EUROPEAN GREEN CRAB

Early Detection and Monitoring

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Abstract

The globally invasive European green crab has been on the Salish Sea's doorstep for two decades, but none were captured from Salish Sea shorelines until 2012. That year, a population was discovered in Sooke Inlet, just west of Victoria, British Columbia. The discovery increased concern about potential impacts of European green crab on Washington's inland marine shorelines and reinvigorated interest in and support for early detection monitoring. In response, Washington Sea Grant developed the Crab Team with support from the US Environmental Protection Agency and Washington Department of Fish and Wildlife (WDFW). Crab Team is a volunteer monitoring network carefully designed to maximize the likelihood of detecting green crab while populations are manageable and for gathering related data to increase understanding of natural conditions in suitable green crab habitat.

During its first year, Crab Team established seven sites that were monitored by volunteers for the last one or two months of the monitoring season. The approach was then refined using volunteer feedback and staff and peer insights. In 2016, the Crab Team was launched in full, monitoring 26 sites from April to September. The monitoring approach included baited traps, a timed molt search and a habitat survey. All individual organisms collected were identified and counted, with size and sex data collected for a subset of trapped crabs. The data can be used in a variety of ways and will be of increasing value as subsequent years of information are added and particularly if green crab become established at any of the monitoring sites. Of the more than 66,500 live organisms and molts examined during Crab Team's first two years, only one European green crab was found.

Discovery of a green crab in Washington's inland marine waters demonstrated the effectiveness of the Crab Team approach, but also required a more detailed assessment of population size and distribution. After volunteers collected a green crab on San Juan Island, WDFW coordinated a rapid assessment using Crab Team expertise and equipment as a resource. After two days of intense trapping and searching for molts, evidence (a molt) of only one other green crab was found. The process was repeated again when staff at the Padilla Bay National Estuary Research Reserve found a small green crab. The three-day response effort netted three additional crabs, but there was no evidence of an established population.

To further increase the likelihood of green crab early detection in the Salish Sea, the Crab Team developed media relationships, materials and contact lists as part of a broad and ongoing outreach effort. News media coverage reached a wide audience, while groups and individuals likely to spend time on, in or around the water were engaged more directly through presentations, flyers and individual interactions.

In this report, we share information about European green crab, the Crab Team approach to monitoring, the Crab Team volunteer training and engagement process and the findings and results from the first two years of Crab Team data collection.

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Introduction

Background

After the 2012 discovery of European green crab (*Carcinus maenas*) in Vancouver Island's Sooke Inlet, the Washington Department of Fish and Wildlife (WDFW) and the Pacific States Marine Fisheries Commission sought support to reestablish a sustainable, volunteer-based monitoring network with the primary goal being early detection of European green crab. In 2014, Puget Sound Marine and Nearshore Protection & Restoration Grant funds were awarded to Washington Sea Grant, based at the University of Washington College of the Environment, to develop and implement a program combining a rigorous monitoring strategy with a broad outreach effort, increasing the likelihood of finding European green crab before they become established in large enough numbers to threaten Puget Sound shellfish and fish species and habitats.

European green crab

A successful global invader, the European green crab has well-documented negative effects on native marine ecosystems worldwide.

Invasion history

The green crab's native range includes most of Europe's western and northern shorelines, as well as the northwest coast of Africa (Figure 1). Its native range reflects the crab's broad tolerance of water temperature, from near freezing to 35° Celsius (95° Fahrenheit). The range of salinity in which green crab can survive is similarly broad, from largely fresh estuarine water, 4 ppt (parts per thousand), to full ocean water at 35 ppt and higher (Cohen and Carlton 1995). Such habitat tolerance in combination with its generalist diet, enable the species to become established in other parts of the world if afforded the opportunity.

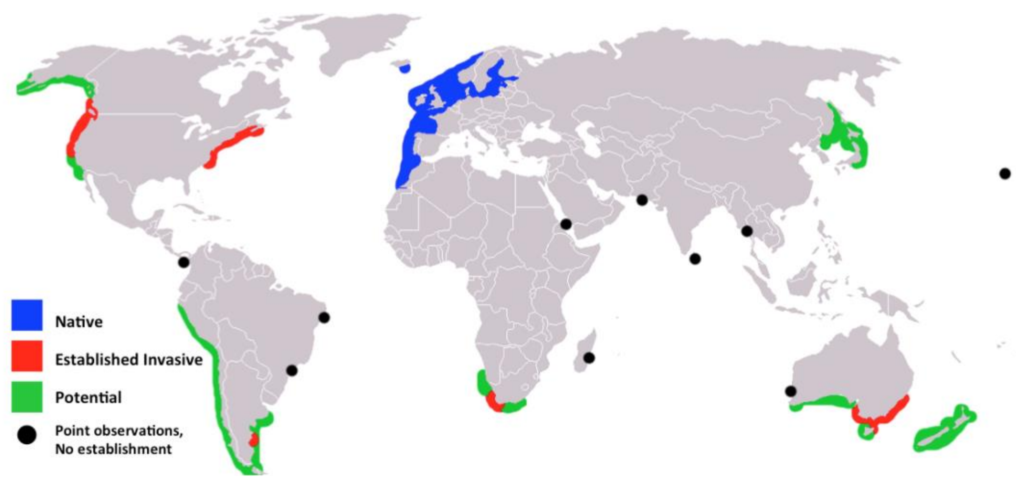

Figure 1 Realized and potential global distribution map of European green crab (*Carcinus maenas*). Map prepared by Stemonitis (2006), English-language Wikipedia, based on a blank world map and data from Commonwealth Scientific and Industrial Research Organization (CSIRO).

Opportunity came as European ships more frequently traversed the world's oceans, carrying with them goods and ballast that could hide stowaway crabs, whether as juvenile or mature individuals or as planktonic larvae (zoeae). Once it arrives in sufficient numbers to become established in a new habitat, green crab can then spread locally on currents as zoeae. On the east coast of the United States, this species was introduced at least 200 years ago and has continued to spread regionally, even up to the present day. It also continues to become more abundant in areas where it was previously rare.

Since its introduction to the United States, green crab have been introduced across the globe with great success in some locations and point observations in others. The establishment and spread of populations on the west coast of North America has occurred as a series of discrete events, beginning with a population in San Francisco Bay — first observed in 1989 — followed by local expansion over the subsequent decade (Figure 2).

Strong, positive, El Niño-Southern Oscillation (ENSO) conditions favor the survival and nearshore retention of green crab larvae from central California (Behrens Yamada et al. 2015). The ENSO of 1997–1998 provided ideal conditions for larvae to spread from the abundant central California populations, north to the outer coasts of Oregon, Washington and British Columbia. While the populations in Oregon and Washington's outer coast estuaries remain small, those in the bays and inlets of Vancouver Island have become well established (Gillespie et al. 2007, Behrens Yamada and Gillespie 2008). Between1998 and 2012, agency, volunteer and outreach early detection efforts in Washington's inland marine waters found no green crab. It appeared that oceanographic conditions associated with water movement through the Strait of Juan de Fuca were reducing the dispersal of larvae into Salish Sea.

In 2012, however, departmental scientists in Fisheries and Oceans Canada confirmed an established European green crab population in Sooke Inlet on the Strait of Juan de Fuca. The crabs in Sooke represented the first population documented in the Salish Sea, the inland marine waters of British Columbia and

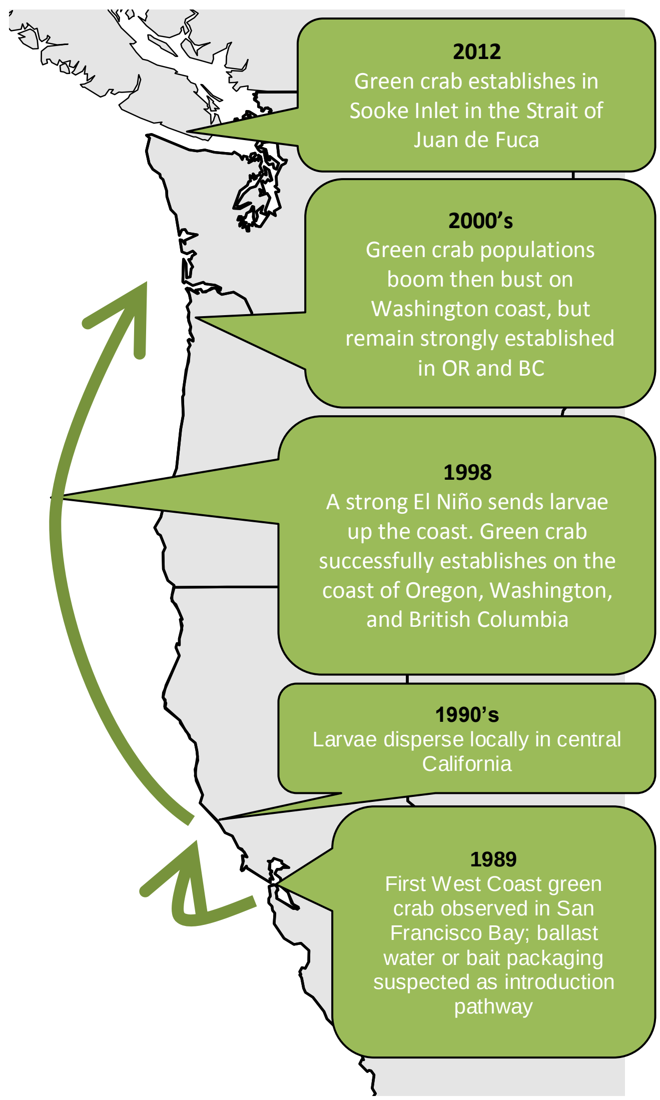

Figure 2 History of US west coast green crab invasion

Washington. Evidence indicates the population in Sooke became established through accidental introduction by human activities and not through natural dispersal (TW Therriault, 2012, pers. comm.), suggesting water exchange through the Strait of Juan de Fuca could remain a substantial barrier to large numbers of green crab larvae entering the Salish Sea. However, with a population inside the Strait, the threat of dispersal into the Puget Sound, Washington's share of the Salish Sea, appeared to be a stronger possibility.

The increased possibility was proven a reality in 2016 by the Crab Team's strategic monitoring and by the watchful eye of an educator on the beach (see Methods and Results).

Life history and identification

The green crab's complex life history (Figure 3) has helped facilitate its spread though both human vectors and by natural processes. On the west coast of North America, female green crab can become reproductively mature during their first year owing to suitable conditions for rapid growth, and can produce up to 200,000 eggs at a time (Behrens Yamada et al. 2005, Cohen and Carlton 1995). When the eggs hatch, the free-swimming zoeae live 17–80 days, depending on water temperature (NIMPIS 2002), and can travel hundreds of miles on ocean currents during that time. During their time in the plankton, they go through four zoeal stages before metamorphosing into specialized megalopae that settle to the seafloor. After 5.5–26 days, the megalopae change into juvenile crab (Dawirs and Dietrich 1986) that then mature into adults.

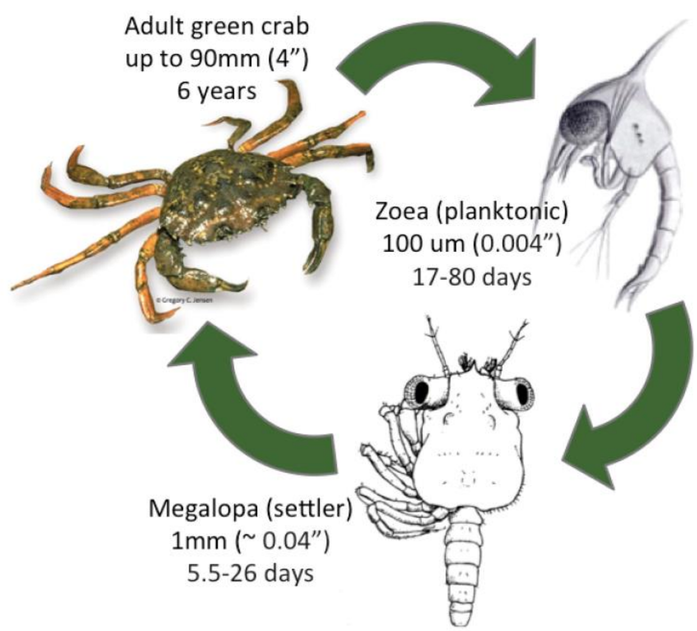

Figure 3 Life cycle of European green crab (*Carcinus maenas*). Adult photo: Greg Jensen; zoea illustration after E. Haeckel; megalopa illustration by Auguste Le Roux (Own work) via Wikimedia Commons.

The European green crab is considered a shore crab, living in the intertidal shallow subtidal. With a maximum carapace width of about 4", the green crab can grow larger than native Puget Sound shore crabs (*Hemigrapsus* spp.) but is smaller than large native cancrid crabs (e.g., red rock, Dungeness and graceful). The carapace is slightly wider than it is long and is distinct from every other Puget Sound crab species in that it has five prominent marginal teeth (points) to the outside of each eye, along the edge of the carapace (Figure 4). Green crab also have three rounded lobes between the eyes, a characteristic not unique to them, but possibly helpful in confirming identification. The shape of the abdomen can be used to differentiate males and females (Figure 5). Although commonly referred to as "green" (Figure 6), this species often turns quite red as it ages (Figure 7), and can be found with many different colors and patterns, particularly as juveniles (Figure 8).

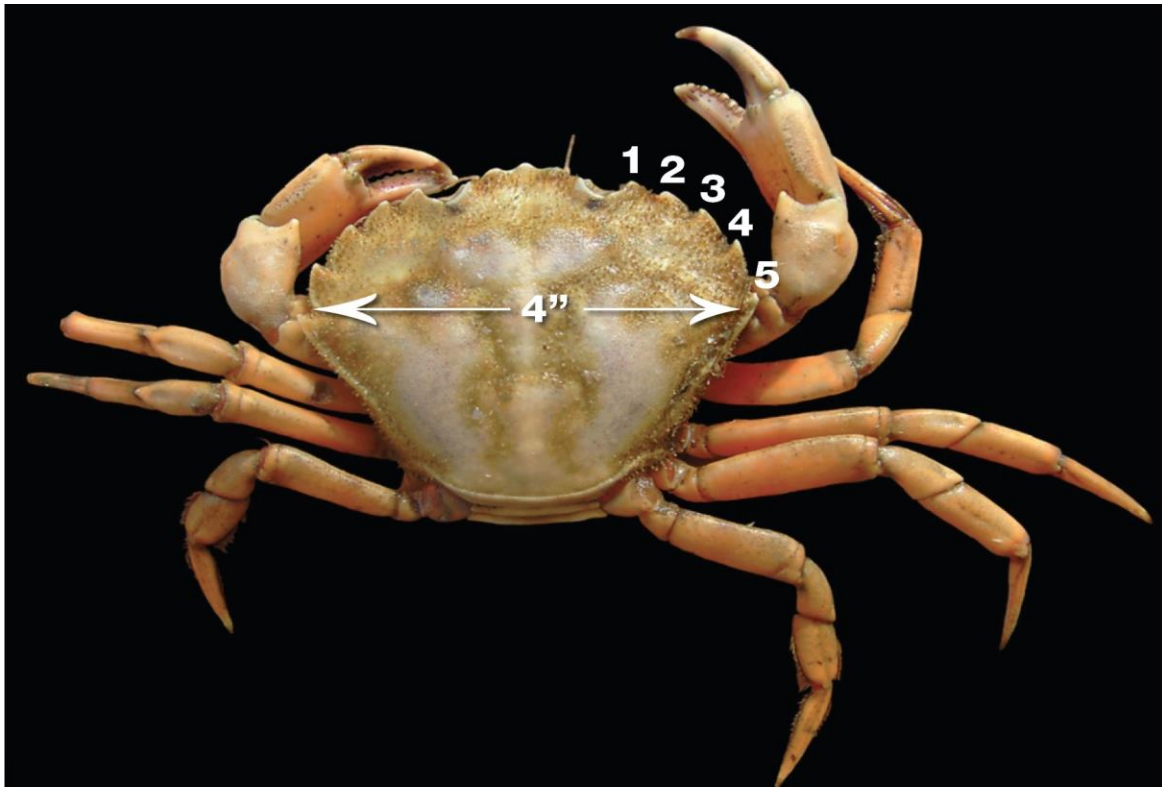

Figure 4 The key identifying feature for European green crab relative to native US west coast crabs is the five large marginal teeth (or lateral spines) from each eye to the widest edge of the carapace. This feature is apparent whether on a live individual or a molt, as shown here. The maximum size is 4" across the carapace. Image modified from Hans Hillewaert ©**.**

Figure 5 Examples of female (left) and male (right) green crab. The differences in the sexes are more subtle than in many native Puget Sound crab species, but the male's abdomen is narrower with a slight constriction in the middle. The female abdomen is progressively wider toward the back of the crab. Photos by Jeff Adams.

Figure 6 Typical European green crab colors and patterns. Photos by Jeff Adams.

Figure 7 European green crab from Willapa Bay Washington. The predominantly reddish color is common in adults that have passed their terminal molt, reinforcing the need to focus on identifying characters other than color. Photo by P. Sean McDonald.

