Winter 2020

European Green Crab Mitigation in Whatcom County

Patty Barry
Western Washington University

Melissa Browning
Western Washington University

Alexis Bryson,
Western Washington University

Harrison Fuchs
Western Washington University

Etilet Maipi
Western Washington University

European Green Crab Mitigation in Whatcom County

Prepared as a Proposal for the Whatcom Marine Resource Committee

Patty Barry, Melissa Browning, Alexis Bryson, Harrison Fuchs, Etilet Maipi

Western Washington University, Huxley College of the Environment

CONTENTS

Summary of Recommendations

Communicate Trapping Suggestions to Agency Partners:

- Add mechanical adjustments to Fukui and minnow traps specific to *C. maenas*
- Try Blanchard-like traps in Drayton Harbor
- Use underwater cameras to determine effectiveness of different types of traps

Work with the Public:

- Increase signage at high risk areas
- Host an informational booth at local events such as Bellingham Seafeast
- Promote use of Washington Invasives application
- Coordinate Citizen Science efforts for beach monitoring and trapping

Collaborate with creators of Circulation Models to Predict Sites at High Risk of Invasion and Determine Priority Sites for Monitoring.

- Coordinate application of current and circulation models to visualize larval transport to predict sites at high risk for invasion
- Use predictions to determine priority sites to monitor
- Collaborate with creators of current and circulation models to interpret and improve accuracy of models

Keep up to Date With New Technology as it Develops

- Keep up to date with mitigation technologies as they may become applicable (e.g. heat treating and eDNA)

INTRODUCTION

The European Green crab (*Carcinus maenas*) is native to the Atlantic coast of Europe and Northern Africa, from northern Iceland and Scandinavia to the Canary Islands and Morocco (Rogers 2001) and the species represents the majority of the crab population throughout their native range (Klassen 2007). Their distribution is now global, due to various human activities. *C. maenas* can now be found in Australia, Southern Africa, Eastern Asia, South America, and North America. Effective management of the species will be necessary to minimize their ecological impact on the region.

On the Pacific coast of the United States *C. maenas* was first observed in San Francisco bay in 1989, and were later observed in Washington after an especially warm El Niño event in 1998, though they weren't found inland in Washington until the 2000's (Grason 2018). Historically introduced *C. maenas* populations have varied from year to year, in some years even being undetectable, though detection becomes more consistent as the population becomes well established (Grason 2018). The crab is able to disperse over long distances during their early development as free swimming pelagic larvae (Porier 2017). The larvae can remain in the water column, carried by currents, for up to 90 days (Colnar 2007). *C. maenas* larvae may also be spread through anthropogenic routes, such as stuck to seaweed or the shells of shellfish in the shipping of live seafood (Darling 2008). Larvae have likely been transported on shipping vessels through ballast water loading and unloading as well (Cohen 2003).

The physiology of *C. maenas* allows it to survive in diverse conditions and live in almost any area of the world. *C. maenas* is tolerant of a wide range of temperatures and salinities, though larvae, especially in their early stages, are less tolerant of extreme temperature and salinity conditions than postlarval crabs (Dawirs 1985, Bravo 2007). Adult crabs can tolerate a temperature range of 0°C to 30°C (32°F to 86°F), while the larvae will only successfully develop in temperatures of 12°C to 25°C (53°F to 77°F), and tend to develop slower at lower temperatures (Dawirs 1985). The adult crabs can also survive in salinities of 4 ppt to 54 ppt, and often show a preference for the lower salinity of brackish water, while the larvae will not tolerate salinities below 20 ppt, and generally do not tolerate significant (above 6 ppt) changes in salinity during larval development (Bravo 2007).

C. maenas thrives in a wide variety of habitats, including eelgrass beds, sandflats, cobble beaches, and rocky shores, and can survive from protected inland waters to exposed coasts. However, as of yet *C. maenas* invasion of rocky habitats is limited on the west coast, compared to European and US east coast invasions (Grosholz 2002). In the Salish Sea, *C. maenas* occur for the most part in soft sandy or muddy bottom environments such as mudflats, saltmarshes, and eelgrass beds (Grosholz 2002) and in areas of lower salinity such as creek or river deltas (Gillespie 2007). *C. maenas* causes damage to both individual species and the ecosystem as a whole as they invade new habitats.

