WA		28	3	3	1	0.4			2	2	0		0			
Willapa Bay, WA		35	43	4	3	3.5	3	3	25	8	1	0	0	12	0	0
Necanicum, OR											P	P				
Tillamook Bay, OR	P	128	P	P	2	3	9	8	11	28	16	1	0	2	0	14
Netarts Bay, OR	P	139			6	0	25	31	49	57	34	19	15	15	24*	14
Nestucca Bay, OR											P	P				
Yaquina Bay, OR	P	192	69	63	57	15	6	3	13	23	21	15	12	8	7	13

Alsea Bay, OR		P				P	P				P		P			
Winchester Bay,		P											P			
Coos Bay, OR	0.2	65	38	P	63	5	7	13	4	8	21	24	6	2	7*	19*
Coquille River, OR		P							5				P	P		

Results

Carcinus maenas Abundance in the Pacific Northwest

The relative abundances of green crabs trapped in Oregon and Washington estuaries in 2012 are tabulated in Appendix 2 and summarized in Tables 2 and 3. As can be seen from Appendix 2, catch per unit effort (CPUE) is extremely variable. Many factors contribute to this variability, including water temperature, wave action, bait type, trap type, tide level, phase in the tidal cycle and the patchy distribution pattern, molt phase, and hunger level of the crabs. Sampling bias also plays a role. When green crabs were rare in Oregon, we focused on known "hot spots" to at least catch a few crabs for age class analysis. For example, most of the crabs caught in Netarts Bay in 2011 and in Coos Bay in 2011 and 2012 came from two hotspots: the "intersection" on Netarts Bay Road and from around a cement bridge footing in John Ney Slough in Coos Bay. One thus must use caution in interpreting differences in CPUE between sites and over time. Minor differences in CPUE are not significant but differences of an order of magnitude would be.

Catches of green crabs in Oregon and Washington estuaries have decreased since the 1998 colonization event when CPUE per 100 traps ranged from 28 to 192 (Table 3). Between 2002 and 2012 average catches had dropped below 20 per 100 traps (Table 2). Slight increases in catches reflect recruitment events in 2005, 2006 and 2010 (Figure 2).

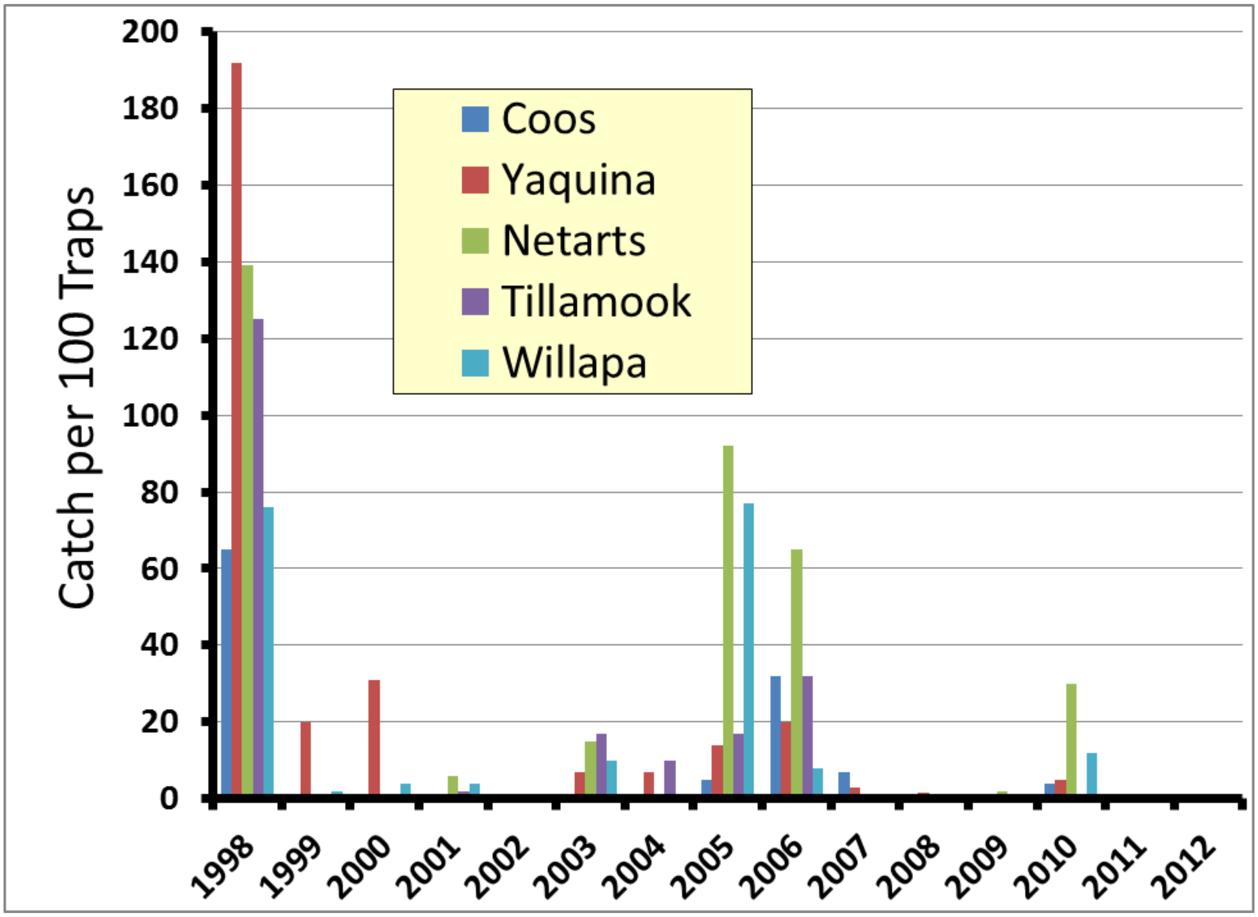
Extensive sampling effort by Fisheries and Oceans Canada, starting in 2006 (Gillespie et al. 2007, Gillespie, pers. com.) reveal an interesting distribution pattern in British Columbia. While no green crabs were trapped in the inland sea between Vancouver, all the inlets sampled on the west coast of Vancouver Island between Quatsino Sound and Barkley Sound yielded green crabs. Densities in many sites were comparable, to those in Oregon and Washington, but those in Pipestem Inlet in Barkley Sound average around 20 per trap in 2007, 2008 and 2011 while those in Amai Inlet averaged 27 per trap in 2010. These catches are two orders of magnitude greater than what has been observed in Oregon and Washington in recent years (Table 3).