Figure 8 Color patterns vary widely in juvenile European green crabs to facilitate camouflage. Photos from Stevens et al. (2014).

Potential impacts

The impacts of European green crab on Puget Sound ecological and economic resources are difficult to foresee and quantify because, like all invasions, they will ultimately depend on abundance of green crab, local biotic and abiotic factors, and historical context. Broadly speaking, one of the best predictors of whether an invasion will have negative impacts on a habitat is whether that species has a history of negative impacts elsewhere. Therefore, evidence of green crab impacts from other regions can provide some indications of what might be expected in Washington's Salish Sea.

Eelgrass

In Puget Sound, eelgrass provides valuable structure, stability and habitat where there would otherwise be relatively bare substrate. It is an important food source, nursery and refuge for birds, fishes, crabs, and many other marine invertebrates and seaweeds. Eelgrass meadows can play an important role in carbon cycling and might even reduce local effects of ocean acidification (Garrard et al. 2014, Hendriks et al. 2014). Eelgrass meadows also improve water quality by filtering sediment and nutrients from the water and help stabilize the sea floor with extensive networks of rhizomes and roots, which can help reduce shoreline erosion.

On eastern shorelines of North America, European green crab have been implicated in damage to eelgrass (*Zostera marina*) beds and failed efforts to restore eelgrass habitats (Figure 9). Green crab damage and uproot shoots as they forage for food and will even graze directly on the basal meristem of the eelgrass, preventing shoots from growing new leaves (Disney et al. 2014, Malyshev et al. 2011). Green crab can also destabilize the substrate and cause changes in the sediment, impacting eelgrass success.

Figure 9: Photos of Maquoit Bay, Maine, before and after dense European green crab populations. Photos by Hillary Neckles USGS.

In Puget Sound, such impacts could:

- reduce habitat availability for juvenile salmonids, forage fishes, crabs and other species;
- impair carbon-storage capacity of Washington tidelands;
- increase wave exposure and change tideland shape and
- reduce available foraging area for shorebirds.

Eelgrass is one of the Puget Sound Vital Sign indicators tracked by the Puget Sound Partnership to measure estuarine health (www.psp.wa.gov/vitalsigns/eelgrass.php). Establishment of dense populations of European green crab could hinder efforts to achieve the Puget Sound recovery goal to increase eelgrass area 20% by 2020.

Shellfish

European green crab are considered generalists because of the wide range of food they consume, but bivalves are among their preferred prey. Across the globe, the most frequently cited effect of green crab is predation on shellfish. On the east coast of the United States, green crab predation on shellfish has been estimated to cost $22.6 million per year (Lovell et al. 2007). In particular, green crab have been cited as a contributing cause in the decline of the soft shell clam (*Mya arenaria*) industry. In the eastern United States, researchers demonstrated that more soft shell clams survived when green crab were excluded (Whitlow 2010), while researchers in Australia found similar patterns for another commercially important species, *Katelysia scalarina* (Walton et al. 2002). In Washington, tribes and shellfish growers face potential economic and cultural losses if green crab are able to establish at high densities. In 2013, Washington shellfish aquaculture production was valued at $92 million, approximately 80% of which was from Puget Sound (Washington Sea Grant 2015).

As aggressive competitors for space, green crab could displace juvenile native Dungeness crab, increasing their vulnerability to predators. Research on the west coast of the United States indicated that young Dungeness crab spent less time in protective shell habitat when green crab were present (Figure 10, McDonald et al. 2001). Like shellfish aquaculture, the commercial Dungeness crab fishery contributes tens of millions of dollars to Washington State's economy every year, with a $61 million value in 2014 (Pacific States Marine Fisheries Commission 2015), approximately 20% of which was from Puget Sound (Childers and Cenci 2015). Puget Sound also hosts a very popular recreational crab fishery that harvested only slightly fewer crab than the Puget Sound commercial fishery between 2011 and 2014. Potential impacts of green crab to Dungeness crab and other crab species have prompted much of the concern related to possible invasion of Puget Sound.

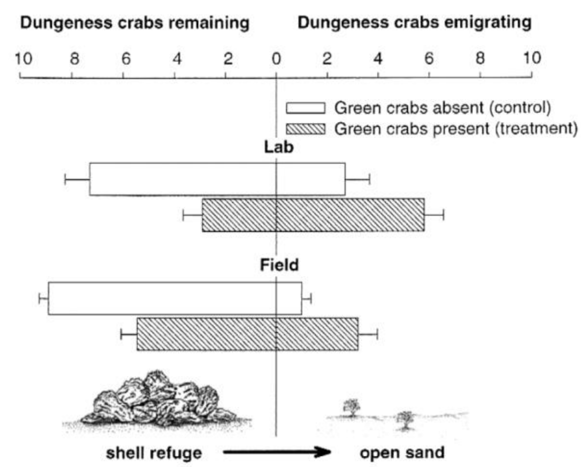

Figure 10 Reduced use of protective shell refuge by Dungeness crab in the presence of green crab. Figure from McDonald et al. 2001

Ecological communities and habitat

Green crab have a broad diet that includes worms, barnacles, snails, bivalves and even vegetation, and the impacts on habitat and ecological functions could be equally as broad and difficult to predict. Direct impacts can also ripple through the ecosystem in complex indirect effects. For instance, in San Francisco Bay, selective predation by green crab on native clams reduced competition for a previously-rare invasive clam, and allowed the invasive clam to become highly abundant (Grosholz 2005). Responses can also change with changes in green crab populations. After 14 years of surveys in central California, green crab were associated with reduced abundance of native hairy shore crab, but hairy shore crab recovered when green crab declined (DeRivera et al. 2011).

By digging and burrowing, green crab can also impact banks in soft-sediment habitats, altering shoreline structure and function. In the eastern United States, European green crab presence reduced the biomass of plant roots in high marsh sediments, resulting in lower bank stability (Figure 11, Aman et al. 2016). With reduced habitat value for native organisms, ripple effects could cascade to birds, fishes and even mammals.

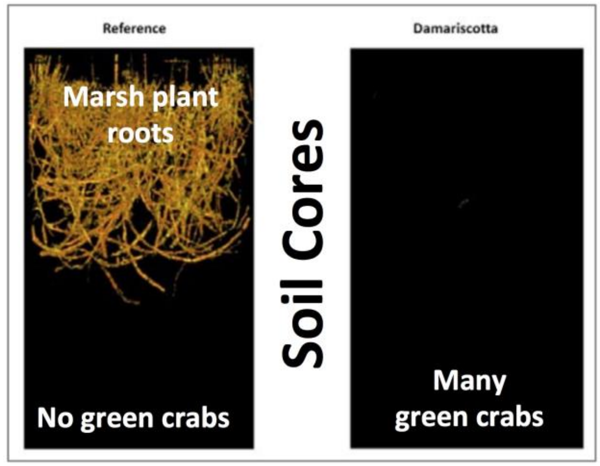

Figure 11 Computed tomography (CT) scans of soil cores, showing the amount of marsh plant root material belowground where green crabs are absent (left) and present (right). Figure modified from Aman et al. 2016.

Puget Sound green crab monitoring

In response to the establishment of European green crab on Washington's outer coast in 1998, WDFW initiated a monitoring program for Puget Sound the following year. With Nahkeeta Northwest Wildlife Services' leadership, guidance from WDFW and other partners, and with the support of as many as 100 volunteer contributors per year, the Marine Invasive Species Monitoring program (MISM) was able to gather data from more than 200 Puget Sound locations by 2008 (Nahkeeta Northwest 2009). Unfortunately, the economic downturn in the late 2000s resulted in the loss of funding for the program and it ceased operations in 2010.

With the discovery of the Sooke green crab population in 2012, efforts to reestablish a volunteer-based early detection program focused on conducting targeted, intensive monitoring at prioritized sites, as well as broad outreach. Washington Sea Grant received support to establish the program from EPA through the Puget Sound Marine and Nearshore Protection & Restoration Grant program at WDFW in late 2014. Serendipitously, the project began just as the strongest ENSO event recorded since the 1997-1998 ENSO that facilitated US west coast range expansion was building steam.

METHODS

The primary goal of this project was to establish a monitoring program that increases the likelihood of detecting European green crab populations within Washington's inland marine waters at the earliest possible stage to give control efforts the highest probability of reducing further spread. To do so, the approach taken was both targeted and broad, rigorous and opportunistic, and involved both monitoring and outreach. A citizen science approach met all these goals. To ensure the quality of volunteer contributions, and the sustainability of the volunteer corps, the program was evaluated on the basis of volunteer knowledge and satisfaction, and protocol efficacy.

Volunteer monitoring early detection program

Habitat suitability mapping

To help target the effort of looking for needles in a haystack, the first step was to use existing expertise to identify and prioritize the most suitable locations for green crab establishment. Using satellite imagery in Google Maps and Google Earth, the Crab Team systematically assessed the shoreline along inland Washington for habitat characteristics favorable to green crab success. Sites were ranked on these characteristics to identify locations that past research (Grosholz and Ruiz 1996) and experience suggested would be most suitable for European green crab establishment:

(+) features positively influencing suitability

- isolated but connected lagoon/pool
- braided and/or highly meandering tidal slough or shallow channel
- river delta or extensive tide flat

(+) attributes positively influencing suitability

- marsh vegetation
- impoundment/artificial structure

(-) attributes negatively influencing suitability

- high energy
- extensive freshwater input

Highly-suitable sites were then ground truthed as time allowed to confirm that the habitat reflected the inferences made from satellite imagery. In some cases, the water was too fresh or the habitat drained completely, making it less suitable for European green crab than originally though.

The map of medium and high suitability sites is available at *tinyurl.com/wagreencrab*, and is regularly updated with monitoring site locations and European green crab findings (**Error! Reference source not found.**12).

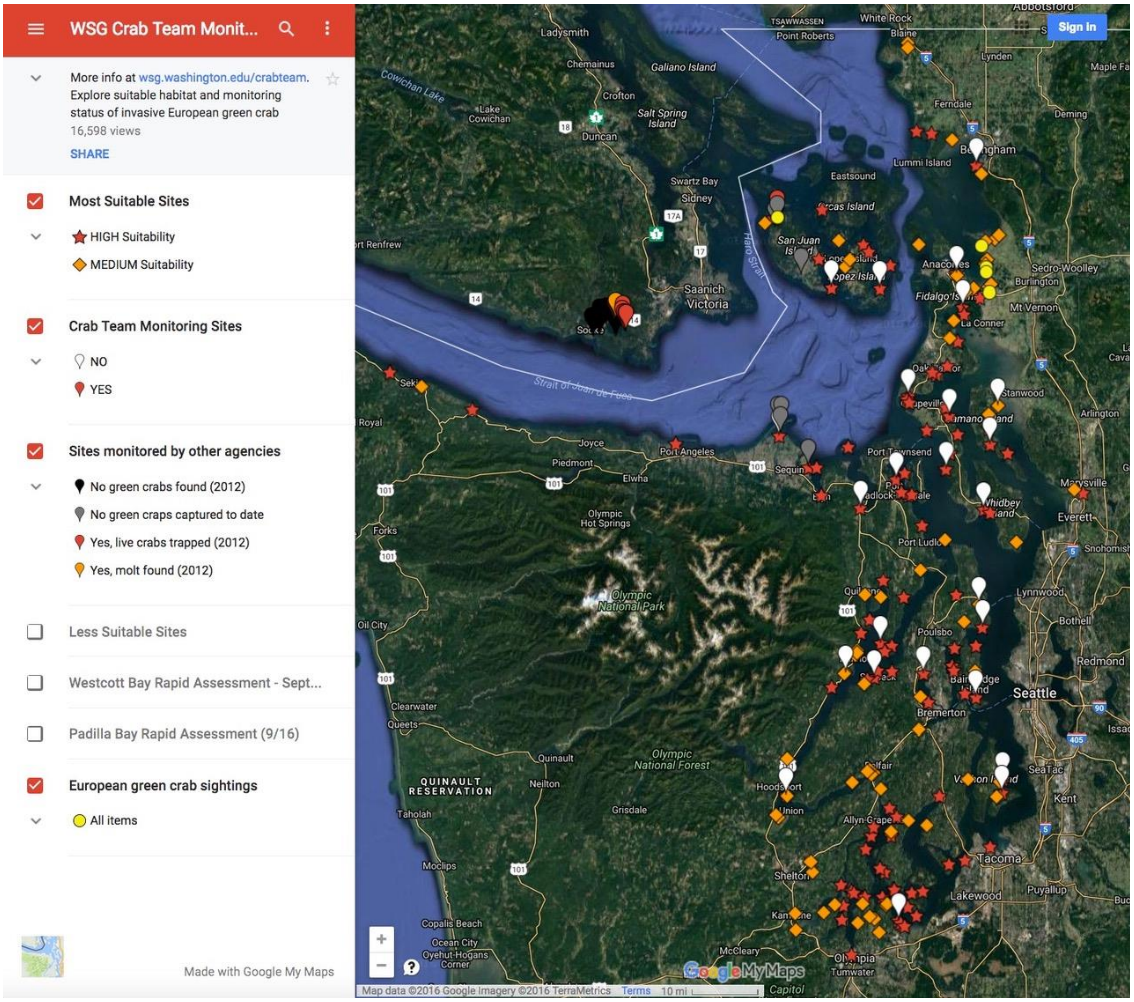

Figure 12 December 1, 2016 screenshot of the Crab Team map with medium and high priority monitoring sites as orange diamonds and red stars; Crab Team monitoring sites as white bubbles (no green crab found) and red bubbles (green crab found). The map also includes sites monitored by other entities for European green crab. The interactive map is available at *www.tinyurl.com/wagreencrab.*

Volunteer training

Trained and supported volunteers are the engines of the Crab Team, expanding the geographic and temporal scope of monitoring and data collection far beyond what would be possible using professionals on the same budget. To ensure the quality and reliability of the volunteer-collected data and to increase the general level of knowledge about European green crab among those likely to frequent Puget Sound shorelines, the Crab Team offered training workshops throughout Puget Sound.

In the first year, the training workshops were typically three hours in length. In year two, based on volunteer feedback, training was extended to five hours to allow additional time for protocol demonstration and practice. Workshop topics included:

- Project staff and background
- What makes European green crab invasive
- What is threatened by green crab invasion

- What is being done about the threat
    - Outreach
    - Monitoring
- Protocols step-by-step in the classroom
- Protocol practice
- Discussion of team selection, map and possible monitoring sites

On-site training was not originally planned, but ultimately emerged as one of the most critical components of preparing volunteers to sample independently. After a monitoring site and date were selected, a Crab Team staff member joined volunteers each time at their assigned site on the first day of monitoring. Staff provided equipment and bait to the team, helped navigate site access and setup, and participated with team members in going through the first day of sampling. Though it was logistically prohibitive to also provide training for day two of sampling (processing trap contents), staff discussed this protocol again in detail and answered any outstanding questions.

Site selection and establishment

In addition to habitat suitability, sites were selected based on a number of logistical factors: safe and legal access, volunteer proximity and convenience, geographic spread, and retention of water at low tide to reduce bycatch mortality. As a result of the latter constraint, all sites monitored had elevated sills that retained water at low tide, and were characterized either as salt marsh channels or restricted lagoons.

Figure 13 Crab Team site marker that identifies the location from which volunteers begin the 50 meter transect, placement of traps and molt count.

During the first year of the project, site access was not addressed until after volunteer teams had formed and identified the site that they were interested in monitoring. The timing proved a challenge to an expedient turnaround time from training to monitoring. Acknowledging that difficulty, staff began seeking landowner permission to access most high priority sites in advance of volunteer recruitment for 2016, recognizing that not all sites with access would be chosen for monitoring. That process readily allowed volunteers to begin monitoring within a month after the training workshops in 2016.

Once a team formed and identified a site, the site was established by recording detailed location and limited habitat information, and setting a rebar stake (tagged with program contact information - Figure 13) in the substrate to ensure consistency in monitoring. This site marker was intended to remain on site as long as the location is monitored and provided orientation for monitoring activities at the site. GPS coordinates of the site marker were recorded as the official site location.

Volunteer protocols
The first several months of the project were spent designing the volunteer protocol and training, and planning for monitoring program implementation. After the first monitoring season, feedback was gathered from volunteers, resulting in slight modifications to the protocol.

The protocol has three essential elements: trapping, molt surveys, and habitat surveys. Combined, the elements are intended to maximize the likelihood that Crab Team volunteers would find evidence of green crab, to improve the understanding of the habitat being monitored, and to maintain volunteer engagement. A team of three to five volunteers is assigned to each site with a volunteer captain as the primary point of contact. The team commits to monitor the site once a month (sampling on two consecutive days) from April through September. The Crab Team protocol elements are described in brief below, and the full volunteer manual is available under the Volunteer Toolbox tab of the Crab Team website *wsg.washington.edu/crabteam*.

Trapping
Two types of traps are used in Crab Team monitoring: galvanized steel cylindrical minnow traps and square Fukui fish traps (Figure 14). With a smaller mesh size and smaller opening, the cylindrical minnow traps were used to target young-of-the-year crab. Fukui traps have a larger mesh size and much larger openings. To reduce the risk of larger, or terrestrial organisms getting into the traps, the Fukui openings were narrowed by half by fastening the entrance panels together at the center with a zip tie. During each sampling event, three of each trap are set on the rising tide, alternating trap type and spacing each trap approximately 10 meters apart at the same tide height (Figure 15). Each trap is baited with approximately 200 grams of frozen mackerel, enclosed in a bait jar, and then staked into the substrate using a 36” metal rod, bent at the top, to help hold the trap in place.

