Washington Coast Sentinel Site Summary | 2021

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Introduction

In 2020, Washington Sea Grant (WSG) piloted a monitoring program for European green crab (*Carcinus maenas,* hereafter "green crab") in coastal estuaries, based on the existing Crab Team network of early detection sites in the Salish Sea. As green crabs were already known to be present in Willapa Bay, Grays Harbor and Makah Bay by that time, the sentinel site network provided a systematic protocol for assessing spatial and temporal variation in green crabs, rather than early detection *per se*, and was part of a larger two-year coast-wide assessment effort. In 2021, the sentinel site program expanded to a total of 10 sites within Washington's coastal estuaries, and monitoring occurred over a six-month period.

The overall goal of the sentinel site program is to systematically track the relative abundance of green crabs while also learning more about the native community composition and dynamics where green crabs are present. Monitors within the network implement a standardized monthly sampling protocol at each site, from April through September, taking detailed observations on a small number of traps repeatedly across the season. Additionally, a timed molt survey is performed each month. Because crustaceans leave molted shells as evidence of growth, seasonality of molt detections can provide insight into the timing of growth and habitat use. Methodological consistency of both survey types across sites and throughout the season allows for robust comparison of trends for green crab, as well as many of the native species likely to be impacted, over geographic space and over time, in an extremely efficient design.

Sentinel sites were one of several complementary trapping approaches employed across Washington's coastal shorelines in 2021. Other trapping efforts, such as assessments and removal trapping, are detailed and summarized in Crab Team's 2021 coastal summary blog post. While each trapping effort improves our understanding of coastal green crab populations, sentinel data currently represents the only dataset to provide systematic information about population dynamics across the geography. Understanding these dynamics in space and time is critical to developing effective management and evaluating the success of control efforts. Moreover, sentinel trapping provides insight into green crab habitat associations and the native community of crab and fish. These additional data, which specifically target components of the ecosystem most likely to be impacted by the invasion, are essential for developing control strategies. This report presents some of the trends and patterns we observed as part of sentinel site trapping in 2021 and, where possible, compares green crab abundance at sites from the previous year.

Acknowledgements

WSG would like to extend a sincere thank you to each of the sentinel site monitors, new and returning. Without your generous participation and adventurous spirit, this work wouldn't be possible: Adrianne Akmajian (Makah Fisheries Department); David Beugli (Willapa-Grays Harbor Oyster Growers' Association); Joe Schumacker, Alan Sarich, Cavin Park and Greg Eide, (Quinault Indian Nation); Larissa Pfleeger-Ritzman, Donovan Wargo, Richard Ashley, and Savannah Walker (Shoalwater Bay Indian Tribe); Lee First and Craig Zora (Twin Harbors Waterkeeper Alliance); Matt Lloyd, Jonathan Bates and Will Ritchie (Willapa Bay National Wildlife Refuge); Mark Ballo, Leroy Bowers, Jon Winbush (Brady's Oysters); Natalie Sahli and Juan Bucio (Goose Point Oysters); Roberto Quintana, Amado Oviedo, Javier

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Sentinel Site Results

Sampling Effort

Monitors at eight of the ten sentinel sites (Figure 1) were able to sample for a full season of six monthly efforts (April through September). In total, 54 sentinel sampling efforts occurred across the network in 2021, but it is worth noting that some minor limitations on sampling add caveats to data comparisons. For example, one site (Stackpole) sampled five of the six months, and the Makah site sampled in April only due to lack of staffing and ongoing limitations under the COVID-19 pandemic. Additionally, at Tokeland, the minnow traps used in August and September were altered relative to traps at other sites, meaning that we are unable to compare observations from those traps to other sites for those months. The species caught in those traps are reported as part of the total catch (Table 1), but for the purpose of comparing capture rates to other months and sites, those minnow trap observations were removed from the dataset (n = 6).