Recruitment strength of 0-age *Carcinus maenas*

Young-of-the-year, or 0-age, green crabs typically enter minnow traps once they reach 30 mm in carapace width. Most years, 0-age crabs of this size, and larger, entered our traps by early September, but in 2010 we did not trap them until October. In 2012 we did not trap any 0-age crab during our fall survey.

As can be seen from Figure 2 and Appendix 4, 0-age green crabs were most abundant in 1998 with average catches for the Oregon and Washington estuaries estimated over 100 per 100 traps. The next highest catches were in 2005 and 2006 with averages of 35 and 27 per 100 traps respectively. For all other years average catches averaged below 11 per 100 traps (Figure 2).

Figure 2. Relative Year Class Strength 0-age *Carcinus maenas* in Oregon and Washington estuaries. *(Files/Papers/Ocean Conditions/Data files 2012recruits)*



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 2012. We assigned crabs to age classes based on their size and coloration (Table 4; Appendix 3). For example, during the summer male crabs between 50 and 70 mm, with green or yellow carapaces would represent the 2011 year class and crabs between 70 to 90 mm, the 2010 year class. Larger crabs would represent by the 2009 and older cohorts. The 2010 year class is now the most abundant one, contributing to around 80% of the population (Table 4).

Figure 3. Size Frequency Distribution of Green Crabs caught in the summer of 2012 from Oregon estuaries. The mean size is 80.3 mm and standard deviation is 9.0mm. Crabs smaller than 70 mm most likely represent the 2011 year class, those between 70 and 90 mm, the 2010 year class, and those larger than 90 mm, the 2009 and older year classes.

