January 2011 Version

Status of the European Green Crab in Oregon and Washington Estuaries in 2010

by

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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 13 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 and 2006. Warm winter water temperatures, high Pacific Decadal Oscillation and Multivariate ENSO (El Niño Southern Oscillation) Indices for March, 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 over 100 years for their numbers to build up to a level to decimate the soft-shelled clam industry during the 1950's when warm ocean conditions prevailed.

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 nor north of Vancouver Island. Therefore, outreach efforts should continue to help 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 the Pacific Northwest is still low when compared to Europe, eastern North America, Tasmania and California, 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 since Summer of 2009

Date	Talks / Activities	Location
Oct. 18-21, 2010	PICES Rapid Assessment Survey of European Green crabs in Yaquina Bay. Comparison of trapping methods used in British Columbia and Oregon.	Hatfield Marine Science Center and Yaquina Bay. Coordinated trapping program with Graham Gillespie of DFO Canada.
Sept. 21, 2010	"Status of the European green crab in the Pacific Northwest"	Poster with Graham Gillespie given at the Pacific Coast Shellfish Growers Association, Tacoma, Washington
August 7-8, 2010	"Status of the European green crab in the Pacific Northwest" Presentation and field sampling exercise	Bi 421 and FW421/521 class: Aquatic Biological Invasions, Hatfield Marine Science Center, Newport, Oregon
May 10-12, 2010	Lobbied Oregon Senators and House Representatives to support a bill to screen animal species BEFORE they are imported for the aquarium and pet trade.	Congressional Education Day- sponsored by Union of Concerned Scientists, Washington, D.C.
April 20-30, 2010	"Claw Morphology and Feeding Rates of introduced *Carcinus maenas* and native *Cancer magister*" "Linking Ocean Conditions to Year Class Strength of the invasive European green crab, *Carcinus maenas*"	Gave two talks to Pacific Estuarine Research Society, Nanaimo, British Columbia, Canada
April 5, 2010	"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
Sept. 29, 2009	"Claw Morphology and Feeding Rates of introduced *Carcinus maenas* and native *Cancer magister*" "Linking Ocean Conditions to Year Class Strength of the invasive European green crab, *Carcinus maenas*"	Gave two talks to Pacific Coast Shellfish Growers Association/ National Shellfish Association at Red Lion Inn, Portland, Oregon
Aug. 24-27, 2009	"Claw Morphology and Feeding Rates of introduced *Carcinus maenas* and native *Cancer magister*" "Linking Ocean Conditions to Year Class Strength of the invasive European	Gave two talks to 6th International Conference on Marine Bioinvasions at to Portland State University

	green crab, *Carcinus maenas*"	
July 11-12, 2009	"Linking Ocean conditions to year class strength in the European green crab." Presentation and field sampling exercise	Bi 408/508 class: Biological Invasions in the Marine Environment. Oregon Institute of Marine Biology, Charleston, Oregon
Date	**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 appears to be 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). With the loss of this strong cohort to senescence and the absence of favorable currents to transport larvae from California in recent years, it was predicted that green crabs in Northwest estuaries would go extinct. This has not happened. Some localized recruitment has occurred. Following the warm winters and springs of 2003, 2005 and 2006 local green crab recruitment occurred in estuaries from Coos Bay to Quatsino Sound, BC on the northern west coast of Vancouver Island (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 (Table 2).
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 patterns in the recruitment strength of 0-age crabs 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).

