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# Status of the European Green Crab in Oregon and Washington Estuaries in 2014

**Sylvia Behrens Yamada,**
Zoology Department,
Oregon State University
Corvallis, OR 97331-2914
541-754-9891 (home)
yamadas@science.oregonstate.edu

**Joel A. Prickett**
P.O. Box 62
Netarts Bay, Oregon 97143
joelprickett@alumni.uidaho.edu

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

*Report prepared for:*

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

# Executive Summary

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 17 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 and vice versa (Behrens Yamada and Kosro 2010). 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 and around Bella Bella on the Central Coast, 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 these 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 2014***

| Date | Talks / Activities | Location |
|---|---|---|
| April 3-5, 2014 | Presented poster:<br>"*Status of the Green Crab in the Pacific Northwest"* with Graham Gillespie, Department of Fisheries and Oceans, Canada | Pacific Estuarine Research Society Meeting, Hallmark Resort, Newport, Oregon |
| April 7, 2014 | Presented talk on Green crab life history. | Sally Hacker's "Marine Biology" class (Bi 450) Hatfield Marine Science Center, Newport, Oregon |
| June 15-17, 2014. | Trapped for European green crabs in Argyle Lagoon, Marine Reserve, San Juan Island, Washington. | Friday Harbor Labs, San Juan Island, Washington |
| June 25-27, 2014 | "Status of the European green crab in the Pacific Northwest"<br>Presentation and field sampling exercise. | John Chapman's **"**Aquatic Biological Invasions class" (FW 421/521) Hatfield Marine Science Center, Newport, 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). 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). Localized 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 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 crayfish 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).

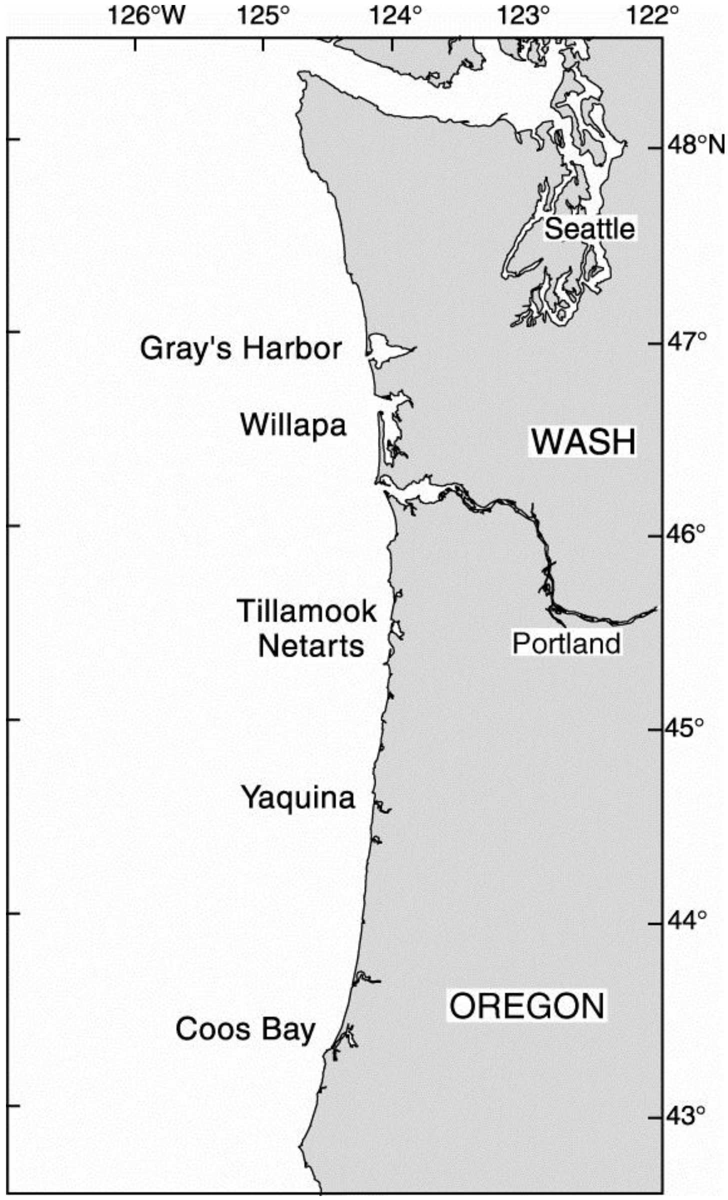



**Figure 1. Major sampling sites in Oregon and Washington**

## Sampling Methods for Green Crabs

Our sampling effort in 2014 included one Washington and four Oregon estuaries: Willapa, Tillamook, Netarts, Yaquina and Coos Bay (Figure 1). All estuaries were sampled at least twice during the 2014 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°-22° 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 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 and subtidal zones with folding Fukui fish traps and 0-age green crabs in the high intertidal with crayfish 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** |
|---|---|---|---|---|
| Fukui Fish trap | Plastic mesh (2 cm) with two slit openings (45 cm) | 63 x 46 x 23 cm | Low to subtidal | >40 mm |
| Frabrill Crayfish trap | Wire mesh (0.5 cm) cylinder with two openings expanded to 5 cm | 21 cm diameter 37 cm long | Medium to high | 20-70 mm |