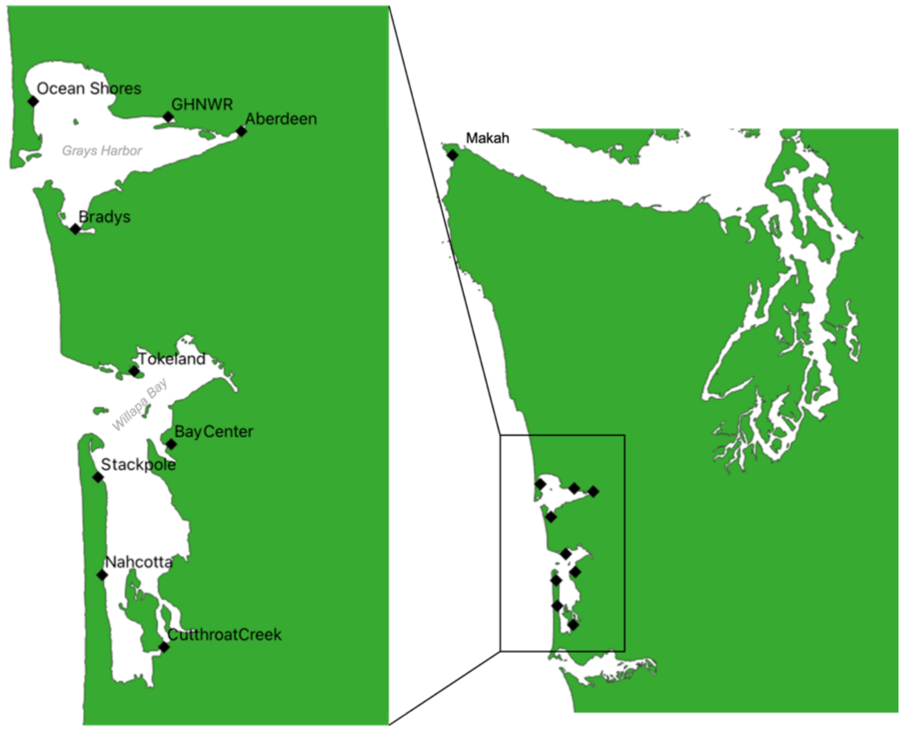

Figure 1. *Locations of 10 sentinel sites along the Washington coast.*

Species Composition

Across all sentinel sites, a total of fourteen species of crustacean, fish and gastropod were caught in traps during the 2021 sampling season (Table 1). These organisms are part of the ecological communities likely to be associated with, and impacted by, green crab. Hairy shore crab (*Hemigrapsus oregonensis*) was the most numerous species in the traps, followed by staghorn sculpin (*Leptocottus armatus*) and three-spined stickleback (*Gasterosteus aculeatus*). Green crab was the fourth most numerous species captured. Three species were caught at all ten of the sites: hairy shore crab, staghorn sculpin, and green crab. Other widespread species include three-spined stickleback, prickly sculpin (*Cottus asper*), eel-like fishes, and crangonid shrimp species, which all were recorded at six or more sites. Cutthroat Creek, in southern Willapa Bay, had the greatest species richness of all the sites, capturing a total of 11 different species, four of which were found only at that site. The capture of the banded killifish (*Fundulus diaphanous*) at Cutthroat Creek was the first time this species had ever been recorded in Willapa Bay. The Atlantic dogwhelk (*Tritia* (formerly *Ilyanassa*) *obsoleta*), the only gastropod recorded in the surveys, is a non-native species with patchy distribution in Willapa Bay, but occasionally appears in great abundances.

It’s worth noting that the apparent low species richness recorded at Makah Bay is likely a reflection of sampling occurring in April only. April is typically a low catch month, and sampling in one month only will likely result in underrepresentation of the total catchable species pool, statistically speaking.

In addition to the trapping survey, the monthly molt survey conducted as part of the standard protocols provides additional information about crustacean communities. Consistent with trapping, species detected in the molt surveys appeared in the same order of relative abundance: hairy shore crab being the most abundant, followed by green crab, Dungeness crab, and purple shore crab. The dominance of hairy shore crabs across nearly all sites highlights the importance of this native crab in habitats also inhabited by green crabs. It is notable, therefore, that one site stood out due to the near absence of this native shore crab in both trapping and molt surveys: Nahcotta. While this site also had the greatest relative abundance of green crabs, it is not possible, without historical baseline observations of hairy shore crab abundance prior to green crab arrival, to determine a causal relationship. That is, are green crabs at Nahcotta reducing hairy shore crab populations (e.g. through predation or competition, as has been observed in other locations on the West Coast), or did the absence of hairy shore crabs at this site due to other factors allow green crabs to survive through juvenile stages at a higher rate than other sites?