EFFECTS ON ECOSYSTEM

Given the ecological consequences of their introduction on the East coast, the appearance of *C. maenas* on the West coast could pose a great threat to local ecosystems. *C. maenas* burrows into soft sediments, causing the erosion of embankments (Ruiz 1996) and the destruction of eelgrass beds, costing several species their habitat and safe environment for their young (Grason 2018). Loss of habitat could cause decline of species reliant on that habitat, such as forage fish and salmon (Shaffer 2020). Declining numbers of those species would in turn impact species that rely on them, such as orca.

C. maenas is able to produce up to 185,000 eggs every time the female molts, which allows for the potential to quickly increase the predation pressure on an ecosystem (Locke, 2007). *C. maenas* is a voracious omnivore with a very diverse diet, which has contributed to the ease with which it spreads across the globe. One of the largest phyla that the crab preys upon are molluscs, eating a range of different organisms such as clams, mussels, oysters and snails (Yamada). In Washington, the crab preys primarily on bivalves, posing a risk for species whose populations are already under pressure, such as the soft-shelled clam *Mya arenaria* (Grason 2018) and the Olympia oyster (*Ostrea lurida*). Across the globe, *C. maenas* also preys on arthropods, marine worms, urchins, tunicates, carrion, and marsh vegetation, and sometimes eat smaller foods such as algae, bacteria, foraminifera and plankton species (Yamada). Due to its varied diet, depletion of one particular species would most likely not affect *C. maenas* populations, as they would readily move onto another source. An established *C. maenas* population could have severe effects on the biodiversity of the region (Grosholz 1996). Here we propose several strategies in order to mitigate the ecological impact of a *C. maenas* invasion.

COMMUNICATE TRAPPING SUGGESTIONS TO AGENCY PARTNERS

Trapping has shown to be one of the simplest and most effective methods for mitigating the negative effects of an invasive population. Most mitigation efforts globally, for the *C. maenas* have centered around different trapping techniques for direct removal of the species from the environment (Bergshoeff, 2018). These targeted removals are popular and used in hopes of reducing population numbers of *C. maenas.* There are a number of factors that go into trapping, including type of trap, bait, time of year (Young, 2017). Catchability of the crabs also depends on different stages in the crab’s life, such as molt and reproduction stages, tidal cycles, and temperature (Duncombe, 2017). The crabs move about less and have decreased catchability when molting or brooding, as well as over the winter. A successful catch rate can be defined as the overall presence of crabs, the number of crabs that approach the traps, and the number that enter or exit. Consideration of all these factors is useful to increase overall numbers of crabs caught in the traps.

Recent meetings with the Marine Resources Committee (MRC), SeaGrant (WSG), and Washington Department of Fish and Wildlife (WDFW) determined that expanding trapping in Drayton Harbor is part of the current plan for *C. maenas* mitigation. The current plan for Whatcom county involves focus on implementing traps near the mouths of rivers and streams in Drayton Harbor (Seaman, Pers. Comm.). There will be about 50 to 70 traps in place in the Drayton Harbor area about 2 to 4 times a week (Seaman, Pers. Comm.). This particular site was chosen because of observations of high numbers of crabs and its geographical advantages for trapping because it is a fairly enclosed location (Seaman, Pers. Comm.). Another trapping program is in place in Mud Bay, and it was found that crabs preferred the top of the bay near the mouth of Chuckanut Creek rather than the entrance channel at the mouth of the bay (Seaman, Pers. Comm).

In order to increase the catch rate of *C. maenas*, making improvements to the traps themselves is highly recommended. The first suggestion would be to add mechanical adjustments to the traps themselves in order to target the *C. maenas* more specifically. The traps currently used by the mitigation team include minnow and Fukui traps. Many of the problems associated with trapping come from the location of the traps and the ability of crabs to enter the traps. In both the studies conducted by Bergshoeff et al. (2018), it was found that while *C. maenas* is active around trap sites, they either do not enter the trap or are able to escape (2018). This was tested specifically with the Fukui traps. The researchers found that simple mechanical fixes could be put in place to improve the catch rates of each trap by allowing easier entry into the trap and decreasing escapes. These include expanding the entry slit to allow for easier access, constructing entrance tunnels with a smaller mesh for easier entry, and attaching a fixed object that they could grasp while pulling themselves into the trap (Figure 2) (Bergshoeff

2019). By implementing these modifications to the traps available to the Marine Resource Committee, the catch rate for the *C. maenas* should improve.