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 (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 and 2013 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*** | ***2013*** | ***2014*** |
| ***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) |
| ***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) |
| ***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) |
| ***Tillamoook*** | 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) |
| ***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) |
| ***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) | 19 (288) | 61 (634) |

| ***Estuary*** | ***Number of crabs trapped per 100 traps per day*** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***2002*** | ***2003*** | ***2004*** | ***2005*** | ***2006*** | ***2007*** | ***2008*** | ***2009*** | ***2010*** | ***2011*** | ***2012*** | ***2013*** | ***2014*** |
| ***Coos Bay*** | 5 | 7 | 13 | 4 | 8 | **21** | **24** | 6 | 2 | 7* | **19*** | 7* | 1 |
| ***Yaquina*** | **15** | 6 | 3 | 13 | **23** | **21** | **15** | 12 | 8 | 7 | 13 | 11 | 5 |
| ***Netarts*** | 0 | **25** | **31** | **49** | **57** | **34** | **19** | **15** | **15** | **24*** | 14 | 0 | **27*** |
| ***Tillamook*** | 3 | 9 | 8 | 11 | **28** | **16** | 1 | 0 | 2 | 0 | 14 | 0 | 13* |
| ***Willapa*** | 3.5 | 3 | 3 | **25** | 8 | 1 | 0 | 0 | 12 | 0 | 0 | 0 | 0 |
| ***Grays Harbor*** | 0.4 | -- | -- | 2 | 2 | 0 | -- | 0 | -- | -- | -- | | |
| ***Total*** | 3 | 6 | 6 | **18** | **16** | **15** | **17** | 7 | 6 | 8 | **15** | 7 | 10 |

**Table 3.** ***Carcinus maenas*** **catch rates (crabs per 100 trap-days) by embayment in the Pacific Northwest, 1997–2013.** "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 | 2013 | 2014 |
| Gale Passage, BC | | | | | | | | | | | 0 | | | | 6 | 112 | | |
| Fish Egg Lake, BC | | | | | | | | | | | 0 | | | | 6 | 0 | | |
| Quatsino Sound, BC | | | | | | | | | | | 34 | | | 62 | | | | |
| Winter Harbor | | | | | | | | | | | **1254** | | | 105 | | | | |
| Klaskino, BC | | | | | | | | | | | 183 | | | 21 | | | | |
| Kyuquot Sound, BC | | | | | | P | | | P | 53 | 38 | | | **1027** | | | | |
| Amai Inlet | | | | | | | | | | | | | | **1388** | | | | |
| Mary Basin, BC | | | | | | | | | | | 33 | | | | | | | |
| Tlupana Inlet, BC | | | | | | | | | | | 3 | | | | | | | |
| Sydney Inlet, BC | | | | | | | | | | | 150 | | | | | | | |
| Nootka/Esperanza, BC | | | | 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, BC | | | | | | | | | | | | | | | | 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 | 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 | P | 13* |
| Netarts Bay, OR | P | 139 | | | 6 | 0 | 25 | 31 | 49 | 57 | 34 | 19 | 15 | 15 | 24* | 14 | P | 27* |
| Nestucca Bay, OR | | | | | | | | | | | P | P | | | | | | |
| Yaquina Bay, OR | P | 192 | 69 | 63 | 57 | 15 | 6 | 3 | 13 | 23 | 21 | 15 | 12 | 8 | 7 | 13 | 11 | 5 |
| 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* | 7* | 1 |
| 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 2014 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 2014 and in Coos Bay in 2011, 2012 and 2013 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 green crabs (Table 3). 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 and 2014 (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).