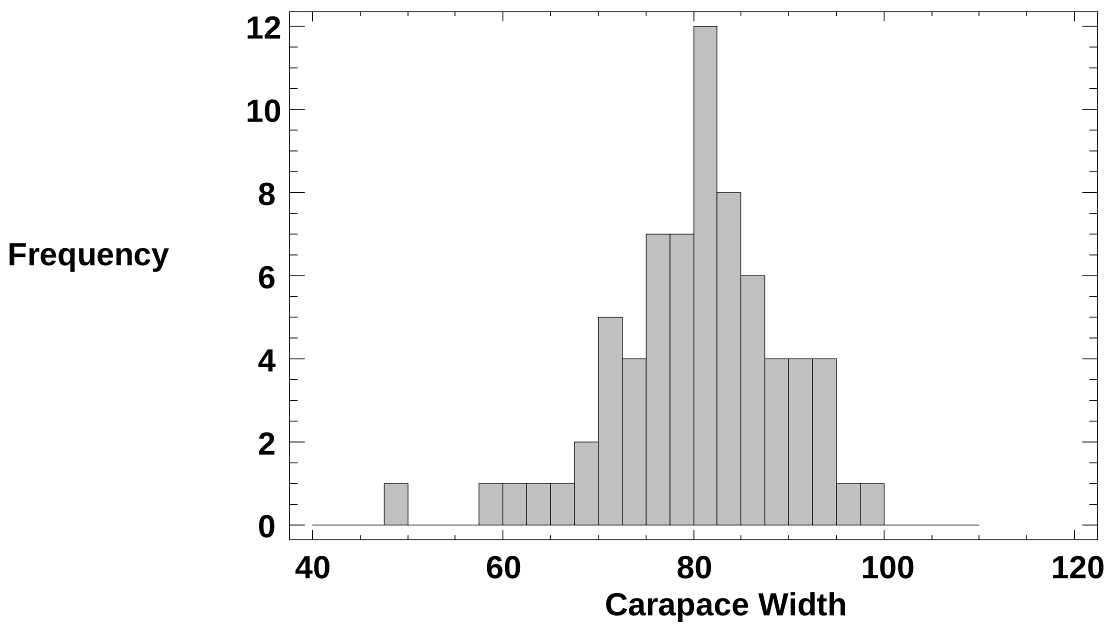


Table 4. Estimated age structure of *Carcinus maenas* retrieved from Oregon and Washington estuaries in 2012. Total crabs include trapped crabs recorded in Table 1 as well as other sightings.

Estuary	2012	2011	2010	older	Total
Coos Bay	0	4	33	4	41
Yaquina	0	2	15	3	20
Netarts	0	1	3	1	5
Tillamook	0	0	5	0	5
Willapa	0	0	0	0	0
Total	0	7	56	8	71
Percent	0	10	79	11	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 15 years. After the arrival of the strong founding year class of 1998, significant self-recruitment to the Oregon and Washington populations occurred only in 2003, 2005, 2006 and 2010. Warm winter water temperatures, high Pacific Decadal Oscillation and Multivariate, ENSO (El Niño Southern Oscillation Indices, late spring transitions and weak southward shelf currents in March and April are all correlated with the these stronger year classes (Behrens Yamada and Kosro 2010). Pacific Oscillation index for March turned out to be the best predictor of year class strength, explaining almost 70% of the annual variation (Appendix 5). Cold winter water temperatures, low Pacific Decadal Oscillation Indices, early spring transitions and strong southward (and offshore) currents in March and April are linked to year class failure. A cool 2011-2012 winter with a negative Pacific Decadal Oscillation Index for March (-1.05) may have depressed the larval supply and may have resulted in the failure of the 2012 year class.

Discussion

Only 70 *Carcinus maenas* entered 448 taps in 2012 yielding an average catch rate of 16 crabs per 100 traps for Oregon and Washington estuaries. This figure is inflated because half of these crabs came from one very productive "hot spot" in Coos Bay. We repeatedly trapped that hot spot in order to obtain an estimate of the age structure of the population. While green crabs in

Oregon and Washington are still rare, they are thriving in some inlets on the west coast of Vancouver (Behrens Yamada and Gillespie 2008 and Gillespie pers. com.). Average catches of over 20 crabs per trap are not unusual (Table 3). 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, one good 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; Appendix 4). When the last crabs of the 98 year class died of senescence in the summer of 2004, the 2003 year class was abundant enough produce larvae in 2005 and adequately “seed” Oregon and Washington estuaries. While we have observed recruitment failure in recent years (2007, 2008, 2009, 2011 and 2012) the 2010 year class broke the cycle. This cohort will be a potential larval source until 2016.

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. Continual cold winter ocean temperatures, low PDO indices and La Niña conditions would result in continual recruitment failures. However, a switch to high PDO and strong El Niño patterns in the next few years would predict green crab population growth.