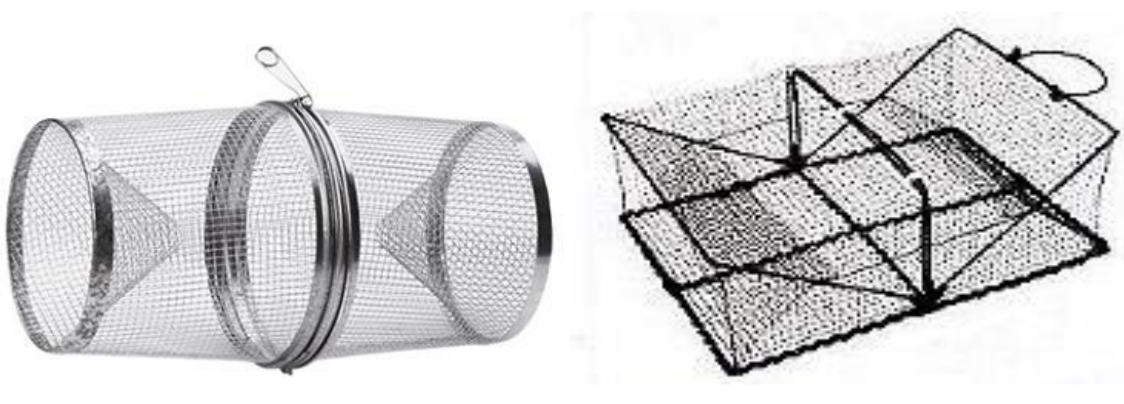

Figure 14 Galvanized steel cylindrical minnow traps (left) and square Fukui fish traps (right) were baited with mackerel and set at Crab Team monitoring sites to target different sizes of European green crab

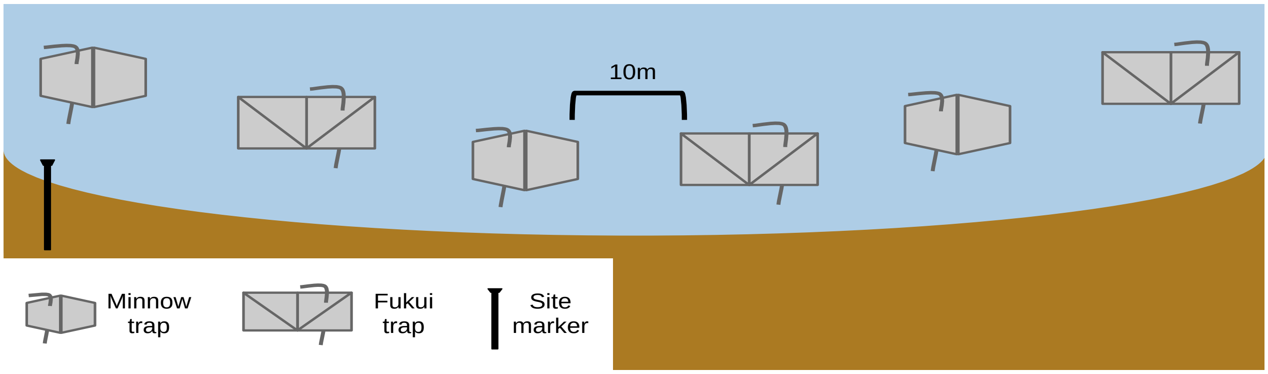

Figure 15 Schematic diagram of arrangement of baited traps in monthly sampling.

After a soak time of typically about 24 hours, less in some cases, the traps are retrieved and the following actions taken:

- Trap contents are photographed
- Fish are identified, counted and released.
- Crabs (except hermit crab) are sexed, sized, counted and released.
- Other invertebrates are identified, counted and released.

If a green crab is found, it is immediately reported to Crab Team staff by phone and retained under the project permit.

Habitat survey
To better understand the type of habitat available to green crab and other species at a monitoring site, the composition of the wrack (debris deposited by high tides), shoreline plants and substrate type are recorded along a 50-meter transect, parallel to the shoreline. A 50-meter rope, marked in one-meter intervals, is laid along the shoreline, starting at the site marker and tracing the lower edge of the terrestrial habitat, which is typically riprap or marsh vegetation such as pickleweed (Figure 16). Volunteers place a .1-square-meter quadrat at each of 10 randomly assigned distances along the transect and record estimates of percent cover of vegetation, animals and four categories of wrack, as well as substrate type.

Figure 16 Examples of habitat survey transect line placement at Crab Team monitoring sites which are typically characterized by riprap (left) or marsh vegetation (right).

Molt survey

All crabs must molt to grow, and the molted exoskeletons are often deposited by the high tide onto the upper beach with seaweed and other beach wrack and debris (Figure 17). In addition to the live trapping, searching for molts provides an additional modality by which to look for evidence of European green crab in nearby waters. Indeed, several range expansions of this species have been identified first through molts rather than through capture of live crabs.

Volunteers begin at the established site marker, then have 20 total person minutes (20 minutes for one molt collector, 10 minutes for each of two molt collectors, etc.) to target the highest concentrations of molts in the general area and collect as many molts as possible. Once the time is up, volunteers identify, count and record the species of all the individual molts collected.

Figure 17 Molts, including European green crab carapace (top left) in beach wrack. Photo: Jeff Adams

Equipment cleaning and maintenance

To prevent any transfer of biological material and to maintain the integrity of the equipment, volunteers are instructed to rinse, inspect and clean their monitoring equipment and boots as much as possible before leaving the site. Once home, the volunteer in charge of the equipment cleans the traps, bait jars, tubs and quadrat with fresh water, then stores the equipment in a dry location until the next month's monitoring event.

Program and protocol evaluation

The rapid growth of citizen science has demonstrated the potential for non-scientists to contribute valuable data on large scales. There are occasionally concerns, however, about the quality of data provided by volunteers, or the sustainability and consistency of programs that must constantly recruit and train new participants. To address some of these concerns, the Crab Team monitoring program was evaluated from several angles: (1) testing volunteer knowledge and effectiveness of training workshops; (2) surveying volunteers to request input and feedback on the monitoring protocols and program resources; (3) investigating the efficacy of alternative bait types; and (4) validating the effectiveness of the trapping protocol in an area where the target species is known to occur. Ensuring volunteer competency and protocol efficacy (1, 2, and 4 above) increases the value of the dataset collected. Investing in volunteer confidence, engagement and comfort (2 above) contributes to volunteer retention, which not only increases program efficiency but increases the consistency with which data are collected over time.

Assessing volunteer knowledge and workshop efficacy

To evaluate the effectiveness of training workshops in teaching relevant content and preparing trainees to monitor, Crab Team staff encouraged trainees to complete a knowledge assessment immediately before and after each workshop (Appendix A). The primary content areas of the assessment were related to species identification and crab sex. Participants were also asked if they felt the training adequately prepared them to monitor. Data from the 2015 trainings were assessed qualitatively to inform changes for 2016 and target areas for which volunteers needed additional time. The 2016 workshop assessment was similar and enabled quantitative analysis of learning gaps and differences between new and returning volunteers.

Volunteer feedback survey and focus groups

At the end of both sampling seasons, volunteer participation was requested in an anonymous online survey. The goal of the survey was to gauge volunteer satisfaction overall and with various components of participation. Because 2015 was a pilot year, the sampling season was quite short, and only those volunteers who had participated in at least one day of independent sampling (working on site without Crab Team staff present) were requested to complete the survey. The survey was supplemented by several focus groups for which a UW Program on the Environment (POE) Capstone student visited volunteers in the field and participated in a brief group discussion about challenges and strengths of the program. The results of the survey and focus groups were used to identify components of the protocol that were confusing, frustrating or boring for volunteers. These results suggested intervention points where additional education or protocol alteration could contribute to volunteer sustainability. In 2016, volunteers had completed up to four months of sampling by the time the survey was administered, and the increased number of volunteers provided a larger pool of feedback to draw on.

Bait testing in Puget Sound

While designing the volunteer monitoring protocol, Crab Team staff discussed tradeoffs of different bait types, including efficacy, cost, and ease of procurement, use and disposal. Most crab experts strongly argue that fish is superior to canned cat food in attracting crabs, but we could find no tests of this assumption in the literature. Because we desired to find effective bait that could be used consistently across space and time without sacrificing volunteer comfort and convenience, we worked with a UW Program on the Environment undergraduate capstone student to test bait efficacy.

At five sites in Puget Sound, we compared the effect of frozen mackerel versus canned cat food on the catches in each of the two trap types. At each site, we set five of each bait-trap combination in the same order and location as the standard Crab Team protocols described previously.

Crab Team investigators tested the effect of bait and trap type on total trap catch, catch per unit effort (CPUE), and catch taxon richness, using model selection. For each response variable, four nested linear mixed effects models were estimated including all possible combinations of the predictors as fixed effects: (1) bait type only, (2) trap type only, (3) bait type and trap type as main effects, and (4) bait type and trap type as well as their interaction. All models included a randomly varying intercept for site. The best model was selected as the one with lowest Akaike Information Criterion (AIC, Burnham and Anderson 2002). The AIC is a measure of the relative quality of statistical models for use with a particular data set, offering an estimate of information lost when a particular model is used to represent the process by which the data was generated. When models were within two AIC, they were considered indistinguishable, in which case the model with the fewest predictors was selected.

Protocol and bait testing in infested waters

Considering the first year of monitoring data, the Crab Team protocols were clearly effective at capturing native crabs. Their sensitivity for capturing invasive European green crabs, however, was difficult to assess without knowing with confidence that green crabs were present at a given site. In August 2016, to demonstrate that the protocols were effective at detecting European green crab when present, Crab Team staff sampled one site in Grays Harbor (near Westport), and three sites in Willapa Bay (Figure 18, Toke Point, Stackpole and Oysterville). Green crab have been periodically abundant in Willapa Bay and Grays Harbor since 1998, with spikes in population abundance following warm years and El Niño conditions.

In Grays Harbor, Crab Team trapping and molt count protocols were employed as written, except the trap soak was both shorter than typical at six hours and 15 minutes, and occurred during the daytime only.

In Willapa Bay, two slightly different designs were used to test whether Crab Team protocols set traps at the best elevations for capturing green crabs. At Stackpole and Toke Point, two sites with large tideflats, five horizontal transects of four traps each (two minnow and two Fukui, alternating) were set across an elevation gradient. Each transect consisted of four traps, rather than the six used in Crab Team protocols, in order to capture a greater vertical range with a limited number of traps. At Oysterville, four horizontal transects of six traps each (three minnow and three Fukui, alternating — identical to the trapping transect used by Crab Team protocols) were set across an elevation gradient. In all cases, the highest trap transects were set immediately adjacent to the upland vegetation, which is analogous to where Crab Team volunteers set traps. An additional advantage of trapping in arrays across elevation gradients is that these observations are comparable with abundance data collected in Willapa Bay by WDFW and researchers over the past two decades and, therefore, can contribute to assessments on population trends.

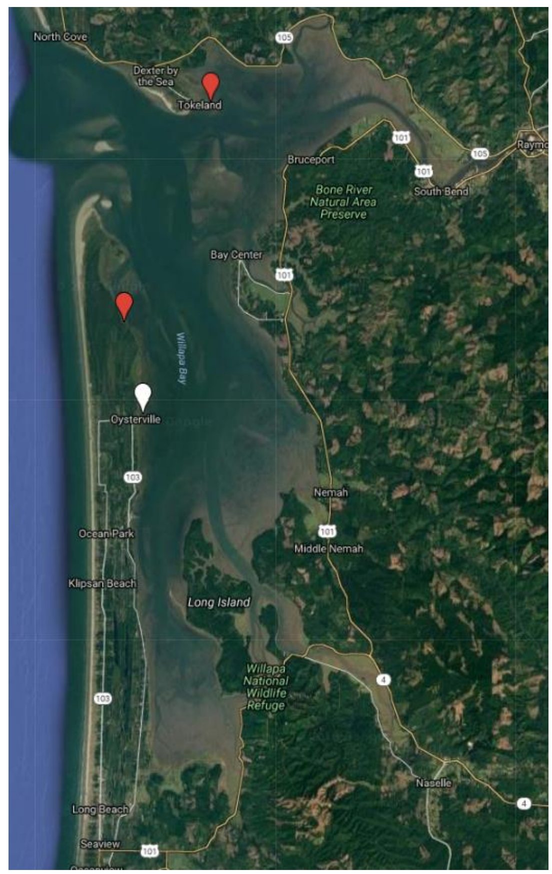

Figure 18 Map of sampling locations in Willapa Bay, August 2016. The red sites markers, Toke Point to the north and Stackpole to the south, indicate where European green crabs were captured. The white site marker, Oysterville, indicates no green crabs were trapped.

In addition, the bait assay described previously for Puget Sound was repeated in marsh channels at Toke Point and Stackpole. The trap transects set in Willapa tideflats represented similar conditions to Crab Team protocols in Puget Sound sites that have a prominent lagoon, while the bait assay was conducted in conditions very similar to Puget Sound sites where monitoring occurs in marsh channels. As in the Puget Sound bait assay, the effect of bait and trap type on total trap catch and taxa richness was analyzed with linear mixed effects models that included site as a randomly varying intercept. Support for the influence of the predictors was evaluated via model selection as described previously.

Rapid assessments

On August 31st 2016, during regular monthly monitoring, WSG Crab Team volunteers captured a large male European green crab, the first confirmed along inland Washington shorelines. In response, WDFW directed a rapid assessment of the area to determine the scale of the infestation. Washington Sea Grant Crab Team staff provided expertise and resources to develop a sampling strategy, mobilize equipment, secure property access and conduct fieldwork.

With the green crab capture location as a focal point, all potentially suitable habitats within a two-mile radius were identified. Access to these locations was secured, if possible, and trap resources allocated based on habitat size and suitability.

At each site, Crab Team directed the placement of baited traps to cover as much of the site as possible and target the best microhabitat. After setting traps, the staff surveyed the area for molts as much as time allowed. On the following day, traps were retrieved, processed, baited again and reset. Depending on habitat size and complexity, some sites were trapped on two consecutive days, and some were sampled on only one of the two days to maximize the geographic scale of sampling with a limited number of traps. All native organisms were released.

In addition to the rapid assessment in the field, Washington Sea Grant's Communications Department took the lead in coordinating related media coverage. In collaboration with WDFW, Washington Sea Grant produced, distributed and followed up with a press release and guided inquiries to appropriate staff. Crab Team staff also gave a public talk on San Juan Island to address local questions and concerns about the green crab sighting and response efforts.

On September 19th 2016, three weeks after the green crab was captured on San Juan Island, staff from the Padilla Bay National Estuarine Research Reserve found a small female European green crab while overturning rocks. In response a second rapid assessment effort was launched, following a similar approach but much larger in scope and staff involvement. Padilla Bay has a much greater proportion and amount of suitable habitat. In addition, the crab was found in habitat that is more characteristic for females after they have mated and are preparing to extrude their eggs. As such, a much greater number of sites was necessary to ensure reasonable coverage of habitat and scale at Padilla Bay. At each assessment sampling site in Padilla Bay, an array of six traps (three Fukui and three minnow) was set, with minnow traps targeting juveniles either directly adjacent to the lower limit of vegetation, or in protected pools and channels, and Fukui traps were set at lower tidal elevations, to target adult crab, either approximately 20 meters further out on the tideflat or in deeper nearby channels. See the Results for a full description of effort in both rapid assessment trapping surveys.

Outreach

In addition to the intensive, targeted monitoring, a Crab Team outreach plan was developed to increase awareness of European green crab among Puget Sound residents and within targeted groups likely to spend time on the beach or water. The outreach approach involved three major elements:

- media,
- targeted audiences who receive presentations and
- targeted audiences who receive materials.

Washington Sea Grant's Communications Department produced, distributed and followed up with three press releases that generated most of the project media coverage.

Presentations were given to several important target audiences, including Beach Watcher and beach naturalist groups, marine science centers, clubs and public science forums. Two UW undergraduate students contributed to the outreach program by developing a list of target audiences and draft outreach materials.

RESULTS

Volunteer monitoring early detection program

Volunteer training

In 2015, the Crab Team held four trainings for 47 participants. The training workshops took place mostly in areas with high-risk sites and close proximity to the Sooke population on Vancouver Island – Whidbey Island, Camano Island, Port Townsend and Olympia.

Seven workshops in 2016 were attended by 79 participants, including 16 who also attended the first year (Table 1). Of the 79 participants, 73 participated in monitoring during the 2016 field season. Such a high participation rate (92% of attendees) reflects, in part, the strong commitment of individuals who choose to attend the workshop, and the effectiveness of our targeted recruitment. In addition, it demonstrates that the workshop successfully convinced potential volunteers of the issue's importance and the efficacy and value of the proposed approach. In 2016, the training workshops focused on north and central Puget Sound: San Juan Island, Lopez Island, Padilla Bay, Whidbey Island, Camano Island, Port Townsend and Poulsbo.