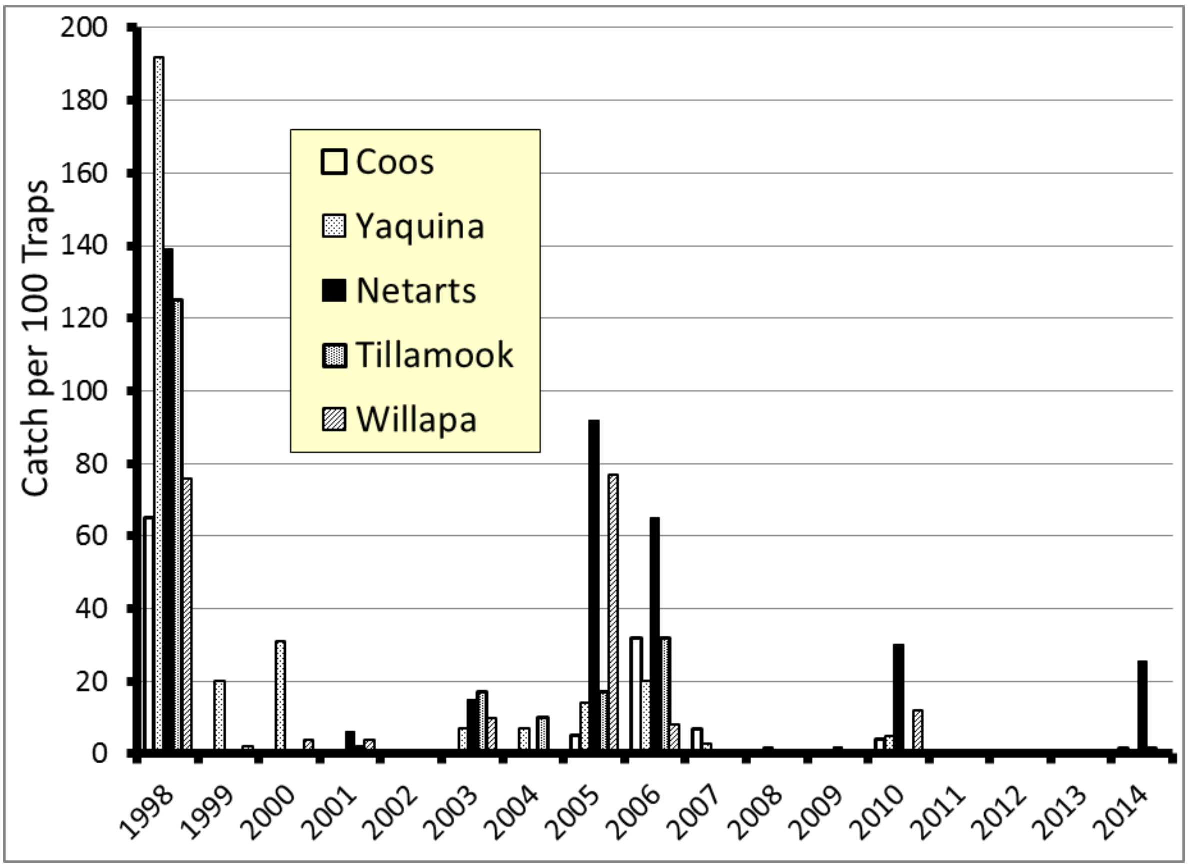
## ***Recruitment strength of Young-of-the-Year Carcinus maenas***

Young-of-the-year (YOTY), or 0-age, green crabs typically enter minnow traps once they reach 30 mm in carapace width. Most years, crabs of this size, and larger, entered our minnow traps by late September. In 2012 and 2013 we did not trap any 0-age crab during our fall surveys (Appendix 4).

As can be seen from Figure 2 and Appendix 4, 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. 0-age green crabs were most abundant in 1998 with average catches for the Oregon and Washington estuaries of over 100 per 100 traps. The next highest catches were in 2005 and 2006 with averages of over 20 per 100 traps. The years 2003 and 2010 showed moderate recruitment in most of the estuaries. The only site exhibiting significant recruitment in

2014 was Whiskey Creek Salmon Hatchery in Netarts Bay. Total recruitment failure was observed in 2002, 2011, 2012 and 2013.

**Figure 2. Relative Year Class Strength 0-age *Carcinus maenas* in Oregon and Washington estuaries.** *(Files/Papers/Papers/Ocean Conditions/Data files 2014recruits)*



### ***Age Structure of Carcinus maenas 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 2014. 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 65 mm, with green or yellow carapaces would represent the 2013 year class, and green crabs between 65 to 75 mm, the 2012 year class. Most of the larger crabs would represent by the 2010 year class since in recent years we observed recruitment failure.

| Estuary | 2014 | 2013 | 2012 | 2011 | 2010 | Total |
|---|---|---|---|---|---|---|
| Coos Bay | 2 | 0 | 0 | 0 | 1 | 3 |
| Yaquina | 2 | 0 | 0 | 0 | 5 | 7 |
| Netarts | 18 | 2 | 2 | 0 | 9 | 31 |
| Tillamook | 1 | 1 | 2 | 4 | 12 | 20 |
| Willapa | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 23 | 3 | 4 | 4 | 27 | 61 |
| Percent | 38 | 5 | 6.5 | 6.5 | 44 | 100 |

**Table 4. Estimated age structure of *Carcinus maenas* retrieved from Oregon and Washington estuaries in 2014.**

### ***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 17 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, 2010 and 2014. 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 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.