Another suggestion is to add Blanchard traps to the existing cache of traps, alongside the Fukui and minnow traps. The current trapping regimen, in accordance with WDFW and WSG protocols, uses minnow traps to target small crabs (Figure 1) and Fukui traps to target larger crabs (Seaman, Pers. Comm.). Young et al. (2017) found that Blanchard-type traps had an especially high catch rate. The Blanchard trap is designed like a large minnow trap, although because it is designed, produced, and sold by Andy Blanchard in Maine it is likely not easily accessible to the MRC. We suggest collaborating with someone capable of building crab traps to build a prototype Blanchard-like trap, and testing its efficacy in Drayton Harbor.

Given enough resources, it may also be beneficial to implement underwater cameras to monitor the entry and capture rate of the crabs around the set traps to allow for further improvement of techniques. In an attempt to determine the success rate of these traps, one study conducted by Bergshoeff (2018) utilized an underwater camera. The MRC could add to their trapping efforts by using underwater cameras to assess success rates of traps in predetermined locations. The MRC and associated agencies (WDFW, WSG) can determine if crabs are present in these locations and whether they are entering the traps They can then refine the locations traps are set to optimize catch. In terms of cost, underwater camera price range varies depending on the level of technology needed. The cameras range in cost anywhere between $200 and $3000. For the MRC’s purposes, a simple GoPro utilized once a week should be sufficient and at a relatively low cost (close to $200 depending on the model and source of the camera). This method could help determine what specifically needs to be modified in order to optimize the catch rate.

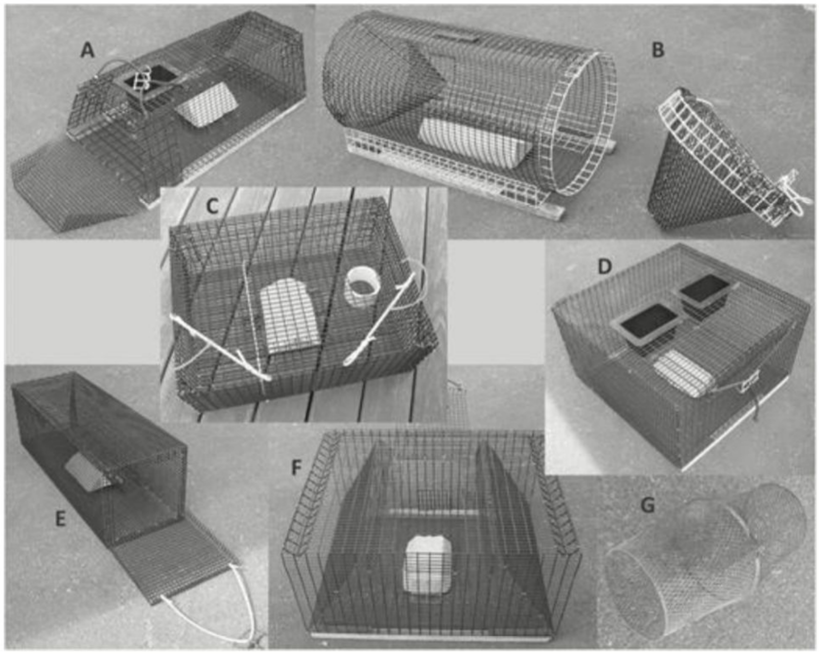

Figure 1. This figure shows the different types of traps that have been tested on the *C. maenas*. The Fukui trap corresponds with F, the Blanchard trap corresponds with B and the Minnow trap corresponds with G.