Speaking more broadly, across all sites, species detected via molt searches (Table 2) were a subset of the list of crustaceans observed in traps (Table 1), except for an unknown amphipod species molt found at Cutthroat Creek. This was not the case, however, on a site-by-site basis. For instance, Dungeness crabs were detected at twice the number of sites via molt searches relative to trap surveys (Tables 1 and 2). This discrepancy might occur if Dungeness crabs are less susceptible to traps than the other species using these protocols, or if their molts, being larger, are more detectable than those of other species. Conversely, molts from sand shrimps (Family Crangonidae) were not found at any site during monthly searches, even though they appeared in traps at more than half the sentinel sites. Failure to detect crangonid molts could occur if relatively fragile shrimp molts are distributed or degraded differently from crab molts. Nevertheless, taken together, these findings underscore the importance of multi-modal searches in fully characterizing the crustacean community at each site.

Molted shells provide evidence of growth in a variety of crustaceans. Thus seasonality of molt detections can provide insight into the timing of growth and habitat use (Figure 2). Hairy shore crabs and Dungeness crabs both appear to have distinct seasonal patterns to molting – though exactly opposite in timing. That is, Dungeness crab molts were most abundant in early spring months, and dropped off starting in June, while shore crab molts were more abundant from June through September relative to April and May. Green crab molt abundance peaked in May, similar to Dungeness crabs, but the signal of seasonality was more variable than the other two common species. This could indicate green crabs experience multiple growth periods, or that growth peaks are

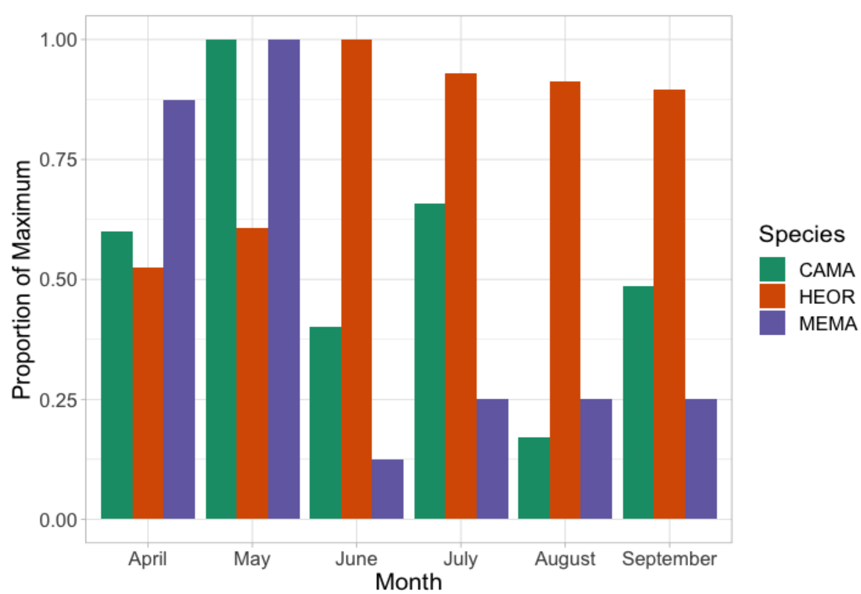

Figure 2. *Seasonality of molts of the three most common species found during the molt survey. Because the numbers of molts vary so greatly depending on the species, these numbers have been standardized to compare the monthly molt detection rate relative to maximum for that species. Absolute number of molts can be found in Table 2.*

respectively influenced by different population factors, such as recruitment.
Beyond cataloging species, data from sentinel sampling can also yield insights into how green crabs might be integrating into resident ecological communities. Another way to phrase this is, are there certain patterns of other species of animals that we observe that are associated with relative success of green crabs? In 2021, preliminary results from sentinel trapping surveys showed a trend toward increased abundance of green crabs at sites with lower species richness, as well as lower total abundance of all species (Figure 3). Currently these patterns are preliminary and driven by a small number of sites with high species richness (Cutthroat Creek) and/or high abundance (Cutthroat Creek and Grays Harbor NWR), but over time, the sentinel network will be better able to evaluate the strength of these relationships. What the data won't show us, however, is an indication of causality in these relationships – that is, are sites with greater abundance or diversity of native species more resistant to green crabs, or are predation and competition by green crabs driving down species richness and abundance at sites where the invasive is highly abundant? It's also possible that an external factor, such as temperature or salinity, or oceanographic circulation patterns, is responsible for both patterns independently. Nevertheless, identifying these community-level patterns and tracking changes in communities over time could enable us to identify sites that are susceptible to green crabs and therefore a priority for removal trapping.