# Discussion

We deployed 634 traps in 5 estuaries and caught 61green crabs, yielding an average catch rate of 10 crabs per 100 traps for Oregon and Washington estuaries. This figure is inflated because most of the crabs came from two known "hot spot" in Netarts and Tillamook Bay. We repeatedly trapped those 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, 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; Appendix 4). When the last crabs from the strong 1998 year class died of senescence in the summer of 2004, the 2003 year class was abundant enough to produce larvae in 2005 and 2006 to adequately "seed" Oregon and Washington estuaries. While we have observed virtual recruitment failure in recent years (2007, 2008, 2009, 2011, 2012 and 2013) the 2010 year class broke the cycle. This cohort still comprises around 44% of the population and will be a potential larval source until 2016. The new 2014 year class, while rare (except at the Whiskey Creek Salmon Hatchery in Netarts Bay), could persist and be a source of larvae until 2020.

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).

## Acknowledgements

We thank the staff and faculty of the Oregon Institute of Marine Biology for their hospitality while sampling in Coos Bay and Oregon Department of Fish and Wildlife for supporting Joel Prickett's sampling activities in Netarts and Tillamook Bay. Chuck's Seafood of Charleston, Oregon provided most of the bait while Graham Gillespie of Fisheries and Oceans Canada provided data from British Columbia.

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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 2013.