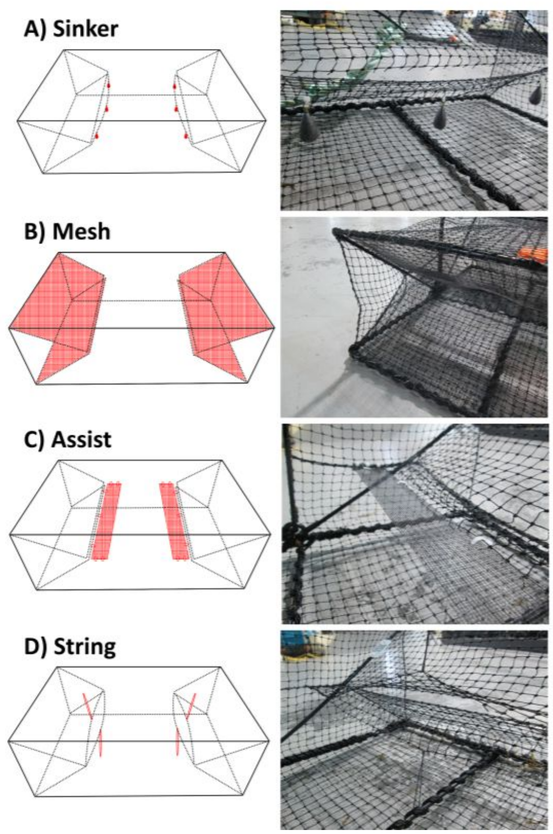

Figure 2. This image shows mechanical adjustments to the Fukui trap to aid in C. maenas entry and capture. **A.** Three sinkers attached to the bottom edge of the entry slit to weigh it open. **B.**

Mesh replaced with a smaller mesh size around the entry slit. **C.** A piece of mesh fixed along the entry slit to assist crabs in entry. **D.** Entry slit pulled wider with string..

WORKING WITH THE PUBLIC

Citizen science strategies are a low cost opportunity to increase spatial and temporal ranges of monitoring *C. maenas*. Although data from citizen science efforts is often sporadic and biased, public outreach can offer baseline information which can be used to extrapolate general trends (Devictor 2010). Armed with smartphones, citizen scientists usually have a camera and GPS tracking system, which allows for expanded monitoring efforts. There are many existing platforms which can easily be used to coordinate between citizen scientists and researchers, such as social media platforms like Twitter and Facebook. Apps specific to invasive species are another way to work directly with citizens, an example of which is the Washington Invasives app. To utilize citizen science strategies, it would be beneficial to define the desired outcomes, such as monitoring (presence or absence), population control, raising public awareness, etc. We suggest promoting use of the WA Invasives app for reporting and monitoring *C. maenas* presence on Whatcom shorelines.

We also suggest raising awareness of the *C. maenas* invasion by posting signs on beaches which include information about the impact of *C. maenas*, how to recognize *C. maenas*, and how to access the WA Invasives app or the Green Crab storymap. Even if a beachgoer doesn’t see any *C. maenas* there, they will know what to do if they see one at a different beach. To avoid costly signage fees and lengthy permitting processes, posters could be posted on beach bulletin boards.

Citizen science methods can have shortcomings in the form of sporadic data and inherent bias due to the sampling location and time (Callaghan 2019). When using a citizen science program in which citizens submit images they take on the beach, specific locations and time ranges will be the most accessible to citizens, causing repeated images being sent in, or temporal gaps in sampling. When working with the general public, coordinating meetings can also be a barrier, as well as ensuring adequate training. To assess the risk of using citizen science, a key question that must be addressed is the quality and of the data, as inaccurate or inconsistent data is useless at best and misleading at worst (Callaghan 2019). Adequate identification training or rigorous double-checking of submitted photos is necessary for quality data to be obtained through citizen science efforts (Grason et al. 2018).

There are several examples of citizen science related to *C. maenas*. Delaney et al. (2008) coordinated a beach survey across seven east coast states with over a thousand participants who documented carapace length, species of crabs found, and gender, using a randomized quadrat system. Upon evaluation of the data collected, it was found that on average participants that were at least 12 (seventh grade age) were able to correctly distinguish *C. maenas* from native species with 95% accuracy (Delaney 2008). In Washington, Emily Grason et al. (2018) employed trapping and beach surveys with researchers focusing at sites where the *C. maenas* had already been observed and the volunteers conducting wide beach surveys in areas where crabs had not yet been observed. The expanded spacial range of this effort allowed for earlier detection of the first recorded *C. maenas* in inland Puget Sound (Grason et al 2018). In Alaska, a Fish and Wildlife department program focused on classroom outreach, where a researcher came to the classroom and taught students how to identify and report *C. maenas*, and then students accompanied a researcher in the field to learn about trapping (Thompson 2007). We suggest hosting an informational booth at local events like Bellingham SeaFeast in order to raise awareness of the *C. maenas* and promote interest in volunteer activities. We also suggest coordinating citizen science efforts, either beach surveys, trapping efforts, or school outreach, to aid in the monitoring and eradication of the *C. Maenas* in Whatcom county.