Table 1. Summary of training provided by Crab Team staff in terms of workshops, individuals and hours. Hours of training provided assumes five hours per workshop in 2016, and three hours per workshop in 2015, and adds in time dedicated to providing on-site training to volunteers unable to attend workshops.

	Training workshops	Workshop participants	Hours of training provided
2015	4	47	149
2016	7	79	427
Total	**11**	**110 (unique)**	**576**

In 2016, 16 additional volunteers received on-site training and participated in data collection during the field season. These volunteers were always paired with volunteers who had attended the training workshops. Two returning volunteers were unable to attend the workshops and received an on-site refresher with Crab Team staff.

Volunteer protocols

Ultimately, 116 volunteers (unique individuals) participated in Crab Team monitoring during 2015 and 2016, contributing 2,109 hours (Table 2) using Crab Team protocols to look for European green crab and increase our understanding of the ecosystems in which green crab were suspected to most likely thrive.

Table 2: Volunteer participation and contributed hours to Crab Team monitoring. The number of volunteers is the number of unique individuals.

Period	Volunteers	Volunteer hours
2015	28	211
2016	108	1,899
Total	116	2,109

The single most critical result of the volunteer monitoring was the capture of a single, large (74 mm carapace width) male European green crab in Westcott Bay on San Juan Island, the first in Washington's inland marine waters. By serendipity, regional green crab expert Sylvia Behrens Yamada from Oregon State University was at a nearby site conducting monitoring of her own and was immediately able to confirm the identification and measurement. Following protocol, volunteers immediately contacted Crab Team staff, who then contacted WDFW to begin the rapid response process (see ensuing Rapid Assessment section).

Habitat survey
Habitat survey data analysis will be explored once the Crab Team database is complete. In general, the 26 Crab Team sites are part of two broad categories — channeled marshes and lagoons. Habitat surveys of all sites but one were dominated by pickleweed and associated saltmarsh plants. The remaining site is adjacent to a large rip rap revetment that supported very little plant growth. Also, in general, and somewhat surprising, the habitat surveys have so far recorded very limited human debris.

Trapping
Crab Team protocols were used to conduct regular monthly monitoring at 26 Puget Sound sites identified as highly suitable green crab habitat (one additional site monitored during the 2015 pilot effort was not monitored during 2016). During 2015 and 2016, volunteers set a total of 918 traps for over 21,000 trapping hours (Table 3).

Table 3: Crab Team trapping summary for 2015 and 2016.

	Number of sites monitored	Trap sets	Monitoring trap hours	Total number organisms recorded	Total number of taxa trapped
2015	7	84	2,230	7,902	9
2016	26	828	18,696	44,216	25
To Date	**26**	**912**	**20,926**	**52,118**	**27**

More than 52,000 organisms belonging to 27 taxa[*], including a single European green crab, were captured in baited traps during the first two years of Crab Team monitoring (Tables 4–5, Appendix B). The native species captured included crabs, shrimp, snails and fishes. The hairy shore crab (*Hemigrapsus oregonensis*) vastly dominated the total catch, comprising 99% of organisms captured in traps in 2015 and 93% in 2016. The Pacific staghorn sculpin (*Leptocottus armatus*) was also a significant part of the assemblage captured. In the absence of hairy shore crab, staghorn sculpin abundance for all sites combined accounted for 53% of the remaining organisms in 2015 and 47% in 2016. Hairy shore crabs were captured at every single site, and staghorn sculpins were captured at all but one (Table 6, Appendix B). The next most-widely captured species, the purple shore crab (*Hemigrapsus nudus*), was only found at 65% of sites.

[*] The Crab Team sometimes uses the phrase "taxon/taxa" rather than "species" because some species within groups (e.g., Majid crabs) are difficult to distinguish and were grouped for volunteer convenience.

Table 4: Total number of organisms captured in traps across all sites (seven) during pilot year (2015).

Species 2015	**Common Name**	**# Trapped**
Hemigrapsus oregonensis	Hairy shore crab	7,824
Leptocottus armatus	Staghorn sculpin	42
Hemigrapsus nudus	Purple shore crab	17
Crangon species	Sand shrimp	10
Gasterosteus aculeatus	Three-spined stickleback	3
Oligocottus maculosus	Tidepool sculpin	3
Cancer (Metacarcinus) gracilis	Graceful crab	1
Pagurus granosimanus	Grainy-handed hermit crab	1
Platichthys stellatus	Starry flounder	1
	Total	**7,902**

Table 5: Total number of organisms captured in traps across all sites (26) during 2016.

Species 2016	**Common Name**	**# Trapped**
Hemigrapsus oregonensis	Hairy shore crab	41,006
Leptocottus armatus	Staghorn sculpin	1,505
Cancer (Metacarcinus) gracilis	Graceful crab	270
Nassarius fraterculus	Japanese nassa	231
Hemigrapsus nudus	Purple shore crab	228
Pagurus granosimanus	Grainy-handed hermit crab	188
Gasterosteus aculeatus	Three-spined stickleback	172
Batillaria attramentaria	Asian mud snail	167
Cancer (Metacarcinus) magister	Dungeness crab	110
Pagurus hirsutiusculus	Hairy hermit crab	101
Cottus asper	Prickly sculpin	64
Cymatogaster aggregata	Shiner perch	42
Haminoea sp.	Bubble shell	34
Amphissa columbiana	Wrinkled dove snail	27
Cancer productus	Red rock crab	22
Nassarius mendica	Western lean nassa	14
Pholidae and Stichaeidae species	Eel-like fishes (gunnels, pricklebacks, etc)	10
Pandalidae and Hyppolytidae species	Broken back shrimp	6
Multiple in Majidae	Spider crabs	5
Oligocottus maculosus	Tidepool sculpin	4
Telmessus cheiragonus	Helmet crab	4
Syngnathus leptorhynchus	Bay pipefish	3
Carcinus maenas	**European green crab**	**1**
Lophopanopeus bellus	Black clawed crab	1
Porichthys notatus	Plainfin midshipman	1
	Total	**44,216**

Table 6: Species frequency by site. Data were combined from 2015 and 2016, and one site was monitored during the pilot year in 2015 that was not monitored in 2016; thus the maximum possible number of sites at which a species could be captured was 27.

Taxon Type	Species	Common Name	# Sites Where Captured
Crab	*Hemigrapsus oregonensis*	Hairy shore crab	27
Fish	*Leptocottus armatus*	Staghorn sculpin	26
Crab	*Hemigrapsus nudus*	Purple shore crab	17
Fish	*Gasterosteus aculeatus*	Three-spined stickleback	13
Crab	*Pagurus hirsutiusculus*	Hairy hermit crab	12
Fish	*Cymatogaster aggregata*	Shiner perch	12
Crab	*Pagurus granosimanus*	Grainy-handed hermit crab	8
Crab	*Cancer (Metacarcinus) gracilis*	Graceful crab	6
Snail	*Batillaria attramentaria*	Asian mud snail	6
Crab	*Cancer (Metacarcinus) magister*	Dungeness crab	5
Fish	Pholidae and Stichaeidae spp.	Eel-like fishes (e.g. gunnels)	3
Crab	*Cancer productus*	Red rock crab	2
Crab	Multiple in Majidae	Spider crabs	2
Crab	*Telmessus cheiragonus*	Hairy helmet crab	2
Snail	*Haminoea* sp.	Bubble shell	2
Fish	*Oligocottus maculosus*	Tidepool sculpin	2
Fish	*Syngnathus leptorhynchus*	Bay pipefish	2
Crab	***Carcinus maenas***	**European green crab**	**1**
Crab	*Lophopanopeus bellus*	Black clawed crab	1
Shrimp	Pandalidae & Hyppolytidae spp.	Broken back shrimp	1
Shrimp	*Crangon* spp.	Sand shrimp	1
Snail	*Amphissa columbiana*	Wrinkled dove snail	1
Snail	*Nassarius fraterculus*	Japanese nassa	1
Snail	*Nassarius mendica*	Western lean nassa	1
Fish	*Cottus asper*	Prickly sculpin	1
Fish	*Porichthys notatus*	Painfin midshipman	1
Fish	*Platichthys stellatus*	Starry flounder	1

Sites varied substantially in abundance (average catch per month) and, to a lesser extent, diversity of organisms trapped during 2016 (Figure 19, Table 7), but Shannon diversity (H') was relatively low for all sites. When catch was totaled for each site across the entire 2016 trapping season, there was an inverse relationship between the diversity of taxa captured at sites and the relative abundance of organisms (Figure 20). The influence of abundance on diversity, modeled as an exponential function, was significant for both taxon richness and H'.

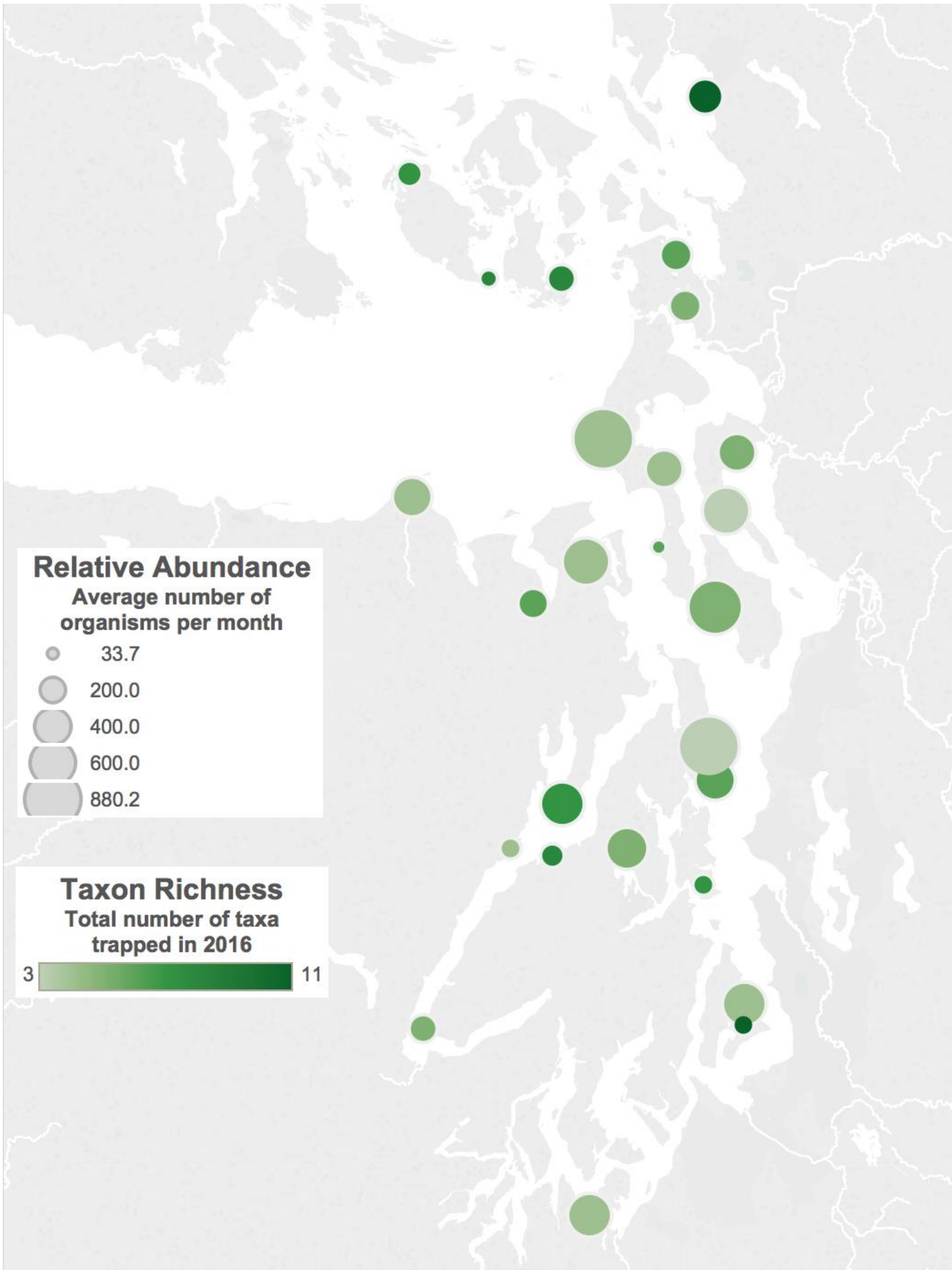

Figure 19 Map of 2016 monitoring sites with markers scaled by relative abundance of organisms trapped (marker size = average number of organisms trapped per month) and total taxon richness for the sampling season (color).

Table 7: Site summary information, arranged north to south, with total 2016 taxon richness, abundance (# organisms), effort (# months sampled), CPUE (catch per unit effort: average # organisms trapped per month), Shannon Diversity (H'), and average rarefaction estimate — the estimated number of species present at the site in an "average" trap (53 organisms across all sites and months). The shading of the cells is scaled to the values in each column to aid visual interpretation.

Site	Site Name	Type	Latitude	Longitude	Months Sampled	Taxon Richness	Total number of organisms	CPUE	H'	Rarefaction Estimate
362	Post Point Lagoon	Lagoon	48.718744	-122.5156	4	11	1,092	273.00	1.061	5.686
533	Westcott Bay	Channel	48.608341	-123.1436	6	7	771	128.50	0.825	3.164
341	Crandall Spit	Lagoon	48.493081	-122.5781	2	6	426	213.00	0.961	3.950
536	Third Lagoon	Lagoon	48.46161	-122.9752	6	8	317	52.83	1.180	5.232
330	Mud Bay	Lagoon	48.46091	-122.8215	6	8	962	160.33	0.962	5.142
323	Kiket Lagoon	Lagoon	48.42112	-122.5578	6	5	1,275	212.50	0.420	2.962
311	Penn Cove	Lagoon	48.23373	-122.73	6	4	5,277	879.50	0.043	1.306
516	Iverson Spit	Channel	48.21409	-122.4464	6	5	1,895	315.83	0.044	1.299
508	Race Lagoon	Lagoon	48.191825	-122.6006	6	4	1,776	296.00	0.166	2.063
214	Dungeness River	Channel	48.149942	-123.1384	3	4	1,047	349.00	0.270	2.083
552	Elger Bay	Channel	48.131296	-122.4705	6	3	3,092	515.33	0.024	1.164
590	Lagoon Point	Lagoon	48.07932	-122.6114	6	6	202	33.67	1.051	4.314
204	Kala Lagoon	Lagoon	48.057836	-122.7698	6	4	3,211	535.17	0.067	1.482
198	Discovery Bay	Lagoon	47.997751	-122.8825	6	6	1,162	193.67	0.343	2.833
306	Deer Lagoon	Lagoon	47.99458	-122.4919	6	5	4,163	693.83	0.087	1.643
177	Carpenter Creek	Lagoon	47.794345	-122.5067	5	3	4,401	880.20	0.055	1.402
173	DoeKegWats	Channel	47.745391	-122.4946	6	6	2,163	360.50	0.231	2.413
161	Zelatched Point	Lagoon	47.7119	-122.8186	6	7	2,649	441.50	0.110	1.795
138	Duckabush	Channel	47.64898	-122.9308	6	4	464	77.33	0.547	2.936
133	Best Lagoon	Lagoon	47.646955	-122.683	6	5	2,368	394.67	0.106	1.783
128	Nick's Lagoon	Lagoon	47.63813	-122.839	6	8	652	108.67	0.781	4.830
553	Blakely Harbor	Lagoon	47.595538	-122.5169	5	7	422	84.40	1.315	4.959
581	Rabb's Lagoon	Lagoon	47.392326	-122.434	4	11	332	83.00	1.412	6.959
74	Musqueti	Lagoon	47.388221	-123.1164	6	5	948	158.00	0.095	1.713
250	Butterball Cove	Lagoon	47.118164	-122.762	6	4	2,706	451.00	0.137	1.841
579	Heyer	Lagoon	47.097559	-123.0855	1	4	433	433.00	0.197	2.369

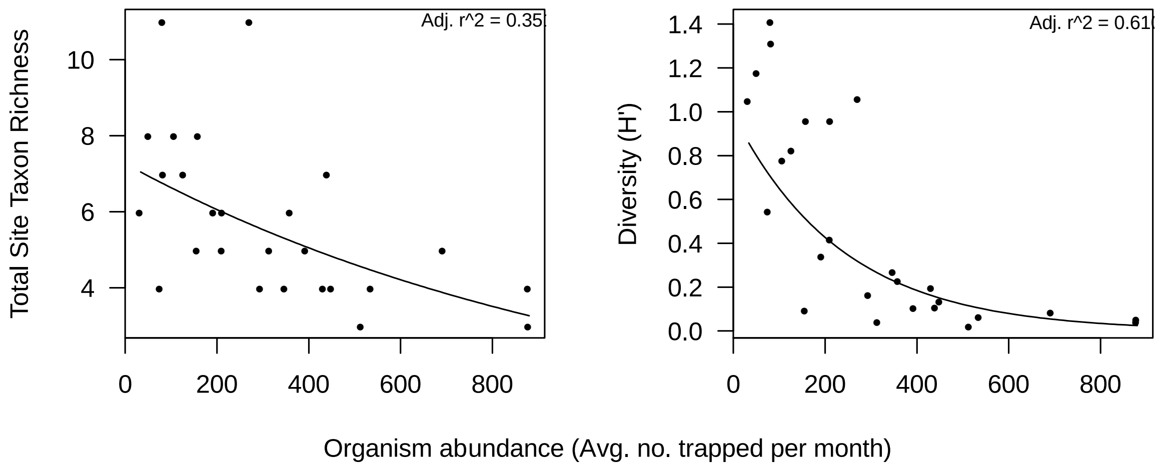

Figure 20 Site diversity aggregated over 2016 trapping in terms of total taxon richness per site (left panel) and Shannon diversity (H') as a function of relative abundance of organisms trapped (average number of organisms per month).