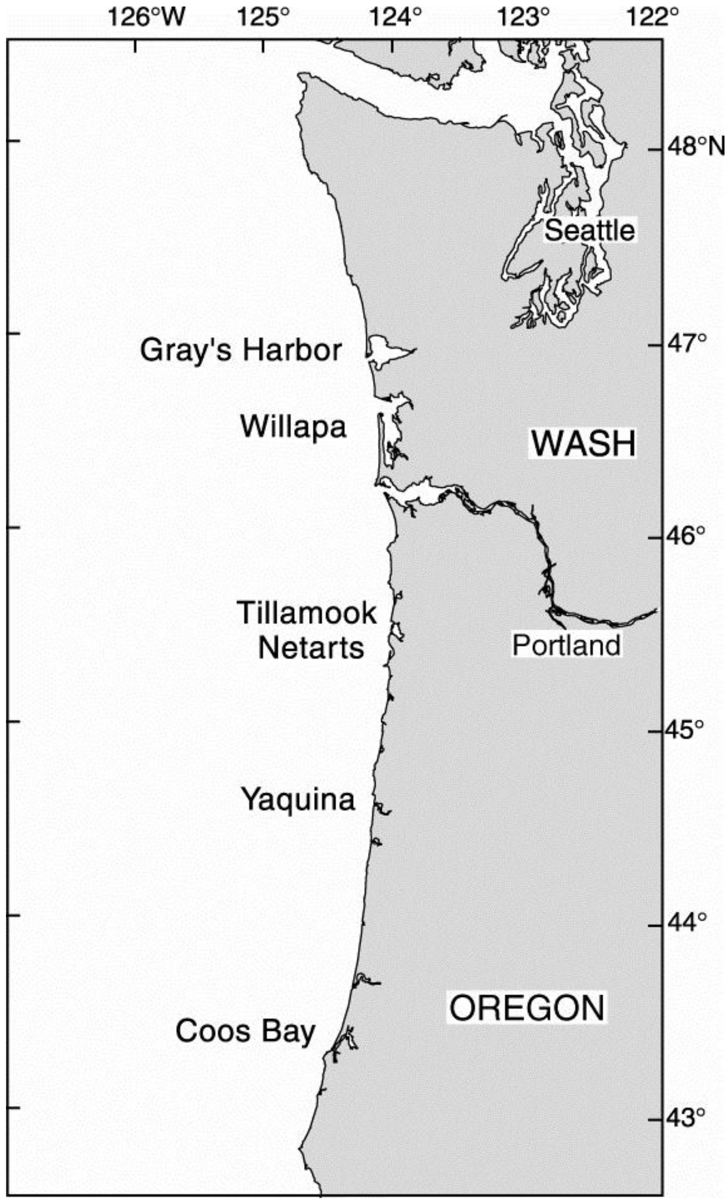


Figure 1. Major sampling sites in Oregon and Washington

Sampling Methods for Green Crabs

Our sampling effort in 2010 focused on four Oregon and one Washington estuaries: Coos, Yaquina, Netarts, Tillamook, and Willapa Bay (Figure 1). All estuaries, except Willapa Bay, were sampled at least three times during the 2010 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. Thus they trap actively foraging crabs of any size. Pitfall traps were primarily used at the Stackpole site in Willapa Bay, but one trap was monitored at Sally's Bend in Yaquina Bay on a weekly basis from August 17 to the end of December to document the arrival of 0-age crabs. Typically, we would trap 0-age green crabs in the high intertidal with minnow and pit fall traps and larger adult crabs in the mid to low intertidal and subtidal zones with folding Fukui fish traps (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 (CW)
Folding Fukui Fish Trap	Plastic mesh (2 cm) with two slit openings (45 cm)	63 x 46 x 23 cm	Subtidal to mid-intertidal	Large >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	Medium-large 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 anteriolateral 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 2004, by P. Sean McDonald.

Estuary	Number of crabs trapped by (number of traps deployed)								
	2002	2003	2004	2005	2006	2007	2008	2009	2010
Coos Bay	9 (180)	14 (203)	18 (137)	9 (242)	22 (273)	52 (246)	65 (276)	18 (292)	6 (259)
Yaquina	26 (168)	63 (1084)	12 (461)	39 (290)	48 (211)	48 (231)	35 (227)	19 (162)	17 (211)
Netarts	0 (44)	11 (44)	12 (39)	52 (106)	47 (82)	35 (103)	17 (89)	13 (86)	14 (95)
Tillamook	2 (71)	6 (70)	4 (51)	12 (102)	41 (147)	15 (93)	1 (100)	0 (113)	2 (90)
Willapa	57 (1640)	13 (409)	6 (195)	113 (449)	19 (245)	4 (318)	0 (98)	0 (35)	2 (17)
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)

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

Table 3. *Carcinus maenas* catch rates (crabs per 100 trap-days) by embayment in the Pacific Northwest, 1997–2010. "P" indicates confirmed presence from public reports. British Columbia data were supplied by Graham Gillespie of the Department of Fisheries and Oceans Canada. Underlined values are still subject to change slightly due to multiple sampling events.