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 crab in the inland sea between Vancouver Island and the mainland, including Puget Sound and Hood Canal. 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 are retained and not carried out to sea, as appears to be the case on the open Oregon and Washington coasts once the summer upwelling pattern starts (Behrens Yamada and Kosro 2010).

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Appendix 1. Physical data for *Carcinus maenas* sampling sites in Oregon and Washington estuaries. Range of values observed includes sampling times from 2002 to 2012.

Site	Date	Location Description	S ‰	Water Temp.	Air Temp.	Green Crabs Found?
COOS BAY						
Jordan Cove		***Range of values observed***	***5-34***	***14-22***	***14-24***	
N 43° 25.971'	9/18/2012		33	15.5	17	No
W 124° 14.981'	9/19/2012		33	15	16.5	No
	9/21/2012		32	14	15	No
Russell Point		***Range of values observed***	***22-33***	***11-20***	***9-28***	
N 43° 25.974'						
W 124° 13.252'						
Trans Pacific N	6/26/2012		24	24	16	No
N 43° 26.575'	6/27/2012		23	24.5	19.5	No
W 124° 14.434'						
Trans PacificS		***Range of values observed***	***13-33***	***10-18***	***9-27***	
N 43° 26.571'	6/25/2012		24	20	18.5	No
W 124° 13.388'	6/27/2012		25	22	17.5	Yes
Charleston Boat Basin	6/26/2012		31	15.5	17	No
Kentuck Inlet	9/22/2012		16	11	13	No
N 43° 25.299'						
W 124° 11.522'						
Joe Nye Slough	6/27/12		26	19	19	Yes

N 43^o 20.343'	9/19/2012		34	13	14.5	Yes
W 124^o 18.590'	9/21/2012		33	13.5	13.5	Yes
Pony Point		***Range of values observed***	***17-32***	***11-17***	***11.5-18***	
N. Bend Airport	7/03/2012		21	15	14	Yes
N 43^o 25.403'						
W 124^o 14.369'						
YAQUINA BAY						
Johnson Slough		***Range of values observed***	***4-32***	***9-20***	***16-22***	
N 44^o 34.692'	7/17/2012	Below bridge/along creek bank , *Salicornia* patches	21	17.5	18.5	No
W123^o 59.333'						
Sally's Bend A		***Range of values observed***	***22-33***	***12-23***	***12-26***	
N 44^o 37.699'	10/27/12	*Scirpus* patches below intersection	20	11	12	No
W124^o 01.482'						
Sally's Bend B		***Range of values observed***	***29-33***	***12-19***	***12-24***	
N 44^o 37.640'	10/17/12	*Scirpus* patches below George Street	2-	11	12	No
W124^o 00.790'						
Sally's Bend C		***Range of values observed***	***19-32***	***9-19***	***9-22***	
N 44^o 37.419'	7/17/2012	*Zostera marina* zone from by gate to fishing platform	30	15	16.5	Yes
W124^o 01.463'						
Hatfield Marine		***Range of values observed***	***16-34***	***9-21.5***	***8-23***	
Science Center	4/9/2012		25		10	No
Pump house	8/3/2012		32	15	15.5	Yes
N 44^o 37.408'						
W124^o 02.576'						

Oregon Coast		***Range of values observed***	***19-34***	***9-25***	***8-23***	
Aquarium	8/3/2012		33	16	16	Yes
N 44^{o} 37.108’	10/15/12		30	12.5	16	Yes
W124^{o} 02.165’						
Idaho Point		***Range of values observed***	***16-35***	***8-27.5***	***7-23***	
N 44^{o} 36.818’	8/3/2012		34	13	13	Yes
W 124^{o} 01.582’						
TILLAMOOK BAY						
Tillamook Spit A		***Range of values observed***	***0-30***	***9-19***	***7-27***	
N 45^{o} 30.843’		mudflat- eelgrass zone below rip rap and in *Scirpus*				
W 123^{o} 56.738’						
Tillamook Spit B	10/17/12		16	13	12	No
N 45^{o} 30.456’	10/18/12		22	11	9	No
W 123^{o} 56.615’						
Pitcher Point		South of Spit B – mudflat in Japanese eelgrass zone				
N 45^{o} 30.365’	10/18/12		14	11	12	No
W 123^{o} 56.508’						
Hayes Oysters		Along *Scipus* patch	17	11	12.5	No
N 45^{o} 29.370’						
W 123^{o} 55.000’						
Viewpoint	7/20/2012	Viewpoint between Garibaldi and Bay City	16	17.5	20	Yes
N 45^{o} 32.623’						
W 123^{o} 54.183’						