| Site | Date | Location Description | S ‰ | Water Temp. | Air Temp. | Green Crabs Found? |
|---|---|---|---|---|---|---|
| **COOS BAY** | | | | | | |
| ***Trans Pacific S.*** | | ***Range of values observed*** | ***13-33*** | ***10-21*** | ***9-27*** | |
| N 43$^{o}$ 26.571' | 7/11/14 | | 30 | 16.5 | 14.5 | no |
| W 124$^{o}$ 13.388' | | | | | | |
| | | | | | | |
| ***Trans Pacific N*** N 43$^{o}$ 26.575' W 124$^{o}$ 14.434' | 7/12/14 | | 27 | 16 | 15 | no |
| | | | | | | |
| ***Jordan Cove*** | | ***Range of values observed*** | ***5-34*** | ***14-22*** | ***14-24*** | |
| N 43$^{o}$ 25.971' | 10/24/14 | | 14 | 14 | 16 | yes |
| W 124$^{o}$ 14.981' | | | | | | |
| | | | | | | |
| ***Kentuck Inlet*** | 10/27/14 | | 20 | 14 | 16 | no |
| N 43$^{o}$ 25.299' | | | | | | |
| W 124$^{o}$ 11.522' | | | | | | |
| | | | | | | |
| ***Charleston Boat*** | 7/11/14 | | 32 | 13 | 16 | no |
| ***Basin*** | | | | | | |
| | | | | | | |
| ***Joe Nye Slough*** | 7/11/14 | | 32 | 16.5 | 15 | no |
| N 43$^{o}$ 20.343' | | | | | | |
| W 124$^{o}$ 18.590' | | | | | | |
| | | | | | | |
| ***Pony Point*** | | ***Range of values observed*** | ***17-32*** | ***11-17*** | ***11.5-18*** | |
| ***N. Bend Airport*** | 7/13/14 | | 30 | 16 | 14.5 | yes |
| N 43$^{o}$ 25.403' | | | | | | |
| W 124$^{o}$ 14.369' | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **YAQUINA** | | | | | | |
| ***Johnson Slough*** | | ***Range of values observed*** | ***9-33*** | ***12-23*** | ***12-26*** | |
| N 44° 34.692’ | | *Scirpus* patches below intersection | | | | |
| W123° 59.333’ | 11/6/14 | | 9 | 14 | 20 | no |
| | | | | | | |
| ***Sally’s Bend A*** | | ***Range of values observed*** | ***20-33*** | ***12-23*** | ***12-26*** | |
| N 44° 37.699’ | 9/11/14 | *Scirpus* patches below intersection | 31 | 18.5 | 28 | |
| W124° 01.482’ | 11/6/14 | | 20 | 13 | 13 | no |
| | | | | | | |
| ***Sally’s Bend B*** | | *Scirpus* patches below George Street | ***20-33*** | ***12-19*** | ***12-24*** | |
| N 44° 37.640’ | 11/7/14 | | 20 | 13 | 13 | yes |
| W124° 00.790’ | | | | | | |
| | | | | | | |
| ***Sally’s Bend C*** | | ***Range of values observed*** | ***19-33*** | ***9-19*** | ***9-22*** | |
| N 44° 37.419’ | 6/27/14 | *Zostera marina* zone from by gate to fishing platform | 30 | 16 | 15 | no |
| W124° 01.463’ | | | | | | |
| | | | | | | |
| ***Oregon Coast Aquarium*** | | ***Range of values observed*** | ***19-35*** | ***9-25*** | ***8-23*** | |
| | 6/27/14 | | 30 | 14.5 | 15 | yes |
| N 44° 37.108’ | 11/6/14 | | 20 | 13 | 13 | yes |
| W124° 02.165’ | | | | | | |
| | | | | | | |
| ***Hatfield Marine Science Center Pump house*** N 44° 37.408’ W124° 02.576’ | 6/27/14 | *No measurements taken* | | | | |
| | | | | | | |
| ***Idaho Point*** | | ***Range of values observed*** | ***16-35*** | ***8-27.5*** | ***7-23*** | |
| N 44° 36.818’ | 6/27/14 | | 30 | 15 | 15 | yes |
| W 124° 01.582’ | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **TILLAMOOK** | | | | | | |
| ***Tillamook Spit A*** N 45° 30.843' W 123° 56.738' | | | | | | |
| ***Tillamook Spit B*** N 45° 30.456' W 123° 56.615' | 9/25/14 | | 26 | 15 | 17 | no |
| | 10/10/14 | | 30 | 14.5 | 11.5 | no |
| | | | | | | |
| ***Tillamook Spit C*** N 45° 30.542' W 123° 56.615' | 10/10/14 | | 30 | 14.5 | 11.5 | no |
| | | | | | | |
| ***Pitcher Point*** N 45° 30.365' W 123° 56.508' | 10/10/14 | | 30 | 14.5 | 11.5 | no |
| | | | | | | |
| ***Viewpoint*** N 45° 32.623' W 123° 54.183' | 6/3/14 | | 20 | 15 | 16 | yes |
| | 7/17/2014 | | | 19.4 | 13.9 | Yes |
| | 8/15/2014 | | | 18.3 | 12.8 | Yes |
| | 9/12/2014 | | | 13.9 | 11.7 | yes |
| **NETARTS** | | | | | | |
| ***Boat Ramp*** N 45° 25.832 W 123° 56.827 | 9/25/14 | | 34 | 14 | 12.5 | no |
| | | | | | | |
| ***RV Park*** | 6/3/14 | | 4 | 13.5 | 15 | no |
| | | | | | | |
| ***Whiskey Creek Salmon hatchery*** | | ***Range of values observed*** | ***0-34*** | ***7-20*** | ***6.5-21*** | |
| | | On mudflat and in creek | | | | |
| | 9/25/14 | | 34 | 14 | 12.5 | no |

| | | | | | | |
|---|---|---|---|---|---|---|
| N 45° 23.670’ W 123° 56.214‘ | | | | | | |
| | | | | | | |
| | | | | | | |
| ***Intersection of Whiskey Creek & Netarts Bay Roads*** N 45° 24.865’ W 123° 56.064’ | | ***Range of values observed*** | | | | |
| | 6/3/14 | Pool below culvert draining Freshwater marsh | 0 | 13 | 14 | yes |
| | 7/4/2014 | | | 16.7 | 14.4 | Yes |
| | 8/8/2014 | | | 11.7 | 15 | Yes |
| | 9/24/2014 | | | 16.7 | 15.5 | yes |
| | | | | | | |
| **WILLAPA** | | | | | | |
| ***Stackpole*** Leadbetter Pt. Sate Park N 46° 35.848’ W 124° 02.195’ | | ***Range of Values observed*** | | | | |
| | | Edge native vegetation | | | | |
| | | | | | | |
| | | *No measurements taken* | | | | |
| | | | | | | |