Crab Team staff investigated similarities among ecological communities by plotting trapping data for each site using non-metric multidimensional scaling (NMDS, Figure 21). This is an exploratory analysis technique that could allow staff to investigate factors determining organism abundance and diversity in coming years. As a demonstration, minimum convex hulls have been drawn around two groups of sites: lagoon sites (blue) and marsh channel sites (red). Communities of mobile animals captured in traps from marsh channels occupy only a small portion of the two-dimensional space covered by trap catches from lagoons. Additional patterns hinted at here will be better tested with additional sites. For instance, sites 553 and 581 both were historical log ponds, currently consisting of lagoons defined by man-made dikes and relatively high, narrow cobble/boulder sills through which water leaves the lagoon. Both sites are similar to each other in terms of ecological community, but distinct from the majority of other lagoons. With additional data including potential green crab captures, staff will be able to gain insight into communities and habitat types that might be most vulnerable to invasion.

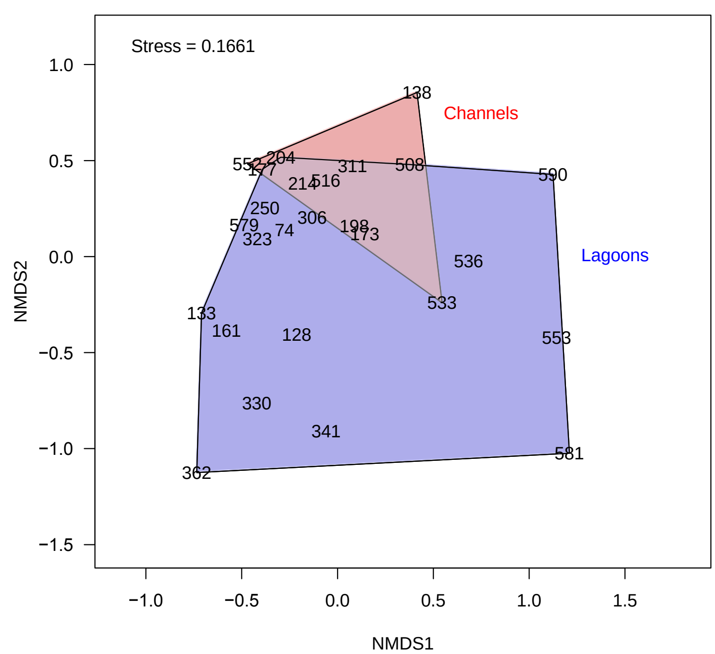

Figure 21 Non-metric multidimensional scaling plot for trap catches by site for 2016. Minimum convex hulls are plotted for sites characterized as marsh channels (red) versus lagoons (blue).

Molt survey

The survey approach changed substantially from 2015, when it was spatially constrained within the monitoring transect, to 2016, when it was constrained by effort in time. Nearly 15,000 molts were identified in 2015 and 2016 with no evidence of European green crab (Table 8, Appendix C). During 2016, 140 molt surveys were conducted across the 26 monitoring sites, totaling 2,800 minutes (46 hours, 36 minutes) of searching.

Table 8: Total number of molts found during molt surveys in 2015 (seven sites, 14 surveys) and 2016 (26 sites, 140 surveys).

Molt Species 2015	Common Name	# Found
Hemigrapsus oregonensis	Hairy shore crab	1,270
Hemigrapsus nudus	Purple shore crab	2
Cancer (Metacarcinus) gracilis	Graceful crab	2
Cancer (Metacarcinus) magister	Dungeness crab	1
Cancer productus	Red rock crab	1
Total		**1,276**

Molt Species 2016	Common Name	# Found
Hemigrapsus oregonensis	Hairy shore crab	12,095
Hemigrapsus nudus	Purple shore crab	739
Cancer (Metacarcinus) magister	Dungeness crab	128
Cancer productus	Red rock crab	76
Cancer (Metacarcinus) gracilis	Graceful crab	49
Multiple in Amphipoda	Amphipods	20
Telmessus cheiragonus	Helmet crab	18
Multiple in Majidae	Spider crabs	14
Multiple in Thalassinidea	Burrowing shrimp	6
Pagurus spp.	Hermit crabs	2
Lophopanopeus bellus	Black clawed crab	2
Multiple in Pinnotheridae	Pea crabs	1
Total		**13,150**

Program and protocol evaluation

Assessing volunteer knowledge and workshop efficacy

Qualitative investigation of knowledge assessments from the 2015 workshops indicated participants wanted more time to learn about the protocols, and especially to learn to identify organisms. The organisms are the biggest draw for the program, as many participants come from beach naturalist groups and have a love for seashore life. The Crab Team initially designed a three-hour training because a full-day training was potentially a barrier to participation. Switching to a six-hour training (with five hours of content) proved to be an effective filter, rather than a barrier. That is, Crab Team monitoring protocols require schedule flexibility and commitment. Many who are unable to fit a day-long training into their work schedule also lack the flexibility to participate in monitoring consistently. This change yielded positive results, as volunteer conversions from workshop attendees to Crab Team members increased from 64% in 2015 to 92% in 2016.

At all trainings in 2016, relevant knowledge increased as a result of participation in training workshops. Averaged across all workshop sites, the pre-test score was 5.5 questions correct (out of 9), and the average post-test score was 7.6 correct questions (Figure 22). Because a number of volunteers who participated in 2015 returned to the workshops in 2016, staff were able to compare the performance of new and returning volunteers. The comparison showed that:

- returning volunteers started with higher scores than new volunteers, presumably because they retained information from participating in monitoring during 2015.
- new volunteers learned more from the training workshops than those who participated in monitoring in 2015 (Figure 23),
- on average, new participants left the workshop with similar knowledge to returning participants (Figure 24), and
- at the end of the workshop, new and returning volunteers were similarly confident in their ability to conduct monitoring as required by protocols (Figure 25).

Species identification was the most challenging aspect for many participants, even those who had prior training as beach naturalists. This might be, in part, because it can be more challenging to identify an organism from a single photo, than from a live specimen, but also might reflect the fact that volunteers do not have much exposure to some of the less common species we see in pocket estuary communities.

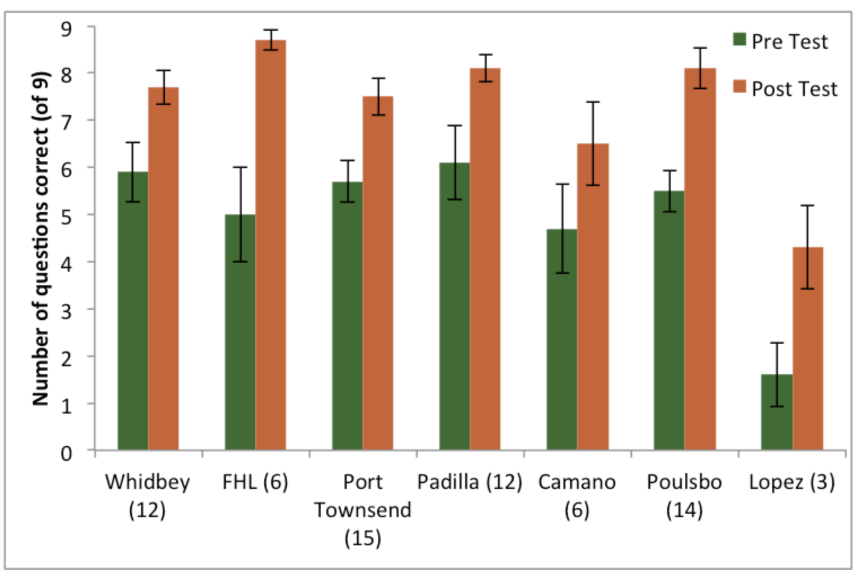

Figure 22 Pre- and post-workshop knowledge assessment scores (+/- 1 SEM) for 2016 trainings, with number of scores reported and arranged in order of date (Whidbey 3/4–Lopez 3/29).

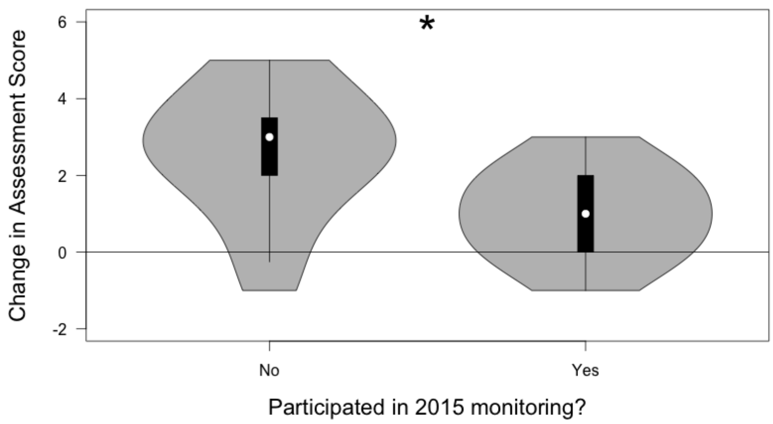

Figure 23 Change in workshop knowledge assessment scores (post-test score - pre-test score) for 2016 workshop attendees, based on whether or not they participated in monitoring in 2015. Box indicates 2nd and 3rd quartiles, and whiskers extend to full range of score changes. White dots mark median score change. Gray bubble width indicates the relative frequency of each score change.

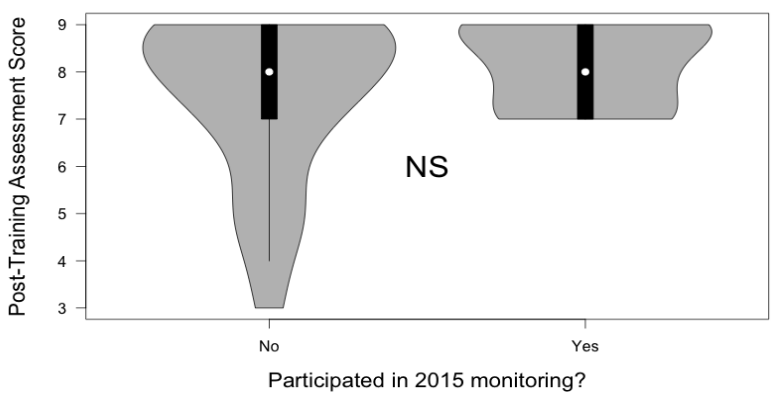

Figure 24 Post-workshop knowledge assessment scores (out of 9) for 2016 workshop attendees, based on whether or not they participated in monitoring during 2015. Box indicates 2nd and 3rd quartiles, and whiskers extend to full range of score changes. White dots mark median score change. Gray bubble width indicates the relative frequency of each score change.

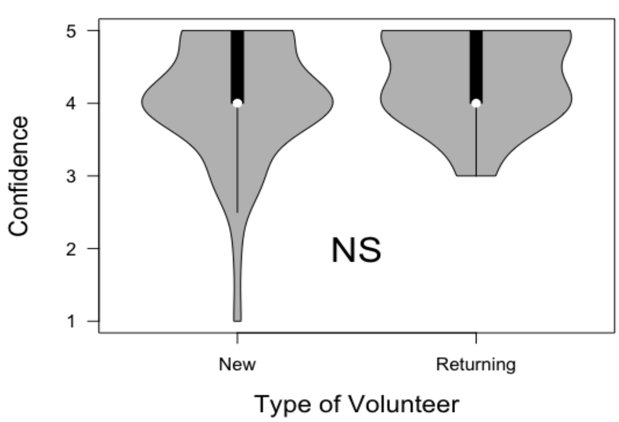

Figure 25 Post workshop Likert agreement (1-5) with the statement: "I feel confident in my ability to begin monitoring independently (with my team, but without Crab Team staff)" for new and returning Crab Team volunteers. Average confidence was 4.25/5. Box indicates 2nd and 3rd quartiles, and whiskers extend to full range of score changes. White dots mark median score change. Gray bubble width indicates the relative frequency of each score change.

Volunteer feedback survey and focus groups

The 2015 volunteer survey provided the program with the first opportunity to reflect on strengths and challenges faced by volunteers. One of the strongest messages that emerged was that the on-site training day, originally an afterthought, proved to be essential to volunteer confidence in independent sampling. Just under 60% of respondents said that they felt the workshop prepared them adequately for monitoring, but that number jumped to 94% when the same question was asked about the on-site training. As a result the on-site trainings were built into the plan for 2016 training. The greatest confusion was expressed regarding the molt survey protocol which, in the pilot year, involved spatially delimited surveys along multiple transects. Volunteers found them time consuming and were not clear on how to navigate contingencies. In response the staff greatly simplified the protocol, focusing primarily on keeping the time commitment reasonable while maximizing the number of molts examined.

Results from the 2016 survey are still in preparation. In general, however, volunteers responded favorably to questions about satisfaction and engagement, and returning volunteers commented positively on the changes in the protocol. One common thread was the desire to see the fruits of their labor — to see aggregated and summarized data, both for their site and to see how their site compared with others. Volunteers are invited to submit questions about the data to Crab Team staff, with the goal of engaging volunteers in the discovery of local and regional patterns in pocket estuary communities.

Bait testing in Puget Sound

For native Puget Sound species, the influence of bait type depended on trap type and response metric (Figure 26). When placed in minnow traps, neither bait attracted more organisms, aggregated over the whole trap set, but in Fukui traps, mackerel was slightly more effective than cat food. This was supported by the inclusion of the interaction term between bait type and trap type in the best model of total trap catch (Table 9). However, the difference between baits across trap types disappeared when catch was corrected for total soak time; the best model for trap CPUE included only trap type as a predictor (Table 10). Last, the diversity of species captured per trap was quite low, and did not depend on bait type, though models supported the inference that minnow traps captured more species than did Fukui traps (Table 11).

The relatively high catch numbers in minnow traps is consistent with observations from Crab Team volunteer trapping, and likely is due to the larger mesh size of the Fukui relative to the minnow trap. The minnow trap retains more of the small grapsid shore crabs, the most abundant organism at nearly all sites in Puget Sound. There was a trend toward greater efficacy of mackerel in Fukui, but not minnow, traps; this could indicate bait preference is only important for larger organisms, which are less abundant in small pocket estuaries than in deeper waters where the majority of crab research is conducted.

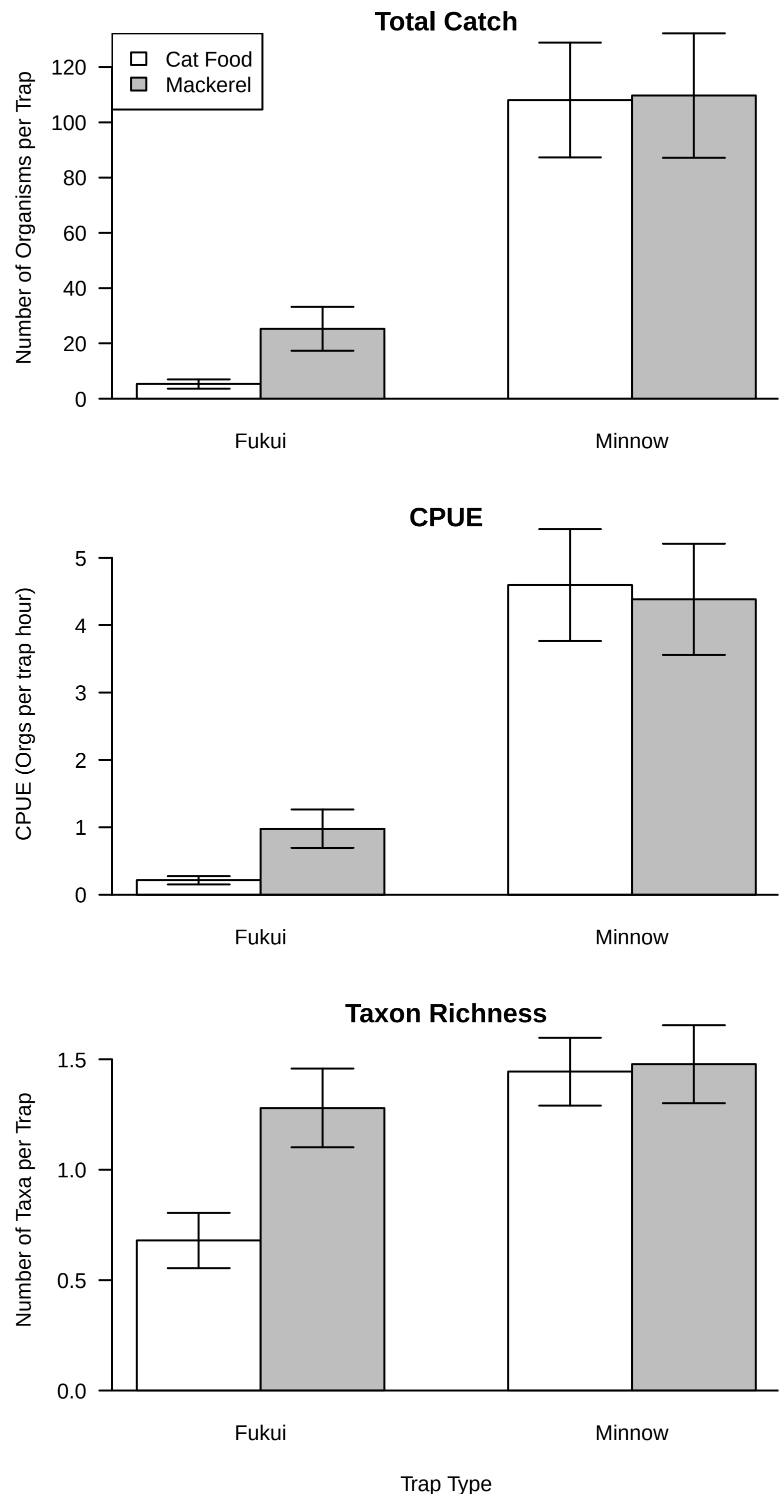

Figure 26 Mean (+/- 1 SEM) total trap catch (top), catch per unit effort (middle) and taxon richness (bottom) of traps based on type and bait (white: cat food, gray: mackerel), from Puget Sound bait assay in 2015. Results have been aggregated across all five sites for a total of 25 traps per treatment × bait combination.