NETARTS BAY						
RV Park N 45^{o} 25.___' W 123^{o} 56___		mud flat east of bridge				
Boat Ramp N 45^{o} 25.832 W 123^{o} 56.827	7/20/2012		24	15	24	No
	10/18/12		14	11	14	Yes
Whiskey Creek Salmon hatchery N 45^{o} 23.670' W 123^{o} 56.214'		***Range of values observed***	***0-34***	***7-20***	***8-21***	
	10/18/12	On mudflat and in creek	13	9	11	No
Intersection of Whiskey Creek & Netarts Bay Roads N 45^{o} 24.865' W 123^{o} 56.064'		***Range of values observed***	***0-34***	***7-20***	***8-23***	
		Pool below culvert draining Freshwater marsh				
WILLAPA BAY						
Stackpole Leadbetter Pt. Sate Park N 46^{o} 35.848' W 124^{o} 02.195'		***Range of Values observed***	***14-30***	***9-19***	***8-28***	
		Edge native vegetation				

Appendix 2. Relative abundance of crab species and sculpins (Numbers/trap/day) in Oregon and Washington estuaries during 2012.

Coos 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
Pony Point/Airport	7/3/12	Fish	*Zostera marina*	0.7			19.1		0.1		10
Kentuck	9/21/12	minnow	*High marsh*				1			0.67	15
	9/22/12	minnow			0.05		0.55			0.1	20
TransPacific Ln. N	6/27/12	Fish	*Mid*				89.2			0.4	5
		Fish									
TransPacific Ln. S	6/25/12	Fish	*Mid*				9.75			0.75	12
	6/27/12	Fish		0.11			5.2			0.67	9
Jordan Cove	9/18/12	minnow	*Scirpus*				0.1			0.71	31
	9/19/12	minnow					0.61			0.42	31
	9/20/12	minnow					0.07			0.47	30
	9/21/12	minnow								0.65	20
Charleston Boat Basin	6/26/12	Fish					1.2		0.4	0.3	10
Joe Ney Slough	6/27/12	Fish		3.8			4.4				5
	6/28/12	Fish		0.5			4				4
	6/29/12	Fish		0.25			7.75				4
	9/20/12	Fish		1.75			6.25				4
	9/21/12	Fish		1.33			5.67				3
Total Number				41							213

Yaquina Bay

Mean CPUE (Catch/trap/day)

Site	Date	Trap Type	Zone	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister* (Recruits)	*Pachygrapsus crassipes*	Sculpins	Number Traps
Johnson Slough	7/17/12	Fish	Below Bridge				4			3.2	2
		Fish									
	10/27/12	Minnow	Marsh	0	0	0	0	0	0	0	10
Sally's Bend A	10/27/12	Minnow	*Scirpus*		0.3	0.2				0.3	15
Sally's Bend B George St	10/27/12	minnow	*Scirpus*	0	0	0	0	0	0	0	5
Sally's Bend C gate	7/17/12	Fish	*Zostera marina*	0.22	0.13	0.13	0.65			3.96	23
HMSC Pump House	4/9/12	Fish	*Zostera marina*				1.73				11
	9/3/12	Fish		0.27	0.09	0.27	0.82	4.0		6.73	11
	4/9/12	Minnow			2.2	1.4	0.4	0.2			5
Oregon Coast Aquarium	8/03/12	Fish	Channels /pools	0.5	5.0		4.33			4.17	6
	10/15/11	Fish		0	0.2		3	3.6		0.2	5
	10/15/12	Fish		0.4	1.6		0.3	1.4		0.4	5
	10/15/11	Minnow			2.18	0.45	0.7	1.1		0.3	20
	10/15/12	Minnow			2.1	0.25		0.15		0.55	20
Idaho Point	8/3/12	Fish	Low	0.55	0.09		6.82	0.09	0.5	4.45	11
Total Number				19							149

Tillamook Bay

Mean CPUE (Catch/trap/day)

Site		Trap	Zone	*Carcinus maenas*	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer magister*	*Cancer magister*	*Cancer productus*	Sculpin	Number