COORDINATE WITH CREATORS OF CIRCULATION MODELS TO PREDICT SITES AT HIGH RISK OF INVASION AND DETERMINE PRIORITY SITES FOR MONITORING

Efforts focusing on *C. maenas* in its larval stages fall primarily into the realm of detection and forecasting. Understanding the larval dynamics of *C. maenas* allows for the possibility to predict sites at risk for invasions and model potential distributions. Larval retention and reliable recruitment are required to establish a self-sustaining population, and self-sustaining populations serve as footholds for further spread (Banas 2009). Larval transport and retention is largely determined by currents (Thresher 2003), and tides, with larvae developing behavioral adaptations to local tidal environments (Moksnes 2014). Currents and upwelling are the dominant forces of transport and retention at the mouths of estuaries, while tidal forces dominate further into the estuary (Pardo 2012). Along the outer Pacific coast of Washington larvae tend to have net northward transport between June and December, while between January and May, there is net southward transport. These patterns are amplified during El Niño conditions (See 2009). Since most eggs are released in November or early December, the transport direction of a given spawn may be variable on the outer coast (See 2009), influencing the entrance of larvae from the Pacific Ocean into the Salish Sea. As larvae are transported in surface waters, models such as the PNNL Salish Sea Model (PNNL 2020) or NOAA’s GNOME (General NOAA Operational Modeling Environment) model (NOAA 2020) can be used to roughly estimate what routes larvae may take and the likelihood of larvae reaching a certain area, and the necessary data to input on local currents, tides, winds may be obtained from NOAA or the National Weather Service. *C. maenas* is also able to spawn multiple times each year, and in some regions the timing of recruitment events differs from those of native crab species (Garside 2015), knowledge which could be used to enhance predictive models.

We suggest coordinating with researchers who create water circulation models and collect water circulation data in order to gain insight on areas at high risk of *C. maenas* invasion.

KEEP UP TO DATE WITH MONITORING TECHNIQUES AS THEY DEVELOP

Monitoring technology is quickly developing. Roux et al. (2020) used environmental DNA (eDNA) for early detection and monitoring. The eDNA (DNA present from plankton in water samples) was collected from five different sites off the coast of Canada (Roux 2020). The researchers were looking for the mitochondrial cytochrome c oxidase subunit 1 gene, a gene present in but highly variable between all crab species, theoretically allowing researchers to identify the species it came from (Roux 2020).. This method still requires further testing to ensure accurate detection of *C. maenas*, but early detection techniques like this could be very useful in preventing further spread. For more information, the Pacific Biological Station in Nanaimo, Canada should be contacted.

Although it is difficult or impossible to remove larvae from natural water systems, larval and juvenile biology can still provide opportunities for mitigation, as we can take advantage of specific larval tolerances.*C. maenas* larvae and juveniles (zoeae and megalopae) have narrower salinity and temperature tolerance than mature crabs. Shellfish businesses may be able to help with larval extermination by heat treating their shellfish. It has been demonstrated that unintentional transport of *C. maenas* larvae in seed mussels (the post-juvenile stage where the small mussels begin to cement to a surface) can be reduced by heat shocking the sample, as the seed mussels have a higher temperature tolerance than juvenile *C. maenas* (Best 2014). As a practical application, any shellfish that are transported that could have been exposed to *C.*

maenas larvae may be heat treated to prevent the spread of the larvae to new areas. This method has also been investigated with Pacific oysters (*Crassostrea gigas*), a commonly grown and eaten species, which can survive temperatures of 37-39°C for up to 1 hour (Rajagopal 2005). These tolerances are well above *C. maenas* larval tolerances, so heat treatment could definitely be feasible to remove the crab larvae and juveniles. Heat shock treatments are usually seconds to minutes however, and *C. gigas* has been successfully treated at 80-85°C for 2-3 seconds (Best 2014), and at 60°C for 10-15 seconds (Table 1) (Park 1998). Larvae can be killed by treatment for just 5 seconds at 55°C (Best 2014). Olympia oysters (*O. lurida*) are also a commonly eaten species, and though they have no heat shock data, *Ostrea conchaphila* is debated to be the same species (Polson 2009) and can tolerate a temperature of 39°C for 1 hour (Brown 2004), so heat shock could be feasible, though preliminary tests would be advisable. Periodic communication with shellfish businesses in Whatcom county would be advised, especially with those that transport or are considering transporting seed or other products that may have been exposed to larvae and will reenter the water at another location. For example, Taylor Shellfish sells oyster, clam, mussel, and geoduck seed, so heat treatment of their product in the event that their stock becomes contaminated could prevent spread to new areas.