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 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jordan Cove | 10/25/14 | crayfish | *Scirpus* | | *0.05* | | *0.41* | | | 0.07 | 44 |
| | 10/26/14 | crayfish | *Scirpus* | | | | *1.52* | | | 0.02 | 44 |
| | 10/27/14 | crayfish | *scirpus* | *0.08* | *0.04* | | *0.84* | | | 0.04 | 25 |
| Kentuck | 10/27/14 | crayfish | *Scurpus/Thule* | | *0.15* | | *1.00* | | | 0.45 | 20 |
| | | | | | | | | | | | |
| Pony Point/Airport | 7/13/14 | Fish | *Zostera marina* | 0.1 | | | 47.6 | | 2.3 | 0.8 | 10 |
| TransPacific Ln N | 7/12/14 | Fish | | | | | 40.33 | | | 0.5 | 12 |
| | 7/13/14 | fish | | | | | 24.9 | | | 0.4 | 12 |
| TransPacific Ln. S | 7/12/14 | Fish | | | | | 47.27 | | | | 15 |
| | 7/13/14 | fish | | | | | 23.83 | | | | 12 |
| | 7/14/14 | fish | | | | | | | | | |
| | | | | | | | | | | | |
| Charleston Boat Basin | 7/11/14 | Fish | | | | | 3.65 | 0.15 | 1.75 | 0.1 | 20 |
| | | | | | | | | | | | |
| Joe Ney Slough | 7/10/14 | fish | | | 0.1 | | 1.13 | | | 1.2 | 10 |
| Total Number | | | | 3 | | | | | | | 224 |

**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 | 11/6/14 | Fish | *Under bridge* | | | | 1.45 | | | 0.50 | 2 |
| | 11/6/14 | crayfish | *Marsh edge* | | 0.25 | 0.05 | 0.05 | | | | 20 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sally's Bend A | 9/11/14 | crayfish | *Scirpus* | | 2.82 | 0.18 | 0.06 | 0.06 | | 0.35 | 17 |
| | 11/6/14 | crayfish | | | 0.50 | 0.06 | | | | 0.28 | 18 |
| | 11/7/14 | crayfish | | | 0.70 | | | | | 0.10 | 10 |
| Sally's Bend B | 11/7/14 | crayfish | *Below George St.* | 0.2 | 2.4 | | | | | 0.6 | 5 |
| Sally's Bend C gate | 6/26/14 | fish | *Zostera marina* | | | 0.1 | 2.5 | | | 2 | 20 |
| | | | | | | | | | | | |
| HMSC Pumphouse | 6/27/14 | fish | | 0.13 | 0.27 | 0.13 | 2.67 | | 2.07 | 1.47 | 15 |
| | | | | | | | | | | | |
| Oregon Coast Aquarium | 6/27/14 | fish | Channels /pools | 0.1 | 3 | | 3.1 | | | 10.6 | 10 |
| | 11/7/14 | crayfish | *Scirpus* | 0.04 | 0.72 | 0.08 | | 2.16 | | | 25 |
| | | | | | | | | | | | |
| Idaho Point | 6/27/14 | fish | | 0.4 | | | 6.8 | | | 1.8 | 5 |
| Total Number | | | | 7 | | | | | | | 147 |

**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 | 6/03/14 | Fish | | 0.3 | 0.1 | 0.1 | 4 | 0 | 0 | 0.4 | 10 |
| | 7/17/14 | Fish | | 0.3 | 0 | 0.1 | 2.4 | 0 | 0 | 0.5 | 10 |
| | 8/15/14 | Fish | | 1.0 | 0 | 0.2 | 5.3 | 1.7 | 0 | 0.4 | 10 |
| | 9/12/14 | fish | | 0.3 | 0 | 0.1 | 4.5 | 1.2 | 0 | 0.4 | 10 |
| | | | | | | | | | | | |
| Tillamook Spit C | 10/10/14 | crayfish | | 0 | | | | | | 0.32 | 25 |
| Tillamook Spit A | 10/11/14 | crayfish | | 0 | *0.8* | | | | | 0.5 | 10 |
| Tillamook Spit B | 9/26/14 | crayfish | *Scirpus* | 0 | 0.2 | | | | | 0.5 | 10 |
| Tillamook Spit B | 10/11/14 | crayfish | | 0 | | | | | | 1.4 | 10 |
| Pitcher Point | 10/11/14 | crayfish | *Scirpus* | 0.1 | 0.2 | | | | | 1 | 10 |
| Total Number | | | | 20 | | | | | | | 105 |