	Number of *Carcinus maenas* per 100 trap-days													
Embayment	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Quatsino Sound											34			62
Winter Harbor											**1254**			105
Klaskino											183			21
KyuquotSound, BC						P			P	53	38			**1019**
Amai Inlet														**2725**
Mary Basin											33			
Tlupana Inlet											3			
Sydney Inlet											150			
Nootka/Esperanza				P	P	P	P		5	38	20		69	13
Queen Cove										124			117	39
Clayoqout Snd. BC				P						20	197			26
Pretty Girl Cove										142	150			38
Barkley Sound. BC			P						P	172	**<u>2202</u>**	**<u>1892</u>**	856	<u>606</u>
Pipestem Inlet											**<u>2202</u>**	**<u>2516</u>**	**<u>1369</u>**	<u>874</u>
Esquimalt BC			P											
Grays Harbor, WA		28	3	3	1	0.4			2	2	0		<1	
Willapa Bay, WA		35	43	4	3	3.5	3	3	25	8	1	<1	<1	12
Necanicum, OR											P	P		
Tillamook Bay, OR	P	128	P	P	2	3	9	8	11	28	16	1	<1	2
Netarts Bay, OR	P	139			6	0	25	31	49	57	34	19	15	15
Nestucca Bay, OR											P	P		
Yaquina Bay, OR	P	192	69	63	57	15	6	3	13	23	21	15	12	8
Alsea Bay, OR		P				P	P				P		P	
Winchester Bay, OR		P											P	
Coos Bay, OR	0.2	65	38	P	63	5	7	13	4	8	21	24	6	2
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 2010 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, 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. For example, when green crabs were rare in Oregon, we focused on known "hot spots" to at least catch a few crabs for age class analysis. 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 have decreased an order of magnitude since the 1998 colonization event when CPUE per 100 traps ranged from 65 to 192 (Tables 2, 3). Between 2002 and 2004 catches had dropped to 3-6 per 100 traps. Averages catches from 2005 to 2008 roughly doubled to 15-18 per 100 traps due to the recruitment of two strong cohorts in 2005 and 2006. In the last two years catches have again decreased to an average of 6-7 per 100 traps due to poor recruitment after 2006.

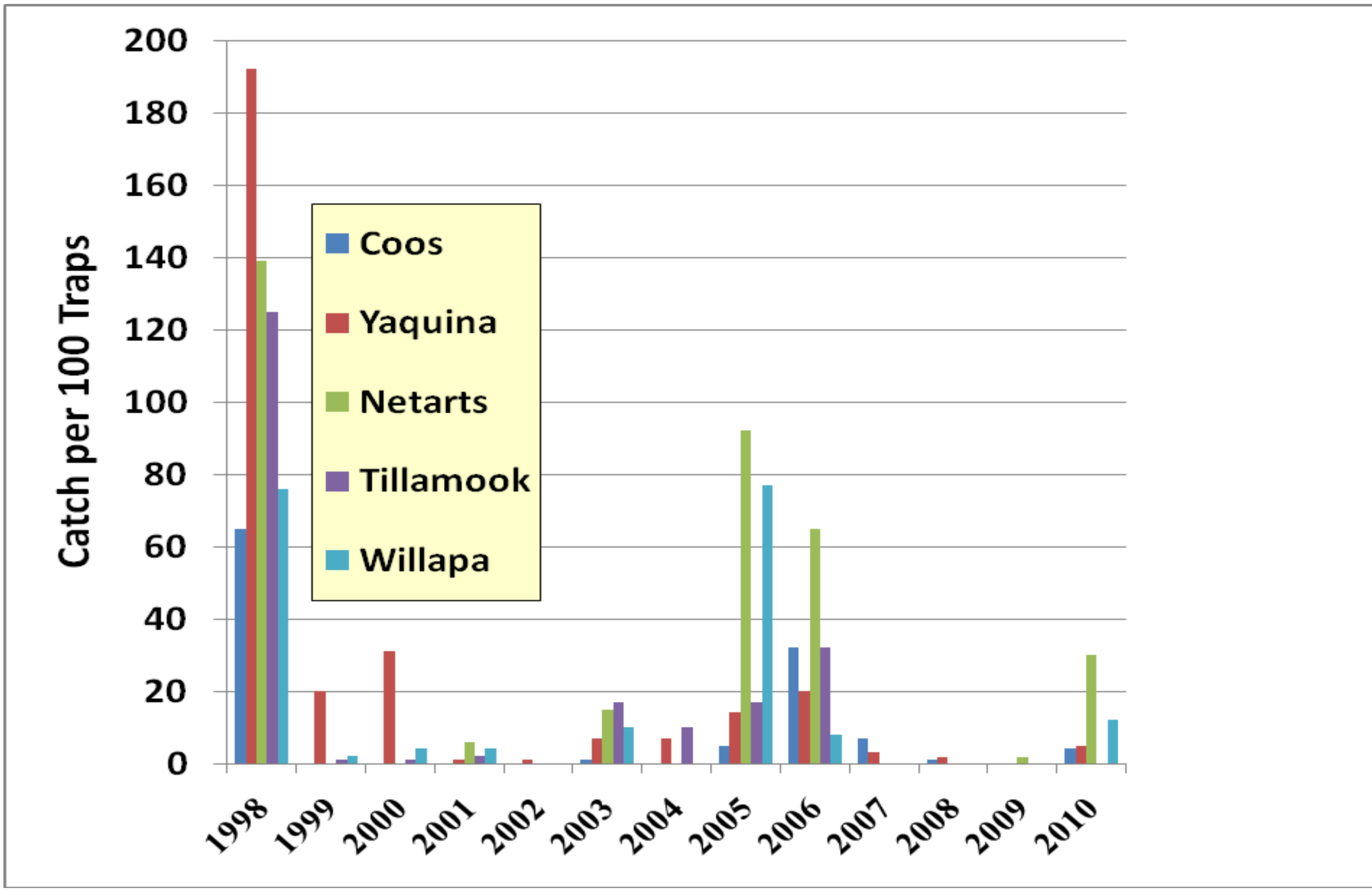
Extensive sampling effort by Fisheries and Oceans Canada, starting in 2006 (Gillespie et al. 2007, Gillespie, pers. com.) reveal an interesting distribution pattern in British Columbia. While no green crabs were trapped in the inland sea between Vancouver Island and the mainland, or north of Vancouver Island, all the inlets sampled on the west coast of Vancouver Island between Quatsino Sound and Barkley Sound yielded green crabs. While densities in many sites were comparable, to those measured in Oregon and Washington, those in Pipestem Inlet in Barkley Sound averaged 22 per trap in 2007 and 2008 and 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 (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. This late detection most likely was linked to a slow growth rate during an unusually cool summer.