		Type						(Recruits)			Traps
Tillamook Spit B	10/18/12	minnow			0.1					3.1	10
Pitcher Point	10/18/12	Minnow	*Scirpus*		0.2					2.0	5
Hayes Oyster	10/18/12	Minnow	*Scirpus*		0.2		0.2	0.4		2.4	5
Viewpoint	7/20/12	Fish	*eel grass*	0.33			8.33			2.07	15
Total Number				5							35

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 Basin	10/18/12	minnow	vegetation/rocks	0.1	0.8	0.1			0.1	1.5	10
RV Park	7/20/12	Fish	creek /mudflat		0.75	3.5	0.5		0.25	1.25	4
Intersection	7/20/12	Fish	pools	0.67	0.67	1.33	5.33			2.67	6
Whiskey Creek	7/20/12	Fish	Creek/ mudflat		1	0.2	1.2	0.4		1.2	5
Salmon Hatchery	10/18/12	Minnow	*Fucus/* mudflat		0.3	0.3				0.3	10
Total Number				5							35

Willapa 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
Stackpole	10/18/12	Minnow	Edge of native grass	0						0.1	15
	10/131/12	Minnow						0.5		0.9	15
	10/18/12	Pit-fall	Open tideflat	0				0.3			6
	10/31/2012	Pit-fall						0.5			6
Total Number				0							42

Appendix 3. *Carcinus maenas* Catches and Sightings from Oregon and Washington Estuaries in 2012. 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: 1= Right claw; 5= last leg on right side, 6= left claw, 10=last leg on left side.

Estuary	Site	Date	Weight (g)	Carapace Width (mm)	Sex	Missing Limbs/ Conditon	Color of ventral side	Estimated Year Class
Coos	Joe Nye	6/27/2012	26.1	49.2	M		green	**2011**
Coos	Joe Nye	6/27/2012	89.3	77.7	M	1 reg., 6	yellow	2010
Coos	Joe Nye	6/27/2012	131	83.15	M		yellow	2010
Coos	Joe Nye	6/27/2012	130	83	M	1 reg.	yellow	2010
Coos	Joe Nye	6/27/2012	91.8	75.2	M		yellow-green	2010
Coos	Joe Nye	6/27/2012	60.1	63.8	M		yellow-green	2010
Coos	Joe Nye	6/27/2012	114	83.7	M		yellow-orange	2010
Coos	Joe Nye	6/27/2012	72	69.9	M	1 reg	yellow	**2011**
Coos	Joe Nye	6/27/2012	150	83.1	M	left-handed	yellow-orange	2010
Coos	Joe Nye	6/27/2012	136	81	M		yellow	2010
Coos	Joe Nye	6/27/2012	190	97.3	M	1	orange	**older**
Coos	Joe Nye	6/27/2012	146	85.3	M	7	orange	2010
Coos	Joe Nye	6/27/2012	189	93.8	M		yellow-orange	**older**
Coos	Joe Nye	6/27/2012	139	85.7	M	left-handed	yellow	2010
Coos	Joe Nye	6/27/2012	117	80.1	M		yellow-green	2010
Coos	Joe Nye	6/27/2012	184.7	92.7	M		yellow	2010
Coos	Joe Nye	6/27/2012	88	72.3	M		yellow	2010
Coos	Joe Nye	6/27/2012	136	83.7	M	2	yellow	2010
Coos	Joe Nye	6/27/2012	107	73	M		orange	2010
Coos	Joe Nye	6/28/2012	74.7	70.9	F	4,5,9	yellow	2010
Coos	Joe Nye	6/28/2012	125	80.3	M		yellow-orange	2010