Table 1. Pacific oyster (*C. gigas*) mortality (%) after heat treatment at different temperatures and durations (Park 1998).

Treated time (second)	Water temperature								
	50°C			55°C			60°C		
	Oyster	Mussel		Oyster	Mussel		Oyster	Mussel	
	(1–2.5)	(1–2)	(4–5)	(1–2.5)	(1–2)	(4–5)	(1–2.5)	(1–2)	(4–5)
1	-	-	-	-	-	-	0	0	0
3	-	-	-	-	-	-	0	70	0
5	0	0	0	0	0	0	0	100	0
10	0	0	0	0	60	0	0	100	0
15	0	10	0	0	100	0	8	100	20
20	0	30	0	0	100	0	13	100	30
30	0	100	0	0	100	10	20	100	60
60	0	100	0	10	100	20	60	100	100

( ) : Shell height in centimeter.

CONCLUSION

In summary, we suggest that in addition to continuing the use of minnow and Fukui traps in Drayton Harbor, Fukui traps be modified to improve catch rate, and Blanchard traps be integrated into trapping efforts. Trapping can control populations but sustained efforts are needed and the method cannot completely eradicate a population or prevent reproduction and possible larval dispersal. We suggest organizing community monitoring and education efforts in order to raise awareness of the impacts of *C. maenas* invasion, as well as use volunteer labor in monitoring or management efforts. We suggest the use of existing current and circulation models, as well as collaboration with those who create such models in order to characterize larval transport along Whatcom county shorelines and determine sites at high risk of *C. maenas* invasion to prioritize for monitoring. Finally, we suggest keeping up to date with developing monitoring and mitigation techniques and keeping methods that aren't immediately relevant in mind in case they become so. Altogether these strategies will hopefully aid in mitigating the effects of *C. maenas* in Whatcom waters.

REFERENCES

Banas, N., McDonald, P., & Armstrong, D. (2009). Green Crab Larval Retention in Willapa Bay, Washington: An Intensive Lagrangian Modeling Approach. *Estuaries and Coasts, 32*(5), 893-905. www.jstor.org/stable/40663592

Best, K., McKenzie, C. H., and Couturier, C.. (2014). Investigating mitigation of juvenile European green crab *Carcinus maenas* from seed mussels to prevent transfer during Newfoundland mussel aquaculture operations. Management of Biological Invasions, 5(3), 255-262.
https://www.reabic.net/journals/mbi/2014/3/MBI_2014_Best_etal.pdf

Bergshoeff JA, McKenzie CH, Favaro B. 2019. Improving the efficiency of the Fukui trap as a capture tool for the invasive European green crab (*Carcinus maenas*) in Newfoundland, Canada. PeerJ 7:e6308 https://doi.org/10.7717/peerj.6308

Bergshoeff JA, McKenzie CH, Best K, Zargarpour N, Favaro B. 2018. Using underwater video to evaluate the performance of the Fukui trap as a mitigation tool for the invasive European green crab (*Carcinus maenas*) in Newfoundland, Canada. PeerJ 6:e4223
https://doi.org/10.7717/peerj.4223

Brown, H. M., Briden, A., Stokell, T., Griffin, F. J., & Cherr, G. N. (2004). Thermotolerance and Hsp70 profiles in adult and embryonic California native oysters, *Ostreola conchaphila* (Carpenter, 1857). *Journal of Shellfish Research*, *23*(1), 135+.

Callaghan, C. T., Rowley, J. J. L., Cornwell, W. K., Poore, A. G. B., & Major, R. E. (2019). Improving big citizen science data: Moving beyond haphazard sampling. PLoS Biology, 17(6) doi:http://dx.doi.org.ezproxy.library.wwu.edu/10.1371/journal.pbio.3000357

Devictor, V., Whittaker, R.J. and Beltrame, C. (2010), Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. Diversity and Distributions, 16: 354-362. doi:10.1111/j.1472-4642.2009.00615.

Duncombe, L., & Therriault, T. (2017). Evaluating trapping as a method to control the European green crab, *Carcinus maenas*, population at Pipestem Inlet, British Columbia. Management of Biological Invasions, 8(2), 235-246.