Table 9: Comparison of linear mixed effects models of total trap catch for Puget Sound bait assay. All models included a randomly varying intercept for site. Akaike Information Criterion (AIC) is used to assess fit of models, which are compared to the model with the lowest AIC as Δ AIC. Best model is indicated in bold as the model with the fewest parameters having Δ AIC < 2.

Model	Number of Parameters	AIC	Δ AIC
1. Bait only	1	1148.73	63.66
2. Trap type only	1	1097.47	12.40
3. Bait + trap type	2	1092.28	7.21
4. Bait * trap type	**3**	**1085.07**	

Table 10: Comparison of linear mixed effects models of trap catch per unit effort (number of organisms per hour) for Puget Sound bait assay. All models included a randomly varying intercept for site. Akaike Information Criterion (AIC) is used to assess fit of models, which are compared to the model with the lowest AIC as Δ AIC. Best model is indicated in bold as the model with the fewest parameters having Δ AIC < 2.

Model	Number of Parameters	AIC	Δ AIC
1. Bait only	1	521.16	54.35
2. Trap type only	**1**	**466.81**	
3. Bait + trap type	2	468.35	1.54
4. Bait * trap type	3	467.13	.32

Table 11: Comparison of linear mixed effects models of taxa richness for Puget Sound bait assay. All models included a randomly varying intercept for site. Akaike Information Criterion (AIC) is used to assess fit of models, which are compared to the model with the lowest AIC as Δ AIC. Best model is indicated in bold as the model with the fewest parameters having Δ AIC < 2.

Model	Number of Parameters	AIC	Δ AIC
1. Bait only	1	256.28	7.20
2. Trap type only	**1**	**250.27**	**1.19**
3. Bait + trap type	2	250.42	1.34
4. Bait * trap type	3	249.08	

Protocol and bait testing in infested waters

Despite expectations that crabs would be abundant in coastal estuaries, very little evidence of green crab was found during sampling in Willapa Bay and Grays Harbor. In Grays Harbor, no live green crab were captured in the traps, though the traps did not soak for an overnight high tide, the period when crabs are often most actively foraging. A single European green crab molt was found, but only during casual searching after the formal molt hunt had concluded. This observation underscores the value of casual searching by informed individuals, even at sites where surveys are conducted.

Six European green crab were found at two of the three sites in Willapa Bay. No green crab were trapped at Oysterville, farther south in the bay than they had been previously reported.

At Tokeland, green crab were only captured in the array of vertical transects, and only at the highest tideflat elevation, immediately adjacent to the vegetation. A total of four green crab were captured, out of 20 traps in this array, for an average catch per unit effort of .4 crab per trap set. At that site, no green crab were caught in traps set in marsh channels to test bait efficacy.

At the Stackpole site, no European green crab were captured in the array of vertical transects, but two were captured in two separate Fukui traps associated with the bait assay, both using mackerel as bait. In Willapa Bay, all European green crab captured were adults (57.4–73.2 mm carapace width) and evenly divided between the sexes.

The apparently low abundance of European green crab in Willapa Bay resulted in trap catches that were too low to properly test bait efficacy for that species (Figure 27, top panel). However, with respect to native species, bait type was more important than trap type in influencing the number and diversity of organisms captured (Figure 27, middle and bottom panels). In contrast to the Puget Sound bait study, mackerel increased the total number of organisms captured in both minnow and Fukui traps (Table 12). In fact, the best model of total trap catch indicates that the effect of bait was significantly greater for minnow than Fukui traps. In terms of taxon richness, the preference for bait was consistent between trap types, but mackerel increased the number of taxa trapped by a factor of five (Table 13).

In reconciling the discrepant patterns between the effect of bait and trap type for assays in Puget Sound and Willapa Bay, it is informative to consider the particular species and their relative abundances in the two regions (Table 14). In both regions, hairy shore crab was the most abundant organism in traps, but in Puget Sound, hairy shore crabs were two orders of magnitude more abundant than the next most abundant species. In Willapa Bay, organisms were more evenly distributed among species. One hypothesis is that the extreme abundance of shore crabs in Puget Sound traps might be reducing the ability of other organisms to enter the traps. When there is little competition (i.e. few organisms in the trap), as in Willapa Bay, and in Fukui traps in Puget Sound, organisms might be more selective about bait. However, if preferred traps fill up with shore crabs, remaining organisms might opt for the less preferable bait - cat food. Shorter soak times or video analysis could be used to test the rate at which traps fill up with crabs, and whether this varies by bait type.

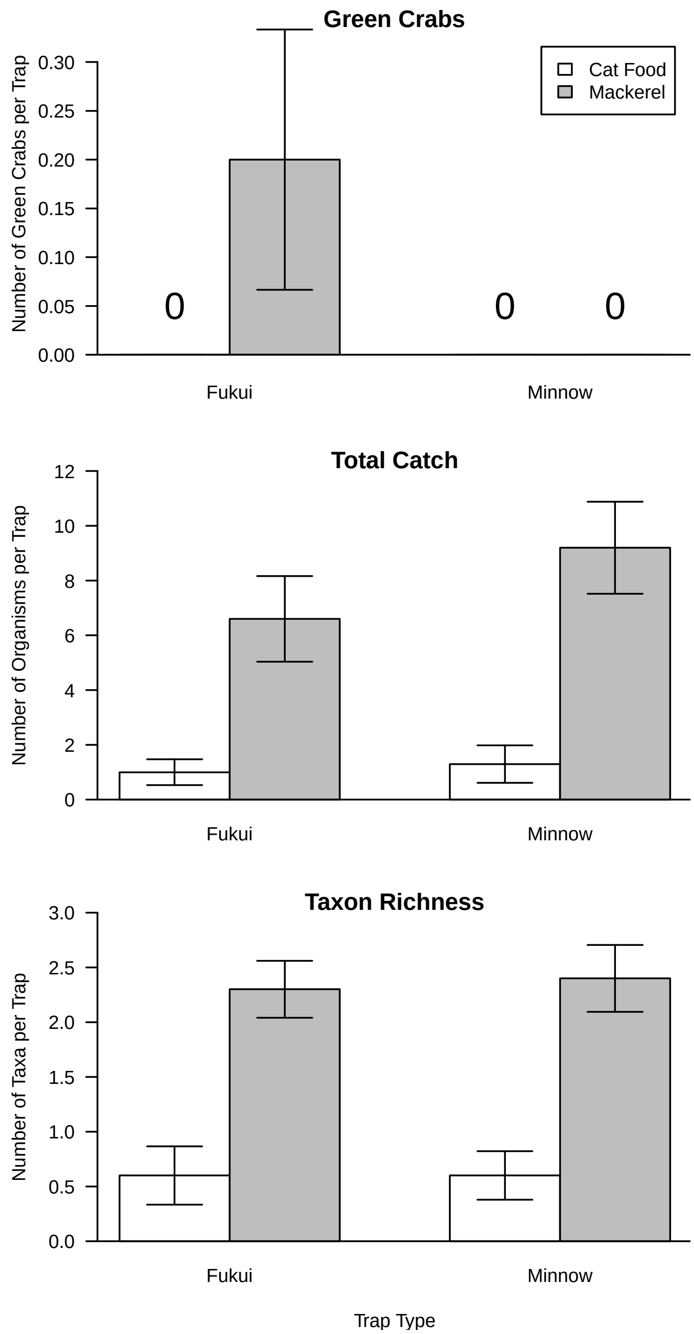

Figure 27 Mean (+/- 1 SEM) catch per trap of European green crab (top), total number of organisms per trap (middle) and taxon richness (bottom) of traps based on type and bait (white: cat food, gray: mackerel), from Willapa Bay bait assay in 2016. Results have been aggregated across both sites, for a total of 10 traps per treatment × bait combination.

Table 12: Comparison of linear mixed effects models of total trap catch (number of organisms per trap), for Willapa Bay bait assay. All models included a randomly varying intercept for site. Akaike Information Criterion (AIC) is used to assess fit of models, which are compared to the model with the lowest AIC as Δ AIC.

Model	Number of Parameters	AIC	Δ AIC
1. Bait type only	1	224.53	4.17
2. Trap type only	1	246.28	25.92
3. Bait + trap type	2	222.88	2.52
4. Bait * trap type	**3**	**220.36**	

Table 13: Comparison of linear mixed effects models of taxon richness, number of taxa per trap, for Willapa Bay bait assay. All models included a randomly varying intercept for site. Akaike Information Criterion (AIC) is used to assess fit of models, which are compared to the model with the lowest AIC as Δ AIC.

Model	Number of Parameters	AIC	Δ AIC
1. Bait type only	**1**	**105.46**	
2. Trap type only	1	136.47	31.01
3. Bait + trap type	2	108.34	2.88
4. Bait * trap type	3	109.80	4.34

Table 14: Average number of each species captured per site in bait assays in 2015 (Puget Sound: five sites) and 2016 (Willapa Bay: two sites). Cells have been scaled by color within each site to facilitate visual comparison of relative species abundances.

Scientific Name	Common Name	Puget Sound	Willapa Bay
Hemigrapsus oregonensis	Hairy shore crab	995.2	27.5
Cottus asper	Prickly sculpin	8.8	9
Crangon nigricaudata	Sand shrimp	5.4	
Leptocottus armattus	Staghorn sculpin	4	27
Hemigrapsus nudus	Purple shore crab	1	
Pagurus hirsutiusculus	Hairy hermit crab	.6	
Cancer (Metacarcinus) gracilis	Graceful crab	.4	
Gasterosteus aculeatus	3-spine stickleback	.4	11
Cymatogaster aggregata	Shiner perch	.2	.5
Platyicthys stellatus	Starry flounder	.2	
Pandalidae and Hyppolytidae	Broken back shrimp	.2	
Cancer (Metacarcinus) magister	Dungeness crab		14.5
Carcinus maenas	European green crab		1
	Total	**1,016.40**	**90.5**

Rapid assessments

The effort to assess the scope of infestations differed between San Juan Island and Padilla Bay (Table 15), reflecting the difference in scale of suitable habitat at the two localities. Because the original find in both cases was a single crab, the focus was on a rapid assessment of populations at the capture site and at nearby suitable habitats.

Table 15: Summary of rapid assessment trapping efforts in response to two European green crab captures in 2016. Abbreviations are WSG = Washington Sea Grant, WDFW = Washington Department of Fish and Wildlife, PBNERR = Padilla Bay National Estuarine Research Reserve.

	Westcott Bay, San Juan County	**Padilla Bay, Skagit County**
Dates	September 12 - 14	September 26-28
Staff	4	13
WSG	3	4
WDFW	1	4
PBNERR		5
Trapping sites	7	31
Trap sets	174	368
Radius from initial green crab	2 miles	4 miles
Live green crabs captured during assessment	0	3 (all juveniles)
Green crab molts found	1	0

In Westcott Bay, trapping captured no additional live green crab at any of the seven trapping sites (Figure 28). However, a single molt was found, in the channel within 30 meters of where volunteers set the trap that had captured the original crab. The sex of the crab that produced the molt could not be determined because the molt had deteriorated. Based on the size of the molt (69 mm), however, and estimates of growth increments (Behrens Yamada et al. 2005), it could not have come from the crab that was captured, indicating another crab was present in Westcott Bay that was not captured by rapid assessment efforts.

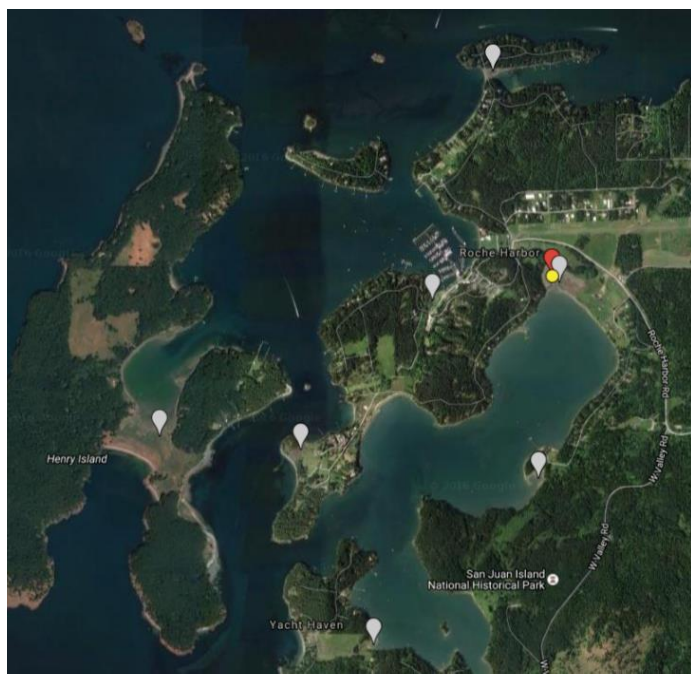

Figure 28 Westcott Bay rapid assessment site map. The red pin and yellow dot represent the initial green crab capture location and location of a single green crab molt found during the rapid assessment. Gray pins represent sites where traps were placed during the rapid assessment. No additional live green crab were found.

The rapid response trapping survey in Padilla Bay resulted in the capture of three additional live European green crab at sites distributed across the eastern portion of the bay (Figure 29). All three crabs captured, as well as the original crab found by PBNERR education staff, were young of the year (+ age class). Their similar age and wide distribution indicate that they likely arrived as a larval cohort during winter 2015-2016. Three of the four crabs were female, and large enough to be reproductively mature (39-40 mm), but none exhibited external evidence of reproduction (i.e. egg-bearing). All of the crabs captured were fairly close to the shoreline, either in high marsh pools or in the traps set closer to the shoreline or marsh vegetation. No green crab molts were found during casual surveys.

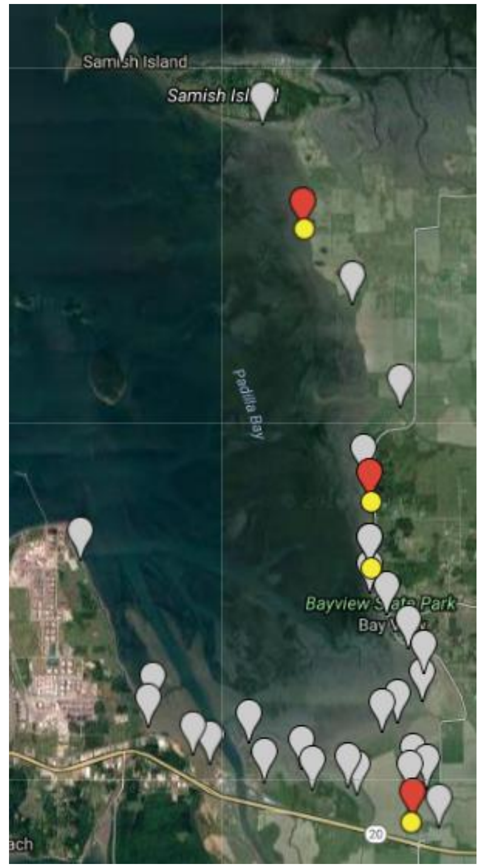

Figure 29 Padilla Bay rapid assessment site map. Yellow dots mark sites of green crab captures. Pins indicate sites where rapid assessment trapping took place (gray = no green crabs captured, red = green crab trapped during rapid assessment). The gray pin with a yellow dot thus indicates the location of the initial green crab found by PBNERR educational staff.

Outreach

Crab Team staff gave 14 public presentations to target audiences to increase awareness of green crab risks, identification and reporting. With the help from Capstone students and the WSG Communications staff, Crab Team has developed three printed outreach pieces: a bookmark-sized information card, a flyer for distribution to target audiences for public posting and a sign informing local users of monitoring activities while they are underway. The materials are included in Appendix D.