Coos	Joe Nye	6/29/2012	99.3	76.2	M	4,10	yellow	2010
Coos	Trans Pacific Lane South	6/27/2012	100	80.9	M	1, head & abdomen damaged	yellow	2010
Coos	North Bend Airport	7/3/2012	180	93.5	M	9	yellow	2010
Coos	North Bend Airport	7/3/2012	92	79.7	M	1,7,8,10	yellow	2010
Coos	North Bend Airport	7/3/2012	68	72.1	M	6	green	2011
Coos	North Bend Airport	7/3/2012	157	87.6	M	2	yellow	2010
Coos	North Bend Airport	7/3/2012	94	76.7	M	1	yellow	2010
Coos	North Bend Airport	7/3/2012	138	87.7	M	6	yellow	2010
Coos	North Bend Airport	7/3/2012	103	79.7	M	6 propus, gill chamber pucture	yellow	2010
Coos	Joe Nye	9/19/2012	78.8	71.2	F		green	2010
Coos	Joe Nye	9/19/2012	109	81	F		green	2010
Coos	Joe Nye	9/19/2012	112.7	82.2	F		yellow-green	2010
Coos	Joe Nye	9/19/2012	171	91.3	M	barnacles of back	yellow-orange	**older**
Coos	Joe Nye	9/19/2012	164.5	88.1	M		yellow-orange	2010
Coos	Joe Nye	9/19/2012	166.4	86.3	M		orange	2010
Coos	Joe Nye	9/19/2012	200	99.9	M	2,3,7,9,10 missing	yellow-orange	**older**
Coos	Joe Nye	9/21/2012	114	81.5	F		green	2010
Coos	Joe Nye	9/21/2012	65.4	67.7	M		yellow	**2011**
Coos	Joe Nye	9/21/2012	154.1	85.2	M		yellow-orange	2010
Coos	Joe Nye	9/21/2012	91.8	75.7	F		green	2010
Yaquina	Sally's Bend -gas tank	7/17/2012		84.5	M		yellow	2010
Yaquina	Sally's Bend -gas tank	7/17/2012		75.8	M	1 regenerating	yellow-orange	2010
Yaquina	Sally's Bend -gas tank	7/17/2012		87.3	M		yellow-orange	2010
Yaquina	Sally's Bend -gas tank	7/17/2012		89.35	M		yellow-green	2010
Yaquina	Sally's Bend -gas tank	7/17/2012		77.1	M		green	2010
Yaquina	Idaho Point	8/3/2012	83	73	M		yellow-green	2010
Yaquina	Idaho Point	8/3/2012	93	73.3	M		yellow-green	2010
Yaquina	Idaho Point	8/3/2012	90	73.9	M		yellow	2010
Yaquina	Idaho Point	8/3/2012	49.5	62.3	F	1	green	**2011**

Yaquina	Idaho Point	8/3/2012	126	80.5	M		yellow	2010
Yaquina	Idaho Point	8/3/2012	184.7	91.1	M	3,7/ dactyl broken/ barnacles	yellow-orange	**older**
Yaquina	HMSC pump house	8/3/2012	187.7	90.9	M	old shell/barnacles	orange	**older**
Yaquina	HMSC pump house	8/3/2012	130.7	81.2	M		yellow-orange	2010
Yaquina	HMSC pump house	8/3/2012	52.7	66.7	F	6	yellow-green	**2011**
Yaquina	Aquarium mudflat	8/3/2012	101	76.6	M	9	yellow	2010
Yaquina	Aquarium mudflat	8/3/2012	129	80.3	M		yellow-orange	2010
Yaquina	Aquarium mudflat	8/3/2012	143.9	83.1	M		yellow-orange	2010
Yaquina	Aquarium mudflat	10/15/2012	200	94.4	M		yellow-orange	**older**
Yaquina	Aquarium mudflat	10/15/2012	127	82.5	M		yellow-green	2010
Yaquina	south of Oyster Farm	9/18/2012		84	M	David Beugli, EPA	yellow-orange	2010
Netarts	Intersection	7/20/2012	38.5	58.7	M	7,8,9	yellow	2011
Netarts	Intersection	7/20/2012	176.5	90.8	M	6	orange	older
Netarts	Intersection	7/20/2012	146.6	87.4	M	2	yellow-orange	2010
Netarts	Intersection	7/20/2012	119.9	81.85	M	9,10	orange	2010
Netarts	Boat Ramp	10/18/2012	93.9	78.1	F	4	green	2010
Tillamook	Viewpoint South of Garibaldi	7/20/2012	99.7	79.1	F	7	orange	2010
Tillamook	Viewpoint South of Garibaldi	7/20/2012	74.9	70.5	M		yellow	2010

Appendix 4. 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 <10°C**	**Mean Winter Temp. °C**	**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		0.01	35.5		
2012				0		0.00			
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			
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			
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			
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				0	0.00	0.00			
2010				2	**0.40**	0.00	43.8		43- 44
2011				0	0.00	0.00			
2012				0	0.00	0.00			
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				

Appendix 5. *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= 0.0001 and explains 69% of the variability. (This figure is an up-dated version of Figure 2b in Behrens Yamada and Kosro 2010.)