Garside, C. J., Glasby, T. M., Stone, L. J., & Bishop, M. J. (2015). The timing of *Carcinus maenas* recruitment to a south-east Australian estuary differs to that of native crabs. *Hydrobiologica*, 762, 41-53.
https://link.springer.com/article/10.1007%2Fs10750-015-2332-z

Grason, E. W., McDonald, P. S., Adams, J., Litle, K., Apple, J. K., & Pleus, A. (2018). Citizen science program detects range expansion of the globally invasive european green crab in Washington state (USA). *Management of Biological Invasions*, 9(1), 39-47. Retrieved from https://search-proquest-com.ezproxy.library.wwu.edu/docview/2287068014?accountid=15006

Grosholz, E. D. & Ruiz, G. M. (1996). Predicting the impact of introduced marine species: Lessons from the multiple invasions of the European green crab *Carcinus maenas. Biological Conservation, 78*(1,2) 59-66.

Moksnes, P., Corell, H., Tryman, K., Hordoir, R., & Jonsson, P. R., (2014). Larval behavior and dispersal mechanisms in shore crab larvae (*Carcinus maenas*): Local adaptations to different tidal environments? *Oceanography and Limnology*, *59*(2), 588-602. https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.4319/lo.2014.59.2.0588

NOAA, National Oceanic and Atmospheric Administration, (2020). General NOAA Operational Modeling Environment (GNOME) Suite. *National Oceanic and Atmospheric Administration*. https://response.restoration.noaa.gov/gnome

Pardo, L. M., Cardyn, C. S., & Garcés-Vargas, J., (2012). Spatial variation in the environmental control of crab larval settlement in a micro-tidal austral estuary. *Helgoland Marine Research*, 66, 253-263.
https://link.springer.com/article/10.1007/s10152-011-0267-y

Park BH, Park MS, Kim BY, Hur SB, Kim SJ (1998) Culture of the Pacific oyster (*Crassostrea gigas*) in the Republic of Korea.
Polson, M. P. et al. (2009). You Say *Conchaphila*, I Say *Lurida*: Molecular Evidence for Restricting the Olympia Oyster (*Ostrea lurida* Carpenter 1864) to Temperate Western North America. *Journal of Shellfish Research*, 28(1), 11-21.

PNNL, Pacific Northwest National Laboratory, (2020). Salish Sea Model. *Pacific Northwest National Laboratory*. https://salish-sea.pnnl.gov/

Rajagopal, S. et al. (2005). Thermal tolerance of the invasive oyster *Crassostrea gigas*: Feasibility of heat treatment as an antifouling option. *Water Research,* 39, 4335–4342.

Roux, L. M. D., Giblot-Ducray, D., Bott, N. J., Wiltshire, K. H., Deveney, M. R., Westfall, K. M., & Abbott, C. L. (2020). Analytical validation and field testing of a specific qPCR assay for environmental DNA detection of invasive European green crab (Carcinus maenas). *Environmental DNA*. https://onlinelibrary.wiley.com/doi/full/10.1002/edn3.65

Thompson, T. (2007). Boys Discover New Crab Species in Kachemak Bay Community Monitoring Provides Bonus Results. Alaska Department of Fish and Game, Alaska Fish and Wildlife News.

Seaman, B. Marine Resource Commission. Personal communication (2020).

See, K. E., & Feist, B. E. (2009). Reconstructing the range expansion and subsequent invasion of introduced European green crab along the west coast of the United States. *Biological Invasions*, *12*(5), 1305–1318.
https://link.springer.com/content/pdf/10.1007%2Fs10530-009-9548-7.pdf

Shaffer, J. A., Munsch, S. H., & Cordell, J. R. (2020). Kelp forest zooplankton, forage fishes, and juvenile salmonids of the northeast pacific nearshore. Marine and Coastal Fisheries, 12(1), 4-20. doi:http://dx.doi.org.ezproxy.library.wwu.edu/10.1002/mcf2.10103

Thresher, R., Proctor, C., Ruiz, G., Gurney, R., MacKinnon, C., Walton, W., Rodriguez, L., & Bax, N., (2003). Invasion dynamics of the European shore crab, *Carcinus maenas*, in Australia. *Marine Biology*, 142, 867-876. https://link.springer.com/article/10.1007/s00227-003-1011-1

Young, A. M., James A Elliott, Joseph M Incatasciato, Mae L Taylor, (2017). Seasonal catch, size, color, and assessment of trapping variables for the European green crab *Carcinus maenas* (Brachyura: Portunoidea: Carcinidae), a nonindigenous species in Massachusetts, USA, Journal of Crustacean Biology, 37(5), 556–570, https://doi.org/10.1093/jcbiol/rux068