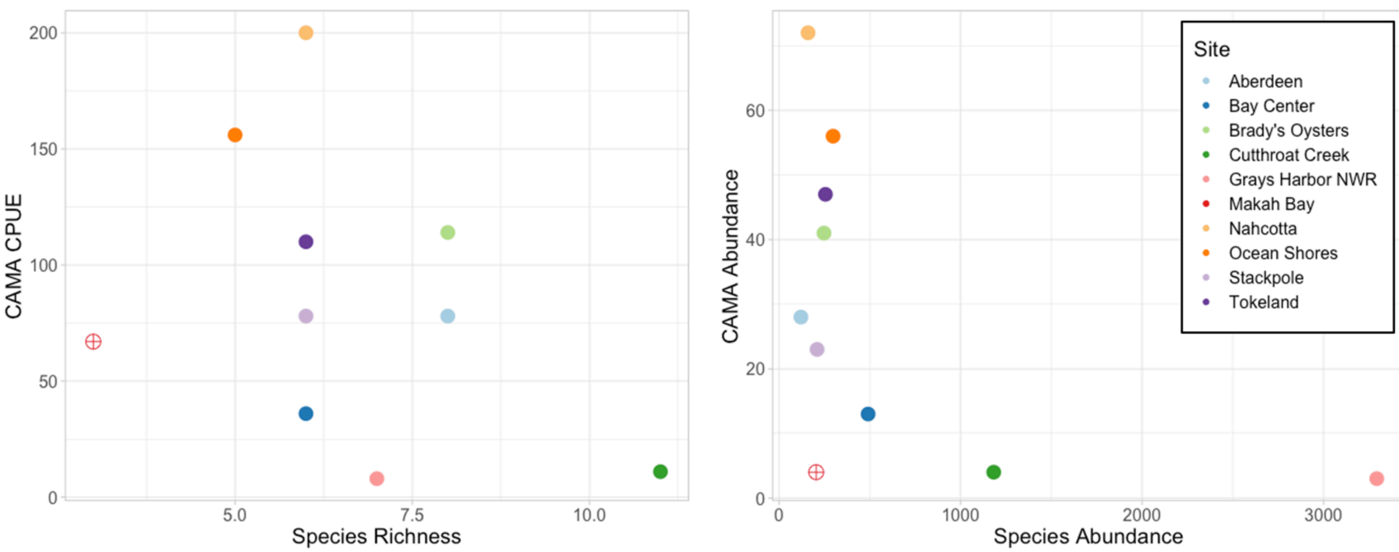

Figure 3. *(Left) Average capture rate of green crab (CAMA CPUE) for the 2021 season in number of green crabs per 100 trap sets as a function of total number of species captured at each of the sentinel sites. (Right) Total number of green crabs captured (CAMA Abundance) during the 2021 season as a function of total number of all organisms captured at each of the sentinel sites. Note that observations from Makah Bay (red open circle with cross) reflect only a single month of sampling in April, which would likely underestimate total season capture rates and species richness.*

European Green Crab Captures

Abundance and Distribution

All 10 sentinel sites caught green crabs, indicating that the invasive species is broadly distributed in Washington's coastal estuaries; however, capture rates showed that their abundance varies spatially. Relative abundance of green crab (CPUE, "catch-per-unit-effort"), standardized as the average number of crabs caught per 100 traps set, varied by an order of magnitude across sites, ranging from a low of CPUE = 8 at Grays Harbor National Wildlife Refuge to a high of CPUE = 200 at Nahcotta (Table 1, Figure 4).

Nahcotta had the highest average capture rate of green crab of all the sites, representing a change from 2020, where Stackpole caught the most green crabs. Molt searches yielded evidence of green crab presence at every site except Bay Center, though green crabs were captured at that location at a relatively low abundance. By this measure, molt searches appear to be a slightly less sensitive detection technique for green crabs but are quite reliable at sites with high green crab abundance.