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 Recruitment Strength 0-age *Carcinus maenas* in Oregon and Washington estuaries.



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 2010. 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 2009 year class and crabs between 70 to 80 mm, the 2008 year class. Larger crabs would represent by the 2007 to 2005 cohorts. We estimate that crabs from the 2006 and 2005 year classes still represent 57% of the breeding population. The next strongest year class is the 2010 one, with an estimated representation of 32 %. The 2007, 2008 and 2009 year classes have been very weak, representing less than 12% of the population. These year class estimates substantiate the relative recruitment strength of 0-age crabs (Figure 2). Thus the strong 2005 and 2006 cohorts are still be the dominant ones and would be capable of seeding Oregon and Washington estuaries until 2011 and 2012 respectively.

Table 4. Estimated age structure of *Carcinus maenas* retrieved from Oregon and Washington estuaries in 2010. Total crabs include trapped crabs recorded in Table 1, sports catches, crabs found by shellfish growers and two molted carapaces found in Netarts Bay.

Estuary	2010	2009	2008	2007	2005/06	Total
Coquille					1	1
Coos Bay	2	0	0	1	3	6
Yaquina	5	2	0	1	12	20
Netarts	8	1	0	1	7	17
Tillamook	0	0	0	0	7	7
Willapa	2	0	0	0	0	2
Grays Harbor						
Total	17	3	0	3	30	53
Percent	32	5.7	0	5.7	56.6	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 13 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 and 2006. Warm winter water temperatures, high Pacific Decadal Oscillation and Multivariate ENSO (El Niño Southern Oscillation) Indices for March, 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, 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. Ocean indices (winter water temperature, day of spring transition, a March PDO of 0.44) in 2010 all predicted a moderate green crab recruitment event. However, no 0-age crabs were detected by the end of September. It was not until October that 0-age crabs entered out traps. It remains to be seen how well this year class will survive its first winter.

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 once the 2005 and

2006 year classes die of senescence. Continual cold winter ocean temperatures, low PDO indices and La Niña conditions would result in continual recruitment failure. However, a switch to high PDO and strong El Niño patterns in the next few years would predict green crab population growth.

Discussion

Only 41 *Carcinus maenas* entered 672 taps in 2010 yielding an average catch rate of 6 crabs per 100 traps for Oregon and Washington estuaries. The fact that 57 % of the crabs could be attributed to the 2005/2006 year classes supports our observation that the last strong cohort entered the population in 2006. While green crabs in Oregon and Washington are still rare, they are thriving in some inlets on the west coast of Vancouver between Quatsino Sound and Barkley Sound (Behrens Yamada and Gillespie 2008 and Gillespie pers.com.). Two hot spots were found on our 2007 cruise around Vancouver Island: Winter Harbor in Quatsino Sound with an average of 12 green crabs per trap and Pipestem Inlet in Barkley Sound with 22 per trap. One trap in Pipestem Inlet yielded 195 green crabs. In 2010, a new hot spot was found in Amai Inlet with an average catch of 27 crabs per trap. 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 5 years to keep the population from going extinct. When the last crabs of the 98-cohort died of senescence in the summer of 2004, the 2003 year class became the dominant one in Oregon and Washington estuaries. Even though the 2003 cohort was less abundant than the 1998 one, it must have produced enough larvae in 2005 to adequately “seed” Oregon and Washington estuaries, thus preventing the population from going extinct (Figures 2; Appendix 4). In 2006, another strong year class was detected in Oregon, but not in Washington, estuaries. These two year classes have dominated the population in recent years as poor recruitments occurred in 2007, 2008 and 2009 (Figures 2, Appendix 4). 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.

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.