The project website *wsg.washington.edu/crabteam* serves as a detailed repository for project information, materials and updates.

Particularly after volunteers collected the first green crab in Washington's inland marine waters, media response and interaction was significant. More than 80 media pieces covered the project (Appendix E) reaching an estimated 300,000 Washington residents.

Conclusions

Crab Team's implementation of an early detection effort for European green crab demonstrates a successful, partner-driven approach to protecting Washington's natural resources and native habitats. Through collaboration with experienced researchers, WSG was able to effectively prioritize monitoring sites, develop protocols, recruit, train and retain committed volunteers, and engage the public. The efficacy demonstrated in the capture of the first European green crab in Washington's inland marine waters by Crab Team volunteers during regular monthly monitoring reinforces the value of this approach for early detection of an invasive species. Moreover, by contributing to the WDFW-coordinated rapid assessments of green crab discoveries, the Crab Team also demonstrated the ability to provide technical expertise and logistical support for response efforts.

While the Crab Team has hit its first major milestone — discovering and addressing the first stages of a potential invasion — the project will capitalize off initial efforts in order to sustain and grow the monitoring program. Program evaluation indicates that Crab Team volunteer training and support are effective. Nevertheless, ongoing assessment of volunteer and scientific needs will guide the program well into the future. Investments in this area not only facilitate high volunteer retention and, in turn, program sustainability, they also increase the value of the dataset assembled by monitoring. If European green crab become established in Washington waters, the Crab Team will have a dataset that can rigorously assess impacts, filling a substantial regional data gap and providing concrete management recommendations (e.g., which species and habitats are most likely to be impacted).

Monitoring

With only a single full season of monitoring data, Crab Team investigators are just starting to explore the structure and dynamics of pocket estuaries. Despite high ecological value, this habitat type is understudied and poorly characterized relative to other shoreline types, such as rocky intertidal or sandy beaches, and even armored urban shorelines. Pocket estuaries are isolated, low-energy sanctuaries for many species, providing protection from predators. Relative to many other types of marine habitat, they are non-contiguous patches, often with low connectivity to other marine habitats owing to flow restrictions. These factors could have a strong influence on their local and regional ecology.

With 2016 data, Crab Team staff began to characterize the communities of crustaceans (through molt surveys) and mobile epifauna (through trapping surveys) at Crab Team monitoring sites. As anticipated, the most abundant crustacean at nearly all sites was the native hairy shore crab, and this crab occasionally occurred at extremely high densities. This species is likely one of the most influential players in pocket estuaries, which is primarily due to its abundance, broad diet and burrowing habit. In this way, and for this reason, it is similar to European green crab, and likely to interact directly and indirectly with the invasive crab if it arrives. The observations in central California of negative impacts by green crab on this species suggest that estuaries currently dominated by native hairy shore crabs could shift to green crab dominance. Alternatively, sites with large populations of hairy shore crab might have greater biotic resistance to invasion. While shore crabs are no match for adult green crab, adult shore crabs can be effective predators of very young crabs, both Dungeness and shore crabs (Jensen et al. 2002, Banks et al. 2000).

Initial characterization of ecological communities at Crab Team sites point to several possible avenues of future research. Overall, diversity of organisms in traps was fairly low, with a maximum Shannon diversity of 1.41. This reflects that only some of the species that live in pocket estuaries will enter baited traps. Certainly, trapping does not sample species living in the mud, such as bivalves and worms. Nevertheless, the consistent monitoring protocol enables comparison across Crab Team sites. For instance, there was a clear negative relationship between diversity, both in terms of taxon richness and Shannon diversity, and trap catch. The relationship could have been driven by the statistical influence of hairy shore crab dominating the total abundance of organisms in traps. This trend offers a jumping off point for further exploration of what factors could be controlling diversity in native communities (e.g., are hairy shore crab reducing diversity, or merely most successful at sites where few other things are able to live). In addition, comparison of the community of organisms captured in traps demonstrated the potential to learn how the structure of pocket estuary habitat (i.e., marsh channel versus lagoon) could influence the ecological community. Refining those interpretations will likely require additional abiotic characterizations of different sites such as temperature and salinity.

Multiple years of data are needed before questions about phenology and long-term trends can be addressed. The addition of monitoring sites will enable geospatial analyses of habitat similarity based on proximity, location, and land cover and use. These site attributes have the potential to answer fundamental questions about how pocket estuaries function, both independently and as a network of connected communities of organisms (meta-population dynamics).

Protocol testing

Testing the Crab Team protocol in areas with known populations of green crab enabled investigators to determine: (1) if Crab Team traps are targeting the appropriate micro-habitat and (2) if the choice of bait was appropriate. First, setting traps in precisely the right location is important because green crab, even as adults, travel only very short distances (<50 m) over the course of one or two tide cycles. In Willapa Bay, green crab were only captured in marsh channels or immediately adjacent to vegetation; no green crab were trapped at lower tideflat elevations. Though the investigators did not design the rapid assessment trapping efforts to test the question of depth preference, findings in Padilla Bay also support this conclusion; all four crabs were found in either high marsh pools or the transect of traps closer to shore. Though somewhat limited, these observations provide evidence that the arrangement of traps in lagoons and channels, adjacent to banks and vegetation, is targeting the best micro-habitat for capturing green crab if they are present. An important caveat to this is that reports from monitoring on Vancouver Island suggest that habitat preference is declining in areas where green crab populations are large. Increasingly, green crab are being found on gravel or cobble beaches, and even in the same traps as red rock crab — a species of native crab that was thought to exclude green crab. It’s therefore possible that the assumptions about green crab habitat preference break down as populations become more dense.

Efforts to assess the efficacy of mackerel as bait relative to cat food are difficult to interpret because too few green crab were caught in the bait assay to make this a strong test of preference. However, green crab notably only came to traps with mackerel as bait and, with respect to native organisms, there was a trend toward increased efficacy of mackerel relative to cat food in attracting more and more diverse organisms to traps. Combined, these lines of evidence suggest that continuing to use mackerel is a conservative choice for our program based on stated sampling goals of early detection of green crab and broad sampling of native communities. It is time intensive to portion and package bait individually, but this is likely important for volunteer comfort. Based on volunteer feedback surveys, and observation, there was minimal objection to use of this bait, and most obstacles (e.g., storage space) were ably navigated by volunteer teams. Finally, observations from the two bait assays combined provided some suggestion that density or size of organisms might influence bait preference, a promising area for follow-up study.

By evaluating different components of the program and protocol, demonstrating the effectiveness of the program strategy and identifying some patterns in collected data, the Crab Team has taken full advantage of its first two years to establish an effective, multifaceted program.

Table 16: **Possible questions that can be explored with a long term Crab Team dataset.**

	Molt Hunt	Trapping	Habitat
Suitability for green crab	Does community of crustaceans influence probability of green crab establishment or success?	Does community of mobile fauna influence probability of green crab establishment or success?	What habitat features are associated with green crab establishment or success?
Impacts of green crabs (BACI: Compare sites Before and After arrival, and Control vs Impacted sites)	Changes in crustacean community due to green crab presence (presence/absence, relative abundance)	Changes in mobile faunal community due to green crab (presence/absence, relative abundance)	Changes in rooted vegetation? Live epifauna? Substrate type? Changes in Eelgrass wrack as evidence of eelgrass impacts?
Phenology	Peak growth periods for various crab species	Peak reproductive periods (M:F, Gravid Females)	Do we see changes in wrack over the year, or rooted veg?
Community composition	Do sites cluster based on crustacean community? I.e., Do "pocket estuary" communities differ in predictable ways?	Do sites cluster based on mobile fauna community? I.e., Do "pocket estuary" communities differ in predictable ways?	Does clustering of community (based on molts or live orgs) relate to habitat characteristics?
Human impacts	Does land cover (metric of human influence) correlate with community characteristics (univariate or multivariate)	Does land cover (metric of human influence) correlate with community characteristics (univariate or multivariate)	Percent wrack of trash, armoring
Trends (outside of green crab influence)	Changes in crustacean communities over years?	Changes in mobile epifauna communities and abundances over years? Shifting baselines due to added stressors of temp/OA? Latitudinal variation in crab size?	Changing habitat over time due to erosion, storm surge, human impacts (e.g. trash, nutrient input)
Citizen Science Methods/Protocol Efficacy	Do the number of searchers affect the total number of molts collected?	Does increased trap catch increase identification errors (reduce attention to detail, potentially result in missing a green crab)? How does trap soak time influence catch (i.e. do traps fill up? If so what is the appropriate "effort" metric)	What tools/strategies improve accuracy for estimating percent cover?

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Appendix A: Volunteer Training Workshop Pre/Post-test

Unique Identifier:

Crab Team Training Workshop

Assessment and Evaluation

This packet is two parts: 1) a pre-training assessment to evaluate your knowledge of pocket estuary organisms before today's training, and 2) a post-training assessment to both determine whether our training was effective, and to get your input and feedback on the training and the program.

Your participation is voluntary and completely confidential -- we will not ask for personally identifying information. Please answer the questions the best you can using only the information in your brain, no ID guides or phones or neighbors. This helps us evaluate how effective we are at teaching this material.

Please complete pages 1 & 2 prior to the start of the workshop. At the end of the workshop, complete the post-training questions and return the materials to Sea Grant staff.

Pre-training assessment: To be completed at the beginning of the training. Please answer all questions honestly and to the best of your ability.

1. Match the crab name to the photos above. Record the corresponding letter in the space provided. There are more names than there are pictures, so some names will not have corresponding pictures.

_____ Graceful crab, *Cancer (Metacarcinus) gracilis*

_____ Hairy shore crab, *Hemigrapsus oregonensis*

_____ Spider crab or kelp crab, *Pugettia producta*

_____ Staghorn Sculpin, *Leptocottus armatus*

_____ Hairy hermit crab, *Pagurus hirsutiusculus*

_____ Shiner perch, *Cymatogaster aggregata*

_____ Dungeness crab, *Cancer (Metacarcinus) magister*

_____ European green crab, *Carcinus maenas*

_____ Hairy helmet crab, *Telmessus cheiragonus*

_____ Purple shore crab, *Hemigrapsus nudus*

[CONTINUE ON REVERSE]

2. Is the crab pictured to the right a male or a female? M / F

How can you tell?_________________________________

____

3 How many marginal teeth are on this crab? (circle one)

a. 15

b. 4 (but there should be 5, i.e., it's missing one!)

c. 9

d. Aha! Trick question, crabs don't have teeth!

	Not confident	**Somewhat confident**	**Confident**	**Very confident**
4. How confident were you in your ability to identify crabs from the photos? (circle answer)	1	2	3	4
5. How confident were you in your ability to determine the sex of the crab in number 7? (circle answer)	1	2	3	4

6. Did you attend a WSG Crab Team training workshop during 2015? Y / N
Where? ___________________

7. Did you attend a WSG Crab Team informational talk during winter 2016? Y / N
Where?___________________

8. Did you conduct monitoring for WSG Crab Team during 2015? Y / N
Number of days you participated in monitoring (1 – 4)___________

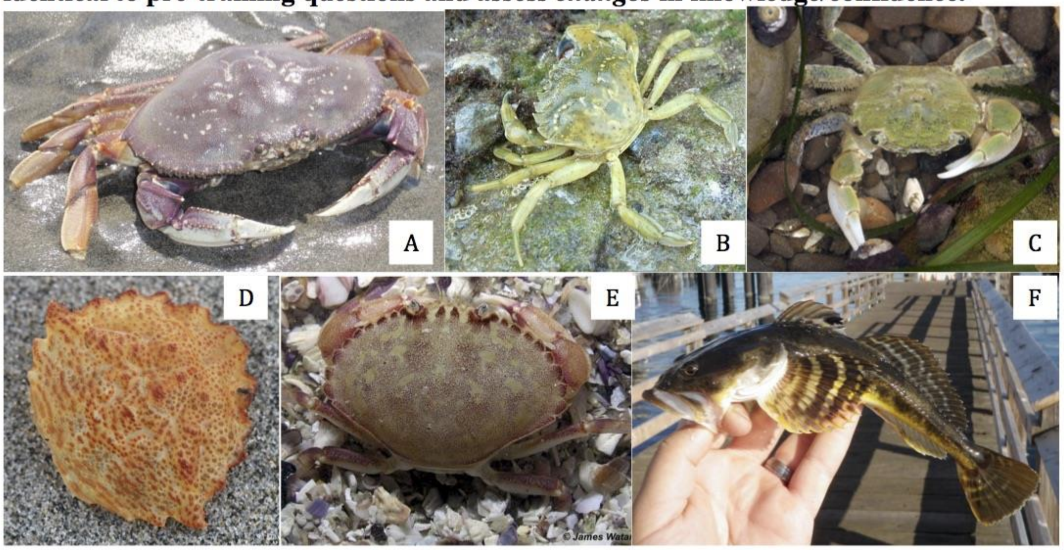
9. Where else did you learn about green crabs or native pocket estuary diversity?

____

____

*****END Pre-training assessment*****
(Complete the remaining sections at the end of the workshop)

Post-training assessment: To be completed at the end of the training. Questions 1-6 are identical to pre-training questions and assess *changes* in knowledge/confidence.



1. Match the crab name to the photos above. Record the corresponding letter in the space provided. There are more names than there are pictures, so some names will not have corresponding pictures.

_____ Graceful crab, *Cancer (Metacarcinus) gracilis*

_____ Hairy shore crab, *Hemigrapsus oregonensis*

_____ Spider crab or kelp crab, *Pugettia producta*

_____ Staghorn Sculpin, *Leptocottus armatus*

_____ Hairy hermit crab, *Pagurus hirsutiusculus*

_____ Shiner perch, *Cymatogaster aggregata*

_____ Dungeness crab, *Cancer (Metacarcinus) magister*

_____ European green crab, *Carcinus maenas*

_____ Hairy helmet crab, *Telmessus cheiragonus*

_____ Purple shore crab, *Hemigrapsus nudus*

2. Is the crab pictured to the right a male or a female? M / F

How can you tell?_________________________________

____

3. How many marginal teeth are on this crab? (circle one)

a. 15
b. 4 (but there should be 5, i.e., it's missing one!)
c. 9
d. Aha! Trick question, crabs don't have teeth!

[CONTINUE ON REVERSE]

	Not confident	Somewhat confident	Confident	Very confident
4. How confident were you in your ability to identify crabs from the photos? (circle answer)	1	2	3	4
5. How confident were you in your ability to determine the sex of the crab in number 7? (circle answer)	1	2	3	4

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
6. I found this training to be helpful and informative.	1	2	3	4	5
7. I feel confident in my ability to begin monitoring independently (with my team, but without Crab Team staff).	1	2	3	4	5

8. What aspects of the training did you find to be especially helpful?

9. Were there aspects of the training that were unclear or confusing? If so, elaborate below.

10. Is there anything you wish had been included in the training to either improve the clarity of the content or increase engagement? If yes, explain below.