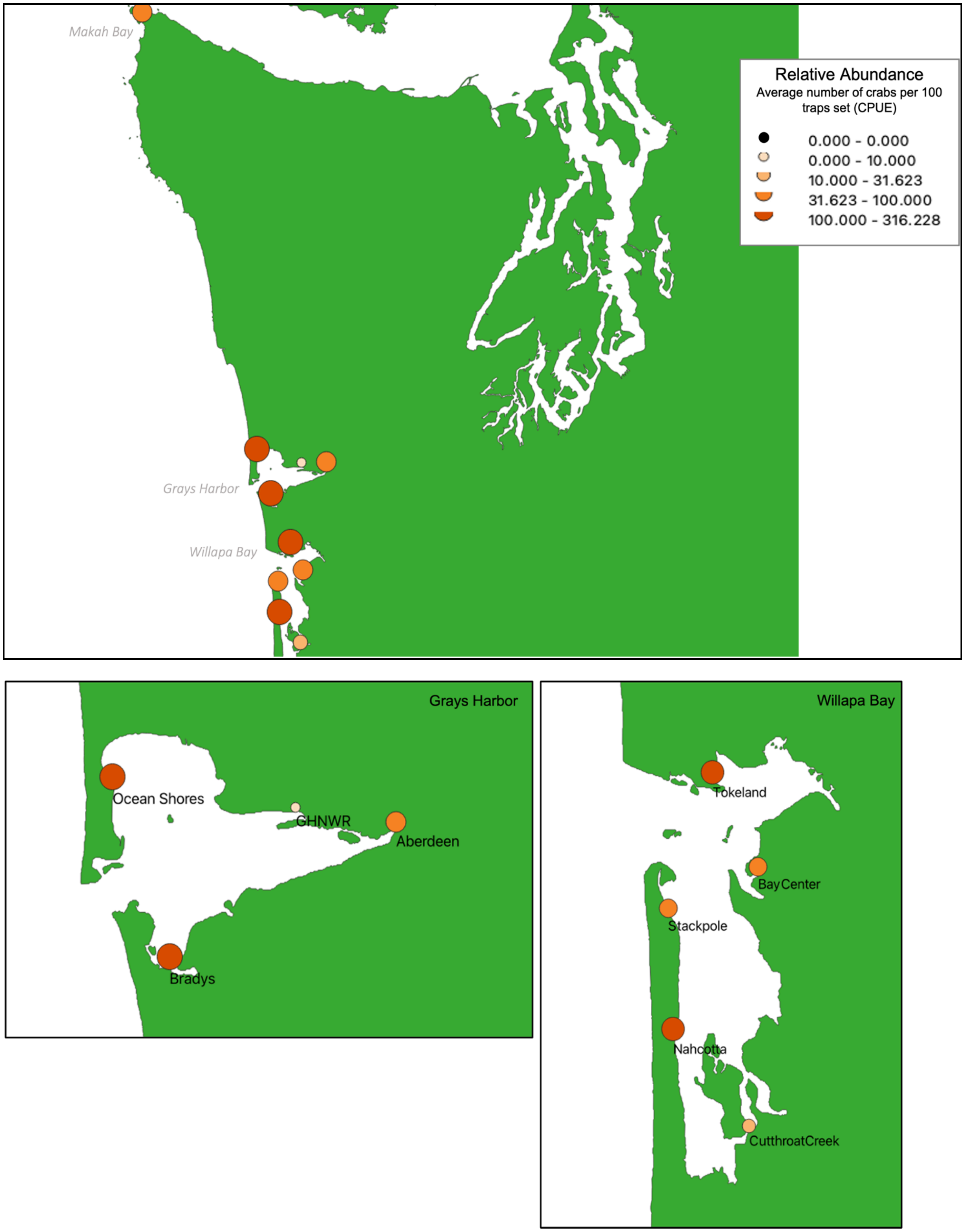

Figure 4. Relative abundance (average number of crabs per 100 traps set) of European green crabs at sentinel sites averaged over the 2021 field season. Ocean Shores and Nahcotta had the highest relative abundance in Grays Harbor and Willapa Bay, respectively. Note: Makah and Stackpole were not sampled for the full 6-month period. Tokeland CPUE does not include data from minnow traps from August and September due to gear alterations.

Sex and size

In order to track population demographics, monitors determine the sex and measure the carapace width of all green crabs captured and record several other physical parameters on crabs as well. Together, these observations can provide insight into the age, growth rates, and condition of crabs.

Green crab captures were male-biased in that, on average across the season, roughly 70% of the total number of green crabs caught was male (Figure 5). Additionally, totaled across all 10 sites, there was no month in which more females were captured than males. This is consistent with previous observations that male green crabs are more likely to come to traps than female green crabs. Anecdotally, independent trappers reported catching females at a higher rate towards the end of the field season. In the sentinel site network, there was a weak trend toward decreasing male bias of captures during the second half of the season. Aggregated over the months of July to September, female green crabs made up almost 10% more of the catch compared to the months of April to June.