Acknowledgements

We thank Graham Gillespie, Scott Groth, Katie Marko, Katie Wrubel, Russ Yamada and Kyle Yamada for help with field sampling. Sightings of green crabs were reported by Scott Groth, of the Oregon Department of Fish and Wildlife, Cleope Jacobs and Wayne Walker. We thank the staff and faculty of the Oregon Institute of Marine Biology for their hospitality while sampling in Coos Bay. Data for Vancouver Island were provided by Graham Gillespie of Fisheries and Oceans Canada. Bait was provided by Harry's Fresh Fish of Corvallis, Chuck's Seafood in Charleston, the Seafood Deli in Newport and Scott Growth of the Oregon Department of Fish and Wildlife.

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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 2010.

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'	9-07-10		30	16.5	16.5	no
W 124° 14.981'	11-04-10		30	12.5	15	yes
Russell Point		***Range of values observed***	***22-33***	***11-20***	***9-28***	
N 43° 25.974'	6-25-10		21	13	13	yes
W 124° 13.252'	9-07-10		31	18.3	18.3	no
Trans Pacific N	6-25-10		19	15.1	13.3	no
N 43° 26.575'						
W 124° 14.434'						
Trans PacificS		***Range of values observed***	***14-33***	***10-18***	***9-27***	
N 43° 26.571'	3-18-10		14	10.3	8.5	no
W 124° 13.388'	3-19-10		26	11.6	11.7	yes
	6-25-10		21	15.6	14.8	no
Haynes Inlet	9-07-10		30	16.5	16.5	no
N 43° 27.003' W 124° 13.478'						
Clausen's Oysters	6-24-10		15	17.5	14	no
N 43° 26.911'						
W 124° 12.209'						
Kentuck Inlet	9-07-10		30	16.5	16.5	no
N 43° 25.299'	11-06-10		25	13.5	15.5	no
W 124° 11.522'						
Joe Nye Slough N 43° 20.343'		Mudflat from *Zostera marina* to high zone Hotspots = near undercut bridge piling				
W 124° 18.590'	6-24-10		13	16.5	13	yes

Pony Point		***Range of values observed***	***17-32***	***11-17***	***11.5-18***	
N. Bend Airport	6-25-10	Mudflat near rip rap, *Zostera marina* zone	20	13.7	12.5	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’	6-15-10	Below bridge/along creek bank , *Salicornia* patches	6	16	21	no
W123^{o} 59.333’	8-08-10		30	17	14	no
	10-08-10		28	15	16.5	yes
Sally’s Bend A		***Range of values observed***	***22-33***	***12-23***	***12-26***	
N 44^{o} 37.699’	7-11-10	*Scirpus* patches below intersection	29	18	20	no
W124^{o} 01.482’	8-08-10		32	14	16	no
	10-08-10		31	13.3	17	no
Sally’s Bend B		***Range of values observed***	***29-33***	***12-19***	***12-24***	
N 44^{o} 37.640’		*Scirpus* patches below George Street				
W124^{o} 00.790’	8-08-10		32	14	16	no
	10-08-10		31	13.3	17	no
Sally’s Bend C		***Range of values observed***	***19-32***	***9-19***	***9-22***	
N 44^{o} 37.419’	6-15-10	*Zostera marina* zone from gate to Fishing platform		tide out		yes
W124^{o} 01.463’	7-11-10		29	18	20	no
	8-18-10		32	14	16	yes
	8-23-10		35	16	18	yes
	8-30-10		29	14	17	no
	9-9-10		34	17	19	no
	9-23-24		31	15	15	no
	10-21-10					
Hatfield Marine		***Range of values observed***	***16-34***	***9-21.5***	***8-23***	
Science Center	4-5-10			10.5		yes
Pump house	7-11-10		30	15	16.5	no
N 44^{o} 37.408’	8-07-10		32	12	14	no
W124^{o} 02.576’	10-21-10		33	11.5	12.5	no
Oregon Coast		***Range of values observed***	***19-34***	***9-25***	***8-23***	