**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 | 10/10/14 | crayfish | | 0 | 3.1 | 2.3 | | | | 1.3 | 10 |
| | 10/11/14 | crayfish | | 0 | 2.2 | 0.7 | | | | 0.9 | 10 |
| Intersection | 6/3/14 | Fish | | 0.71 | 0.57 | | 7.86 | | | 0.86 | 7 |
| | 7/4/14 | Fish | | 0.6 | 0.8 | 0.6 | 3.7 | | | 0.1 | 10 |
| | 8/8/14 | fish | | 0.1 | 0.6 | 1.1 | 3.7 | 1.1 | | 0.2 | 10 |
| | 9/24/14 | Fish | | 0.1 | 0 | 0.4 | 9.8 | 3.0 | | 0.4 | 10 |
| | | | | | | | | | | | |
| RV Park | 6/03/14 | Fish | | | | | | 0.75 | | 1.75 | 4 |
| | | | | | | | | | | | |
| Whiskey Creek Salmon Hatchery | 6/03/14 | Fish | | | 1.25 | | 4.25 | | | 0.5 | 4 |
| | 9/26/14 | crayfish | | 0.2 | 1.3 | 0.2 | | | | 0.3 | 10 |
| | 10/10/14 | crayfish | | 0.4 | 0.2 | | 0.4 | | | 0.05 | 20 |
| | 10/11/14 | crayfish | | 0.4 | 0.9 | | 0.45 | | | 0.45 | 20 |
| Total Number | | | | 31 | | | | | | | 115 |

**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 | 10/8/14 | crayfish | Edge of grass and tide flat | 0 | 0 | 0 | 0 | 0.4 | 0 | 0.1 | 15 |
| | 10/8/14 | pitfall | Edge & open tideflat | 0 | 0 | 0 | 0 | 1.75 | 0 | 0 | 4 |
| | 11/29/14 | crayfish | Edge of grass and tide flat | 0 | 0.05 | 0 | 0 | 0.15 | 0 | 0.2 | 20 |
| | 11/29/14 | pitfall | Edge & open | 0 | 0 | 0 | 0 | 2.5 | 0 | 0 | 4 |
| Total Number | | | | 0 | | | | | | | 43 |

Appendix 3. *Carcinus maenas*. Catches and Sightings from Oregon and Washington Estuaries in 2013. 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.