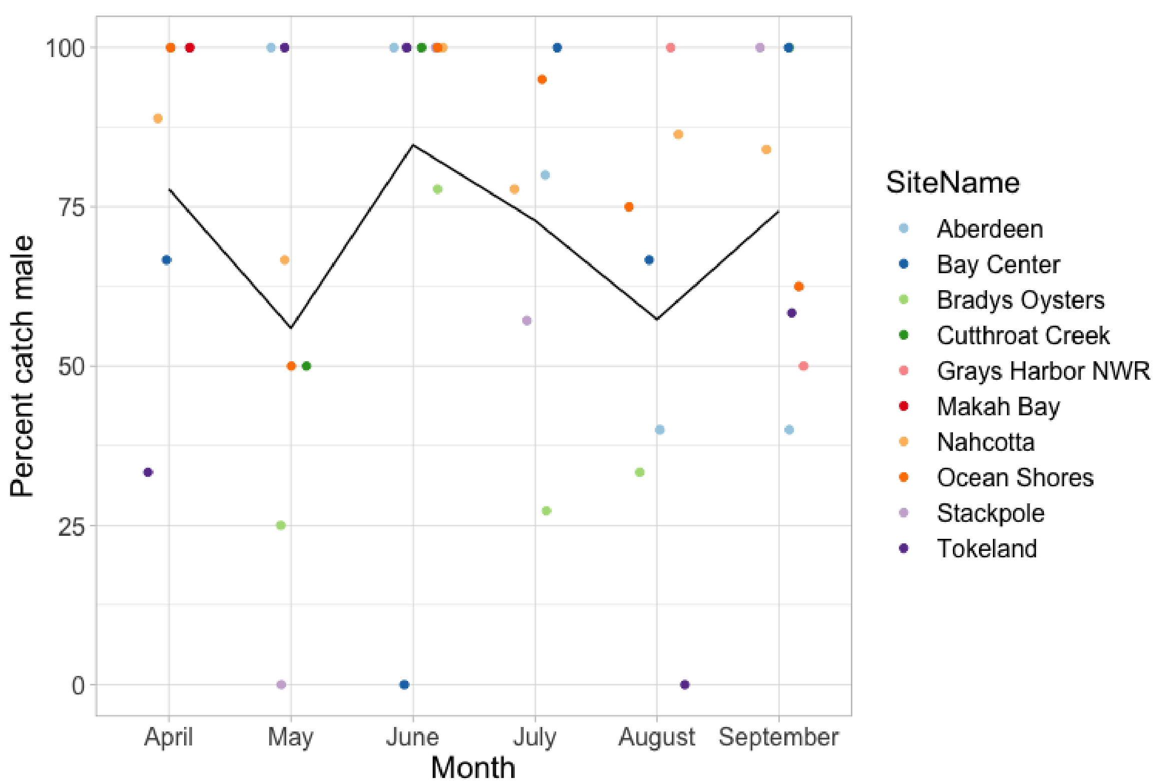

***Figure 5.** Sex ratio of European green crabs (*Carcinus maenas*) in sentinel traps by month. Points (jittered for visibility) represent observations for each site's monthly sample when green crabs were captured, and black line is drawn to reflect the monthly average across all sites sampled.*

Size data and other condition information is used to track age classes of green crabs within the estuaries, and this information can provide insight into how long crabs have been settled at a location, as well as the strength and timing of recruitment. In molt surveys, green crabs spanned 8 mm to 80 mm (Figure 6) and those in sentinel traps ranged from 17 mm to 92 mm (Figure 7), indicating that multiple age classes, from young-of-the-year (YOY) to 4-5+, are present within the monitored estuaries. While it can be challenging to definitively identify the YOY cohort based on size alone, crabs sized 30 mm or less during the field season are generally considered YOY crabs (though later in the season, YOY crabs could size up to 40 mm). The proportion of crab detections that are YOY offers insight into the strength of the newest cohort. A strong YOY cohort could indicate potential for rapid population growth in the coming years. Using the rough benchmark size of 30 mm as a cutoff, YOY crabs comprised nearly 6% of the live green crabs trapped in 2021. In contrast to traps, however, green crabs under 30 mm comprised about 50% of the molts encountered. Crabs molt frequently when they are young and growing quickly, but they are often more reluctant to enter traps until they reach about 20 mm. These two observations may explain the discrepancy in these two estimates of cohort strength but comparing trapping data to other seasonally trapped sites along Washington's inland shore suggests the 6% observed across coastal estuaries is a relatively weak juvenile cohort. Because some early-cohort crabs could reach 40 mm by the end of their first year, this cutoff might slightly underestimate recruitment, but the few crabs caught between 30 and 40 mm in August and September are unlikely to substantially increase the estimate of cohort strength.