Aquarium N 44° 37.108' W124° 02.165'	6-15-10		23	14	16	no
	7-11-10		30	15	16.5	no
	8-07-10		33	13	14.5	yes
	10-21-10		30	11.5	12.6	no
Idaho Point		***Range of values observed***	***16-35***	***8-27.5***	***7-23***	
N 44° 36.818'	6-15-10		24	16	14.5	yes
W 124° 01.582'	10-21-10		33	11.5	12.5	yes
TILLAMOOK BAY						
Tillamook Spit A		***Range of values observed***	***0-30***	***9-19***	***7-27***	
N 45° 30.843'	6-18-10	mudflat- eelgrass zone below rip rap and in *Scirpus*		tide out	15	no
W 123° 56.738'	8-23-10		31	18.2	18.4	no
Tillamook Spit B	6-18-20		0	13	15.5	no
N 45° 30.456'	8-23-10		30	20	18	no
W 123° 56.615'	10-09-10		26	14	16	no
Pitcher Point		South of Spit B – mudflat in Japanese eelgrass zone				
N 45° 30.365'	10-09-10		26	14	16	no
W 123° 56.508'						
Garibaldi N 45° 33.307' W 123° 54.682	7-25-10	eel grass bed across from marina	16	14	12	no
Old Mill Marina N 45° 33.169' W 123° 54.319	7-25-10	on either side of boat ramp/ all along floats	5	14	14	no
Viewpoint N 45° 32.623' W 123° 54.183'	7-26-10	Viewpoint between Garibaldi and Bay City	21	15	13	yes
NETARTS BAY						
RV Park	6-18-10	mud flat east of bridge	0	13	16	no
N 45° 25.___'	7-25-10		0	13	12	no
W 123° 56___	10-9-10		29	13.5	15	yes

Boat Ramp						
N 45° 25.832 W 123° 56.827						
Whiskey Creek		***Range of values observed***	***0-34***	***7-20***	***8-21***	
Salmon hatchery	6-18-10	On mudflat and in creek	0	14	14.5	yes
N 45° 23.670’	7-25-10		4	18	13	no
W 123° 56.214‘	8-23-10		5	19	17.5	no
	10-09-10		31	16.8	16.8	yes
Paddle Creek	6-18-10	Between intersection and Mile 2	0	17	16	yes
N 45° 24.438’ W 123° 55.896‘						
Intersection of		***Range of values observed***	***0-34***	***7-20***	***8-23***	
Whiskey Creek	6-18-10	Pool below culvert draining Freshwater marsh	0	17	16	yes
& Netarts Bay	7-25-10		33	13	12	yes
Roads N 45° 24.865’ W 123° 56.064’	8-23-10		31	19.5	20	no
WILLAPA BAY						
Stackpole		***Range of Values observed***	***14-30***	***9-19***	***8-28***	
Leadbetter Pt.	10-06-10	Edge native vegetation	20	13.3	14.4	yes
Sate Park						
N 46° 35.848’						
W 124° 02.195’						

Appendix 2. Relative abundance of crab species and sculpins (Numbers/trap/day) in Oregon and Washington estuaries during 2010.

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
Russell Point	6-25-10	Fish	Pools by bridge		0.2		38.6			4.6	5
	6-26-10	Fish	*Zoster marina*	0.2			36.6			0.4	5
	9-07-10	Fish					73.6			0.2	5
Pony Point/Airport	6-25-10	Fish	*Zostera marina*	0.1		0.2	10.7		0.9	1.7	10
Haynes Inlet	9-07-10	Minnow	*Scirpus*				0.4				5
Clausen's Oysters	6-24-10	Fish	*Mid*		0.7		18.1			3.6	15
Kentuck	9-07-10	minnow	*High marsh*		0.1		0.9			0.45	20
	11-6-10	minnow			0.13						30
TransPacific Ln. N	3-19-10	Fish	*Mid*		0.4		0.7				10
	3-20-10	Fish			0.1		0.1	0.2			10
	3-21-10	Fish			0.3		0.3	0.4			10
	6-25-10	Fish					35.7			1.1	9
	6-26-10	Fish					75.9			0.4	10
TransPacific Ln. S	3-19-10	Fish	*Mid*				1.9	0.9			10
	3-20-10	Fish		0.1			1.7				10
	3-21-10	Fish					2.5	0.1			10
	6-25-10	Fish					90.6				10
	6-26-10	Fish					69.9			1.6	20
Jordan Cove	9-07-10	minnow	*Scirpus*							0.68	25
	11-6-10	minnow		0.1						0.1	20
Joe Ney Slough	6-24-10	Fish		0.1			27			1.0	10
Total Number				6							259