| **Estuary** | **Site** | **Date** | **Sex** | **Carapace width (mm)** | **Weight (g)** | **Color of Abdomen** | **Estimated Year Class** | **Comments** |
|---|---|---|---|---|---|---|---|---|
| Coos | Airport | 7/13/14 | F | 77 | 81.0 | orange | 2010?? | L4,5,6 missing |
| | Jordan Cove | 10/27/14 | F | 45.5 | 19.3 | Green | **2014** | |
| | | | M | 47.2 | 21.8 | yellow | **2014** | |
| Yaquina | Idaho Point | 6/27/14 | M | 83.0 | | Orange | 2010 | L1 |
| | Idaho Point | 6/27/14 | M | 84.1 | | Orange | 2010 | |
| | OCA mudflat | 6/27/14 | M | 82.1 | | Orange | 2010 | R1 |
| | Pumphouse | 6/27/14 | M | 85.5 | | Orange | 2010 | |
| | Pumphouse | 6/27/14 | M | 97.7 | | Yellow green | 2010 | R1 |
| | OCA mudflat | 11/7/2014 | F | 49.5 | 24.0 | green | **2014** | |
| | Sally's Bend | 11/7/2014 | F | 42.3 | 15.7 | green | **2014** | |
| Netarts | Intersection | 6/3/14 | F | 53.8 | 32 | green | 2013 | |
| | | 6/3/14 | M | 85.9 | 132 | Orange | 2010 | R1 regenerating/no L5 |
| | | 6/3/14 | M | 89.5 | 180 | Orange | 2010 | |
| | | 6/3/14 | M | 88.3 | 163 | Red-orange | 2010 | Missing L2 |
| | | 6/3/14 | M | 87.8 | 158 | green | 2010 | |
| | | 7/4/2014 | M | 65 | 105 | Yellow-orange | 2013/2012 | |
| | | 7/4/2014 | M | 83 | 155 | Orange | 2010 | |
| | | 7/4/2014 | M | 74 | 100 | Red-orange | 2012/2011 | |
| | | 7/4/2014 | M | 79 | 80 | Yellow | 2012 | Missing L1,2,3 |
| | | 7/4/2014 | M | 96 | 200 | Yellow | 2010 | Scale maxes out at 200 g |
| | | 7/4/2014 | M | 87 | 175 | Orange | 2010 | Missing L4 |
| | | 8/8/2014 | F | 76 | 80 | Yellow-green | 2010 | Missing L1 |
| | | 9/24/2014 | M | 90 | 200 | Orange | 2010 | Scale maxes out at 200 g |
| | Whiskey Creek | 9/26/14 | M | 49 | 21.3 | Yellow | **2014** | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Salmon Hatchery | 9/26/14 | M | 41 | 14.8 | Yellow-green | **2014** | |
| | | 10/10/14 | M | 43.95 | 17.8 | Yellow | **2014** | |
| | | 10/10/14 | M | 36.72 | 11.8 | Yellow | **2014** | |
| | | 10/10/14 | F | 49.28 | 26.2 | Yellow | **2014** | |
| | | 10/10/14 | M | 45.03 | 19.2 | Yellow | **2014** | |
| | | 10/10/14 | M | 44.48 | 18.2 | Yellow | **2014** | |
| | | 10/10/14 | F | 43.07 | 17.9 | Yellow | **2014** | |
| | | 10/10/14 | M | 42.41 | 15.5 | Yellow | **2014** | |
| | | 10/10/14 | F | 43.18 | 16.2 | Yellow | **2014** | |
| | | 10/11/14 | M | 44.9 | 20.5 | Yellow-green | **2014** | |
| | | 10/11/14 | F | 42.6 | 15.5 | Green | **2014** | |
| | | 10/11/14 | M | 44.8 | 17.3 | Yellow-green | **2014** | |
| | | 10/11/14 | F | 33.3 | 7.5 | Green | **2014** | |
| | | 10/11/14 | M | 45.6 | 20.2 | Yellow | **2014** | |
| | | 10/11/14 | F | 45.6 | 19.1 | Yellow-green | **2014** | |
| | | 10/11/14 | M | 44.4 | 17.1 | Yellow | **2014** | |
| | | 10/11/14 | M | 45.1 | 17.7 | Green | **2014** | |
| Tillamook | Viewpoint | 6/03/14 | M | 85.5 | 152.4 | Orange-red | 2010 | |
| | | 6/03/14 | M | 95.8 | 191 | Yellow-orange | 2010 | |
| | | 6/03/14 | M | 82.6 | 141 | orange | 2010 | |
| | | 7/17/2014 | M | 82 | 150 | Orange | 2010 | Missing L4 |
| | | 7/17/2014 | M | 73 | 80 | Yellow | 2012 | Missing L4, R4 |
| | | 7/17/2014 | M | 83 | 115 | Yellow-orange | 2011/ 2010 | |
| | | 8/15/2014 | M | 85 | 150 | Orange | 2010 | Missing R3 |
| | | 8/15/2014 | F | 82 | 115 | Yellow-orange | 2010 | |
| | | 8/15/2014 | M | 91 | 190 | Yellow | 2010 | |
| | | 8/15/2014 | M | 82 | 120 | Orange | 2011/ 2010 | Missing R1 |
| | | 8/15/2014 | M | 91 | 200 | Orange | 2010 | Scale maxes out at 200 g |
| | | 8/15/2014 | F | 81 | 120 | Orange | 2011 | |
| | | 8/15/2014 | M | 92 | 190 | Yellow | 2010 | |
| | | 8/15/2014 | M | 87 | 150 | Orange | 2010 | |
| | | 8/15/2014 | M | 75 | 85 | Yellow | 2012 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 8/15/2014 | M | 88 | 110 | Yellow | 2010 | Missing L1,2 |
| | | 9/12/2014 | M | 84 | 160 | Orange | 2010 | |
| | | 9/12/2014 | M | 79 | 190 | Orange | 2011 | Error - Too heavy |
| | | 9/12/2014 | F | 60 | 50 | Green | 2013 | |
| | Pitcher Point/ Tillamook Spit | 10/11/14 | F | 51.4 | 27.4 | Green | **2014** | |
| | | | | | | | | |

**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 | 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 |
| 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 | | | 0.021 | | | 42-49.5 |
| 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 | 33-49.5 |
| 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 | | | |
| 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 | | | |
| 1998 | Grays Harbor | | | 3 | | **1.00** | 45.3 | 5.0 | 40-50 |
| 1999 | | | | 24 | | 0.02 | 37.4 | 7.7 | 34-51 |
| 2000 | | | | 3 | | 0.01 | 41.3 | 6.5 | 35-48 |
| 2001 | | | | 1 | | 0.01 | 47.9 | | |
| 2002 | | | | 0 | | 0.00 | | | |
| 2003 | | | | | Not Sampled | | | | |
| 2004 | | | | | Not Sampled | | | | |
| 2005 | | | | 2 | | 0.03 | 47.3 | | 44-50 |
| 2006 | | | | 1 | | 0.02 | 49.0 | | |
| 2007 | | | | 0 | | 0.00 | | | |
| 2008 | | | | | Not sampled | | | | |
| 2009 | | | | 0 | | 0.00 | | | |

| | | | | | |
|---|---|---|---|---|---|
| 2010 | | | | | Not sampled |
| 2011 | | | | | Not sampled |
| 2012 | | | | | Not sampled |
| 2013 | | | | | Not Samples |
| 2014 | | | | | 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= 0.0000 and explains 69% of the inter-annual variability in year class strength. (This figure is an up-dated version of Figure 2b in Behrens Yamada and Kosro 2010**.)**