In contrast to previous observations from other locations on the West Coast, the timing of YOY appearance in traps did not suggest a single seasonal pulse of recruitment in 2021. This conclusion is supported by both trapping and molt survey data. Young crabs were found in molt surveys as early as April (Figure 6) and entered traps from May through August (Figure 7). Historically, data collected by colleagues at Oregon State University has suggested that green crabs produce a single YOY cohort a year in coastal waters, usually growing large enough to capture in minnow traps in late August. However, the sentinel data demonstrate that the recruitment window starts earlier and lasts throughout the entire sampling season. Other data show that this change appears to be taking place in Oregon as well and may indicate a shift caused either by different conditions (i.e., warming temperatures supporting protracted recruitment) or increased crab population size at the sites where larvae are originating. During such a protracted opportunity for reproduction, YOY may appear in multiple overlapping cohorts that appear as a

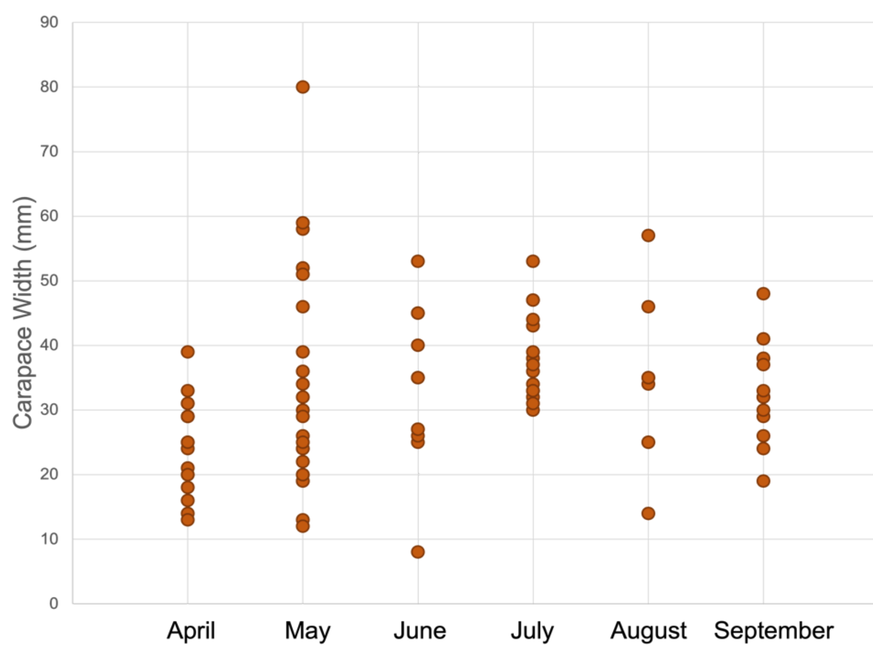

Figure 6. *Size, in carapace width (mm) of European green crab molts collected during monthly molt surveys.*

single long-term recruitment event.

The ability to detect crabs of differing sizes and life stages depends on the gear used for sampling. The purpose of using two trap types with different opening and mesh sizes is to target different size and age classes of green crabs and other native species that appear in traps. Of the two trap types used in sentinel monitoring YOY green crabs were primarily captured in minnow traps, with conical funnels narrowing to circular openings 2.5 cm in diameter (about 1”). The second trap type, Fukui traps, are rectangular shaped with ramps narrowing to horizontal slit openings on either end. The slit openings are 45 cm wide and are modified with a zip tie in the middle to reduce the opening size to approximately 20 cm wide on either side of the tie. The larger mesh size of the Fukui traps can allow for more escapement of smaller animals than minnows. To verify that Fukui and minnow traps are indeed functioning to catch different size crabs, Figure 7 visualizes green crab captures by trap type. Green crabs caught in sentinel minnow traps ranged from 17 mm to 36 mm, while green crabs caught in Fukui traps measured 30 mm and above. Young crabs come to traps at a lower rate than adult crabs, so while minnow traps caught significantly fewer green crabs, as expected, they effectively target YOY crabs.