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	6-15-10	Fish	Below Bridge				0.8			5	5
	8-18-10	Fish					3			3	2
		Fish									
	8-18-10	Minnow	Marsh							1.8	5
	10-08-10	Minnow	Marsh	0.2	0.5					0.5	10
	10-21-10	minnow			0.9					0.1	10
Sally's Bend A	7-11-10	Minnow	*Scirpus*		0.6					4.6	11
	8-18-10	minnow								1.33	6
	10-08-10	minnow			0.07	0.13					15
	10-21-10	minnow		0.1	0.1						10
Sally's Bend B	8-18-10	minnow	*Scirpus*					0.2		0.4	5
	10-08-10	minnow			0.6						4
Sally's Bend C gate to Fishing Platform	6-15-10	Fish	*Zostera marina*	0.3			4.5			1.2	10
	7-11-10	Fish				0.1	24.8	0.3		0.2	11
	8-18-10	Fish		0.5			1.5		2	1	2
	8-23-10	Fish		0.5			6			0.5	2
	8-30-10	Fish					2			1.5	2
	9-9-10	Fish					3			0.5	2
	9-23-24	Fish					6.5			2	2
	10-21-10	Fish		0.2	0.1		0.7	0.1		0.2	10
HMSC Pump House	4-5-10	Fish	*Zostera marina*	0.2	0.2		2.4	0.3	1.3		10
	7-11-10	Fish			0.1		0.6	0.1	1.2	3.5	10
	8-07-10	Fish					0.6	1.6		1	5
	10-21-10	Fish				0.1	2.7	0.1	1.2	0.3	10
Oregon Coast Aquarium	6-15-10	Fish	Channels /pools		6.6		0.8	5.8		20.2	5
	8-07-10	Fish	pools	0.4	0.4			2.4		1.8	5

	6-07-10	Minnow	*Scirpus*		0.1			2.9		1.4	11
	10-21-10	Minnow			0.2			16.3			10
Idaho Point	6-15-10	Fish	Low	0.2	0.9		9.4	0.3		8.6	10
	10-21-10	Fish		0.09	0.18		4.8	0/2		0.2	11
Total Number				17							211

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
Tillamook Spit A	6-18-10	Fish	*Z. japonica*		0.1		0.3			11.1	12
	8-24-10	Fish					5				1
	8-24-10	Minnow	*Scirpus*				0.6			1.2	5
Tillamook Spit B	6-18-10	Fish	*Tidal chanel*							33.3	3
	8-24-10	Fish					5			5	1
	8-24-10	Minnow	*Scirpus*							1.8	10
	10-09-10	Minnow								0.2	10
Pitcher Point	10-09-10	Minnow	*Scirpus*							0.1	10
Garibaldi Marina	7-26-10	Fish	*eel grass*				17.9			0.2	9
Old Mill Marina	7-26-10	Fish	*mid and low*				23.6			2.1	11
	7-27-10	Fish					4.3			1.1	8
Viewpoint	7-27-10	Fish	*eel grass*	0.2			16.7			3.4	10
Total Number				2							90

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	10-09-10	minnow	vegetation/rocks	0.2	1.2	0.4				0.6	5
RV Park	6-18-10	Fish	creek /mudflat		0.5				22.5	5	5
	7-27-10	Fish					1.6			2.4	5

Intersection	6-18-10	Fish	pools	1	1.6		10.6			5	5
	7-26-10	Fish			6	1.4	7.8			6.8	5
	7-27-10	Fish		0.2	4.6	1.2	4.2			4.0	5
	8-25-10	Fish			1		15.8				5
Paddle Creek	6-18-10	Fish		0.5	1	15	12			5	2
Whiskey Creek	6-18-10	Fish	Creek/ mudflat	0.5	0.5		1.5	0.5		3	2
Salmon Hatchery	7-27-10	Fish			2.8	0.1	2.1			3.8	8
	8-25-10	Fish									1
	6-18-10	Minnow	*Fucus*/ mudflat		0.25	0.5				0.5	4
	7-27-10	Minnow			0.1	0.5				2.1	10
	8-25-10	Minnow			0.06	0..28	0.11			0.44	18
	10-09-10	Minnow		0.33	0.07		0.13			0.6	15
Total Number				14							95

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	10-07-10	Minnow	Edge of native grass	0							12
	10-07-10	Pit-fall	Tide flat	0.4							5
Total Number				2							17

Appendix 3. *Carcinus maenas* Catches and Sightings from Oregon and Washington Estuaries in 2010. 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	Sex	CW	Color	Estimated Year Class	Condition/Comments
COQUILLE		7-16-10	M	85	orange	2005/06	sports catch
COOS	Airport /Pony Pt	6-24-10	F	79.69	orange	2006	No #6; #1 Dactyl chipped; no eggs
	Under 101 Bridge	6-25-10	M	87.8	yellow	2006/07	no #6
	Jordan Cove	11-06-10	M	40	green	**2010**	good
	Jordan Cove	11-06-10	M	41.4	green	**2010**	good
	Trans Pacific South	3-10-10	M	73.5	yellow-orange	2008?	missing #1 claw
	Joe Neye Bridge	6-23-10	M	80.5	red orange	06 or 07	perfect shape
YAQUINA	Johnson Creek	10-8-10	M	49.9	green	**2010**	good
	Johnson Creek	10-8-10	M	45.3	green	**2010**	no #1
	Sally's Bend A intersection	10-2-10	F	30.4	green	**2010**	good
		10-19-10	M	38.7	green	**2010**	good
		10-21-10	M	32.5	green	**2010**	good
		10-26-10	F	40.4	green	**2001**	good
		10-26-10	M	43.6	green	**2001**	good
		11-05-10	F	45.6	green	**2010**	good
	Sally's Bend C by fence to fishing platform	6-15-10	M	92.4	yellow	05/06	Small barnacles
		6-15-10	F	75.6	Orange-red	07	Small barnacles
		6-15-10	M	91.8	Orange-red	05/06	#1 dactyl chipped; #6 regenerating
		8-12-10	F	83.6	orange	05/06	#2 missing /barnacles on back
		8-23-10	M	96.5	yellow orange	05/06	#1 missing /barnacle
		10-21-10	F	76	yellow	05/06	#1 regenerating
		10-21-10	M	91.5	yellow orange	05/06	#1 regenerating
	HMSC Pump house beach	4-5-10	M	91.6	orange	06/05	
		4-5-10	M	78.8	yellow orange	07	
	Aquarium mud flat	8-08-10	M	57.2	green	09	good
		9-08-10	M	88.9	orange-red	05/06	barnacles on carapace
	Idaho Point	6-15-10	M	93.4	yellow	05/06	No#5, #1 chipped propus
		6-15-10	M	61.8	green	09	