Unique Identifier:

Appendix B: Trapped Species by Site Table

Site	Site Name	Region	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer (Metacarcinus) gracilis*	*Cancer (Metacarcinus) magister*	*Cancer productus*	Majidae - Spider crabs	*Telmessus cheiragonus*	*Lophopanopeus bellus*	*Carcinus maenas*	*Pagurus hirsutiusculus*	*Pagurus granosimanus*	Broken back shrimp	*Leptocottus armatus*	*Gasterosteus aculeatus*	*Cymatogaster aggregata*	*Cottus asper*	Eel-like fishes	*Oligocottus maculosus*	*Sygnathus leptorhynchus*	*Porichthys notatus*	*Batillaria attramentaria*	*Haminoea spp.*	*Amphissa columbiana*	*Nassarius fraterculus*	*Nassarius mendica*
362	Post Point	Bellingham Bay	729	25		1						26	48	6	8						1		3			231	14
533	Westcott Bay	SJI	337								1	2			414	2	7						8				
536	Third Lagoon	SJI	111	1	6	1									160	21	2							15			
330	Mud Bay	SJI	696	13		9						109	18		13		1						103				
341	Crandall Spit	Fidalgo Bay	274			98						4	4		45				1								
198	Discovery Bay	Strait of JDF	1,069	18	5										68	1	1										
214	Dungeness River	Strait of JDF	971	1											74	1											
323	Kiket Lagoon	Whidbey Basin	1,139	78		1						1			56												
311	Penn Cove	Whidbey Basin	5,244												23	4	6										
508	Race Lagoon	Whidbey Basin	1,716												7	50	3										
516	Iverson Spit	Whidbey Basin	1,884	3											4	2	2										
552	Elger Bay	Whidbey Basin	3,082	3											7												
204	Kala Lagoon	Admiralty Inlet	3,185	4					1						31												
306	Deer Lagoon	Admiralty Inlet	4,103	36											22		1		1								
590	Lagoon Point	Admiralty Inlet	16				2		3			1			99	81											
161	Zelatched Point	Hood Canal	2,605	2								4	9		7								3	19			
138	Duckabush	Hood Canal	385												14		1	64									
128	Nick's Lagoon	Hood Canal	522	6	1							32	5		55	2							29				
74	Musqueti	Hood Canal	934	6								3			4	1											
177	Carpenter Creek	Central Sound	4,360	2											39												
173	DoeKegWats	Central Sound	2,059	18											78	2	2			4							
133	Best Lagoon	Central Sound	2,327									3	14		3								21				
553	Blakely Harbor	Central Sound	122		92		20	1							177		2		8								
579	Heyer	Central Sound	416	11								1			5												
581	Rabb's Lagoon	Central Sound	93		166			4		1			3		16	5	14				2	1			27		
250	Butterball Cove	South Sound	2,627	1								2			76												

Appendix C: Molt Hunt Species by Site Table

Site	Site Name	Region	*Hemigrapsus oregonensis*	*Hemigrapsus nudus*	*Cancer (Metacarcinus) gracilis*	*Cancer (Metacarcinus) magister*	*Cancer productus*	Majidae - Spider crabs	*Telmessus cheiragonus*	*Lophopanopeus bellus*	*Pagurus*	Pinnotheridae	Amphitpoda	Thalassinidea
362	Post Point	Bellingham Bay	145	271		1								
533	Westcott Bay	SJI	193	7	6	3		2						
536	Third Lagoon	SJI	2	1	5	3	19		13					
330	Mud Bay	SJI	280	38		86	2		1		1			
341	Crandall Spit	Fidalgo Bay	205	9	2	6			1					
198	Discovery Bay	Strait of JDF	128	10	2	1	1							
214	Dungeness River	Strait of JDF	399	3		1			1				19	
323	Kiket Lagoon	Whidbey Basin	198	145		1								
311	Penn Cove	Whidbey Basin	788		2									
508	Race Lagoon	Whidbey Basin	577			1	4							
516	Iverson Spit	Whidbey Basin	548			2								
552	Elger Bay	Whidbey Basin	585				2							
204	Kala Lagoon	Admiralty Inlet	1437	23	1	4	2		2					
306	Deer Lagoon	Admiralty Inlet	13	11		5								
590	Lagoon Point	Admiralty Inlet	128	70	2									
161	Zelatched Point	Hood Canal	100			5	5	3						
138	Duckabush	Hood Canal	958							1				
128	Nick's Lagoon	Hood Canal	2297	17			2				1			
74	Musqueti	Hood Canal	479	17										
177	Carpenter Creek	Central Sound	482	20		1								
173	DoeKegWats	Central Sound	107	53	2	3	35	6						
133	Best Lagoon	Central Sound	197		5	1								
553	Blakely Harbor	Central Sound	243	7	18	3	4	2						1
579	Heyer	Central Sound	352	4		1								
581	Rabb's Lagoon	Central Sound	257	7	4			1		1		1		
250	Butterball Cove	South Sound	997	26									1	5

Appendix D: Crab Team Outreach Products

European green crab and Crab Team information flyer.

EUROPEAN GREEN CRAB

KEEP A WATCHFUL EYE

Washington's diverse and productive salt marshes and pocket estuaries, already threatened by shoreline development and pollution, now face a potentially destructive invader. The European green crab (*Carcinus maenas*) is considered one of the world's worst invasive species. It can alter shoreline ecosystems and negatively impact economically important species.

YOU CAN HELP PROTECT WASHINGTON HABITATS FROM THESE CRABS IN TWO WAYS.

- Look for green crabs next time you stroll the beach.
- If you suspect you have found a live green crab or molt, email photos and detailed location information to *crabteam@uw.edu*. You can take a molt with you, but please leave a live crab where you found it, because European green crab are currently illegal to possess live, and fortunately, most of the suspected sightings are actually native species.

GET YOUR BOOTS MUDDY AND VOLUNTEER WITH THE CRAB TEAM.

Washington Sea Grant, the Washington Department of Fish & Wildlife and partners have teamed up to lead a volunteer-based early detection and monitoring program for European green crab. The program is also designed to improve our understanding of native saltmarsh and pocket estuary organisms, and how they could be affected by green crabs.

To volunteer, contact *crabteam@uw.edu* to learn how you can participate.

CRAB TEAM

SUSPECT YOU HAVE FOUND A GREEN CRAB?

Take photos but leave the crab where you found it. Email photos and detailed location information to *crabteam@uw.edu.*

Sea Grant
Washington
www.wsg.washington.edu

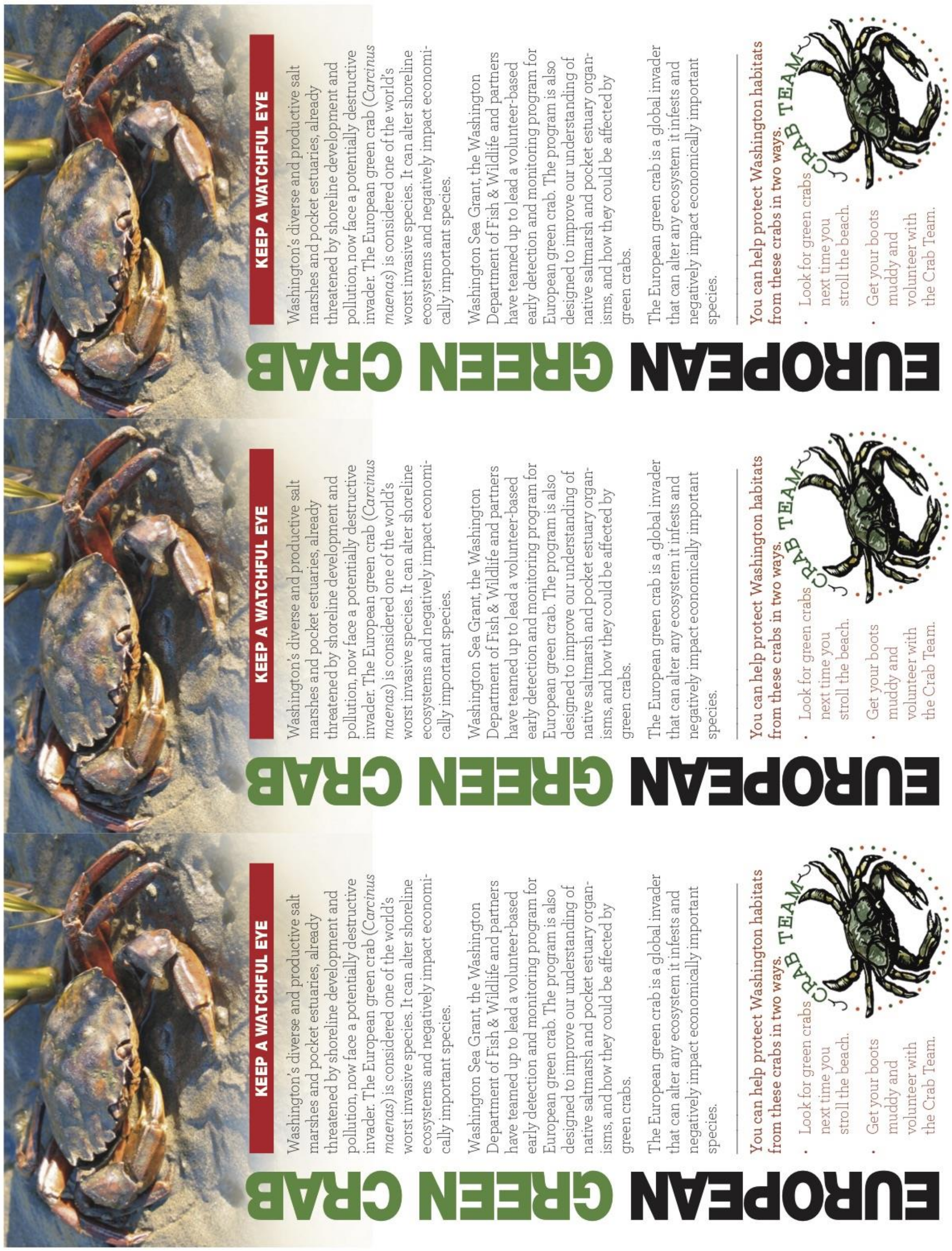
WSG.WASHINGTON.EDU/CRABTEAM

HOW TO IDENTIFY EUROPEAN GREEN CRABS

- 5 spines (or marginal teeth) to the outside of each eye
- Up to 4" across the carapace (or back shell)
- Wider at front than back of the carapace
- Although often referred to as "green crab," color is not its distinguishing feature. The actual color can vary from dark mottled green to orange or red.

This project has been funded wholly or in part by the United States Environmental Protection Agency under Assistance Agreement PC 00J29801 to Washington Department of Fish and Wildlife. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade Names or commercial products constitute endorsement or Recommendation for use.

European green crab and Crab Team information bookmark front.



European green crab and Crab Team information bookmark reverse.

HOW TO IDENTIFY EUROPEAN GREEN CRABS

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- Up to 4" across the carapace (or back shell)
- Wider at front than back of the carapace
- Although often referred to as "green crab," color is not its distinguishing feature. The actual color can vary from dark mottled green to orange or red.

THE CRAB TEAM NEEDS YOUR HELP

The best way to protect shoreline habitats from the invasive European green crab is to learn how to recognize them and report sightings.

If you suspect you have found a green crab, email photos and detailed location information to *crabteam@uw.edu* and leave the crab where you found it.

To learn more go to *wsg.washington.edu/crabteam*

Join the conversation: follow *@WAGreenCrab* and *@WASeaGrant*

Sea Grant Washington

www.wsg.washington.edu

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Sea Grant Washington
www.wsg.washington.edu
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To learn more go to wsg.washington.edu/crabteam
Join the conversation: follow @WAGreenCrab and @WASeaGrant
Sea Grant Washington
www.wsg.washington.edu
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Crab Team yard sign for use in field during monitoring.

Appendix E: Crab team Media Coverage

October 2016
Puget Sound's Padilla Bay Sees Invasive green Crabs, *CDA News, October 5, 2016*
http://cdanews.com/2016/10/puget-sounds-padilla-bay-sees-invasive-green-crabs/

Invasive green crabs found in Puget Sound, *The Bellingham Herald, October 3, 2016*
http://www.bellinghamherald.com/news/state/washington/article105648261.html

Invasive green crabs found in Puget Sound, *Q13 Fox, October 3, 2016*
http://q13fox.com/2016/10/03/green-crabs-found-in-puget-sound/

Green crab sightings in Puget Sound put experts on alert. *Ballard news-Tribune, October 3, 2016*
http://www.ballardnewstribune.com/2016/10/03/news/green-crab-sightings-puget-sound-put-experts

Invasive green crabs found in Puget Sound, *Kiro 7, October 3, 2016*
http://www.kiro7.com/news/local/invasive-green-crabs-found-in-puget-sound/453005143

European green crabs make their home in Sooke Basin, *Sooke News Mirror, October 3, 2016*
http://www.dailyuw.com/science/article_72e1f09a-891d-11e6-b041-4f87b1c2af5f.html

Little Pests, big problems, *UW Today, October 3, 2016*
http://www.dailyuw.com/science/article_72e1f09a-891d-11e6-b041-4f87b1c2af5f.html

September 2016

Invader crabs from Europe threaten havoc in Puget Sound, *Crosscut, September 28, 2016*
http://crosscut.com/2016/09/invader-crabs-from-europe-threaten-havoc-in-puget-sound/

Scientists Try Trapping To Halt Puget Sound's European Crab Invasion, *OPB, September 26, 2016*
http://www.opb.org/news/article/scientists-try-to-trap-european-crabs/

Second invasive green crab discovered in northern Puget Sound, *Kitsap Sun, September 24, 2016*
http://pugetsoundblogs.com/waterways/2016/09/24/second-invasive-green-crab-discovered-in-northern-puget-sound/

State and researchers respond to invasive European Green Crabs found in Northern Puget Sound, *San Juan Islander, September 23, 2016*
http://sanjuanislander.com/news-articles/environment-science-whales/environment/22965/state-and-researchers-respond-to-invasive-european-green-crabs-found-in-northern-puget-sound

Second Invasive Green Crab Found In Washington's Inland Waters, *KNKX 88.5, September 23, 2016*
http://knkx.org/post/second-invasive-green-crab-found-washington-s-inland-waters

Crabuccino, anyone? Chef cooking up European green crab to help rid ocean of invasive species, *CBC News, September 19, 2016*
http://www.cbc.ca/news/canada/newfoundland-labrador/american-chef-cooking-green-crab-invasive-species-1.3765130

European green crab found in Puget Sound, *KTOO Public Media, September 11, 2016*
http://www.ktoo.org/2016/09/11/european-green-crab-found-puget-sound/

Green crab invade farther north on B.C. coast, *KSTK, September 8, 2016*
http://www.kstk.org/2016/09/08/green-crab-invade-farther-north-on-b-c-coast/

Why a Single Crab has West Coast Researchers Worried, *Motherboard, September 7, 2016*
http://motherboard.vice.com/read/invasive-european-green-crab-salish-sea-puget-sound

Invasive crab species discovered in Washington's inland waters, *Peninsula Daily News, September 7, 2016*
http://www.peninsuladailynews.com/news/invasive-crab-species-discovered-in-washingtons-inland-waters/

Wicked little arthropod found on San Juan Island, *La Conner News, September 7, 2016*
http://laconnerweeklynews.com/main.asp?SectionID=2&SubSectionID=27&ArticleID=1019

Green Crab Invaders Show up in Puget Sound, *Oregon Public Broadcasting, September 6, 2016*
http://www.opb.org/news/article/green-crab-invaders-show-up-in-puget-sound/

Invasive European green crab caught in Salish Sea for the first time, *CBC News, September 6, 2016*
http://www.cbc.ca/news/canada/british-columbia/green-crab-san-juan-island-salish-sea-1.3750345

B.C. ocean-watchers fear European crab invasion, *Montreal Gazette, September 6, 2016*
http://www.montrealgazette.com/news/local+news/ocean+watchers+fear+european+crab+invasion/12174397/story.html

Invader shows up in Puget Sound, *KUOW, September 6, 2016*
http://kuow.org/post/green-crab-invaders-show-puget-sound

Invasive green crab found on San Juan Island by citizen science volunteers, *Phys.org, September 5, 2016*
http://phys.org/news/2016-09-invasive-green-crab-san-juan.html

European green crab found in San Juan Island waters, *The Spokesman Review, September 5, 2016*
http://www.spokesman.com/stories/2016/sep/05/european-green-crab-found-in-san-juan-island-water/

Invasive Crab found in San Juan Island waters, *KIRO 7, September 5, 2016*
http://www.kiro7.com/news/local/invasive-green-crab-found-in-san-juan-island-waters/437179738

Invasive Crab found in San Juan waters, *Lewiston Tribune, September 5, 2016*
http://lmtribune.com/northwest/invasive-crab-found-in-san-juan-waters/article_0cee2663-9b5d-579c-a910-e1c26719af2e.html

Invasive Green Crab Found on San Juan Island by Citizen Science Volunteers, *Journal of the San Juan Islands, September 4, 2016*
http://www.sanjuanjournal.com/news/392278801.html

European green crab found in San Juan Island waters, *The Eagle, September 4, 2016*
http://www.theeagle.com/news/nation/european-green-crab-found-in-san-juan-island-waters/article_6e60bf2a-5518-50ad-b46b-e82c110a7942.html

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European green crab found in San Juan Island waters, *Union-Bulletin, September 4, 2016* http://www.union-bulletin.com/news/northwest/european-green-crab-found-in-san-juan-island-waters/article_02c2382b-191e-5db6-bbbb-2ec8eebaa78e.html

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http://www.heraldnet.com/news/european-green-crab-found-in-san-juan-island-waters/

European green crab found in San Juan Island waters, *San Francisco Chronicle, September 4, 2016*
http://www.sfchronicle.com/news/article/European-green-crab-found-in-San-Juan-Island-9202912.php

European green crab found in San Juan Island waters, *The Houston Chronicle, September 4, 2016*
http://www.chron.com/news/article/European-green-crab-found-in-San-Juan-Island-9202912.php

European green crab found in San Juan Island waters, *Times Union, September 4, 2016*
http://www.timesunion.com/news/article/European-green-crab-found-in-San-Juan-Island-9202912.php

European green crab found in San Juan Island waters, *Seattle PI, September 4, 2016*
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European green crab found in San Juan Island waters, *SF Gate, September 4, 2016*
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http://www.mysanantonio.com/news/article/European-green-crab-found-in-San-Juan-Island-9202912.php

European green crab found in San Juan Island waters, *The Bellingham Herald, September 4, 2016*
http://www.bellinghamherald.com/news/state/washington/article99969057.html

European green crab found in San Juan Island waters, *CT Post, September 4, 2016*
http://www.ctpost.com/news/article/European-green-crab-found-in-San-Juan-Island-9202912.php

European green crab found in San Juan Island waters, *The Hour, September 4, 2016*
http://www.thehour.com/news/article/European-green-crab-found-in-San-Juan-Island-9202912.php

European green crab found in San Juan Island waters, *The Washington Times, September 4, 2016*
http://www.washingtontimes.com/news/2016/sep/4/european-green-crab-found-in-san-juan-island-water/

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http://www.fairfieldcitizenonline.com/news/article/European-green-crab-found-in-San-Juan-Island-9202912.php

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http://www.dailyprogress.com/european-green-crab-found-in-san-juan-island-waters/article_8c3cf71c-cd25-5281-bbb1-03d3185ca72d.html

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