		10-21-10	M	88.4	orange	05/06	no # 1, 3
		10-21-10	F	77	very old	05/06	claw & leg missing, claw regenerating
TILLAMOOK	Garibaldi	3-14-10	F	83.7	yellow	06	sports catch Wayne Walker 503-730-1891
	Miami Cove	7-12-10	M	80	red orange	06	sports catch, Cleope Jacobs
	Miami Cove	7-12-10	M	85	red orange	06	sports catch, CleopeJacobs
	Miami Cove	7-12-10	F	85	yellow orange	06/05	sports, no #5, 6, Cleope Jacobs
	Viewpoint between Bay City and Garibaldi	7-27-10	M	79.2	orange	06	#7 missing/barnacles/ right 4th spine clipped
		7-27-10	M	92	yellow	06	good/ right 4th spine clipped
		7-27-10	M	90	orange	05	very sluggish – sports catch
NETARTS	Main channel	3-13-10	F	81.2	yellow	05/06	sports catch /empty egg cases/ No # 5, 9
	Boat Basin vegetation	10-9-10	M	43.3	green	**2010**	good
	Intersection of Netarts Rd. and Whiskey Creek Rd	6-18-10	M	94.6	Yellow-orange	05/06	No # 1, 6
		6-18-10	M	87.5	Yellow-orange	06	No # 7
		6-18-10	F	82.4	red	05/06	No egg cases, no #1, 7mm barnacles
		6-18-10	M	78.2	yellow	07 est	No # 6, 8, 10
		6-18-10	M	91.0	green	06	No # 8, 10
		7-27-10	M	96.2	green	06	good - right 4th spine clipped
	Paddle Creek	6-18-10	M	84.2	yellow	07	No # 1
	Whiskey Creek Salmon Hatchery	6-18-10	M	59.6	yellow	09	
		6-18-10	?	21	molt	**2010**	Molt → 28 mm crab
		9-24-10	M	26.5	molt	**2010**	Molt → 35 mm crab
		10-9-10	M	48.2	green	**2010**	good
		10-9-10	M	40.3	green	**2010**	good
		10-9-10	F	36.6	whitish	**2010**	good –close to molting →47.6
		10-9-10	M	51	green	**2010**	good
		10-9-10	M	48.7	green	**2010**	good
WILLAPA	Stackpole	10-8-10	M	44.5	green	**2010**	good
		10-8-10	M	43.0	green	**2010**	# 2 missing

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
1998	Yaquina	0	10.9	201		**5.00**	46.9	5.0	32-60
1999		4	9.0	13	**0.20**		38.0	5.0	30-47
2000		3	9.5	14		**0.31**	37.5	5.0	30-45
2001		3	9.5	Not sampled					
2002		4	9.2	1		0.01	38.9		
2003		0	10.5	9		0.07	44.9	5.5	41-59
2004		3	9.9	4		0.07	35.3	5.1	32-43
2005		2	10.3	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				0		0.00			
2010				8	0.05	0.05	40.8	6.7	30-50
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
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			
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**	0.0	43.8		43- 44
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				

Appendix 5. *Carcinus maenas* year class strength as a function of ocean conditions. Average catch data for the six estuaries were log 10-transformed and regressed against Pacific Decadal Oscillation Index for March . This figure is an up-dated version of Figure 2b in Behrens Yamada and Kosro 2010. (Up dated version relating year class strength to winter water temperature, day of spring transition and alongshore currents will be generated as soon as we can get the physical data from David Specht (EPA) and Mike Kosro (OSU College of Ocean and Atmospheric Sciences.)