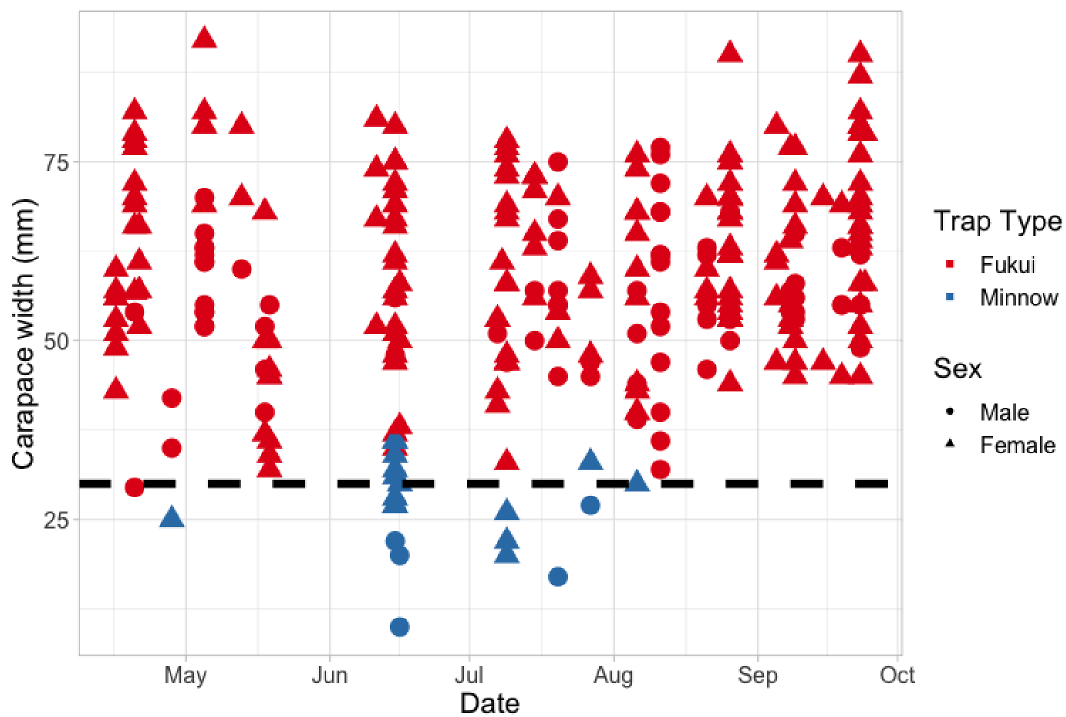

Figure 7. *Size (mm) and sex of green crab caught at sentinel sites during the 2021 season, shown by trap type. The dashed line at 30 mm is generally the size considered to be young of the year. Note: A total of 14 green crabs (4 M/10 F) were captured in altered minnow traps with enlarged openings in August and September and are not included in this figure.*

Determining whether green crabs are actively self-recruiting in a place because of larval retention, and thereby contributing to local population growth, cannot be answered with trapping data alone. However, two lines of evidence from sentinel trapping and molt surveys indicate that green crabs are likely to continue population growth across the site network: (1) the presence of YOY confirms successful recruitment into a site, whether from a local or a distant larval source, and (2) good survivorship and longevity (presence of large adult crabs) indicates habitat suitability. While presence of YOY indicates that larvae can arrive and survive at a site, the source population for those larvae could be quite distant, and sites, even within a single estuary, could contribute differently to population growth rates for the estuary as a whole. Identifying which sites are the most important sources of larvae contributing to regional population growth will be an area of continued investigation, and the consistency of sentinel site trapping will be a critical element of better determining source populations.

Seasonal Patterns

Green crab capture rates were lowest in April and May across all 10 sites, with the exception of Brady's Oysters, where catch rate peaked in May (Figure 8). While capture rates generally increased in the second half of the season, there were two sites where capture rates were highest in the earlier months (Brady's Oysters and Cutthroat Creek). Of the eight sites that were sampled for the entirety of the season, six observed the highest capture rates July through September. There could be two possible explanations for this trend: green crabs may be the most "catchable" in the later summer and early fall months, or there are simply more green crabs to catch. The YOY cohort is strongest from June – July (Figure 7), meaning that YOY crabs would be sizing up to catchability around the same time that we observe greater CPUE at most sites, in the second half of the summer. Thus, the increase in captures during the second half of the season may be, at least in part, due to the arrival of new crabs. Seasonal patterns in capture rates did not appear to differ between Grays Harbor and Willapa Bay, indicating that the green crab populations in these water bodies exhibit similar seasonal behavior, at least as it translates to trapping rates.

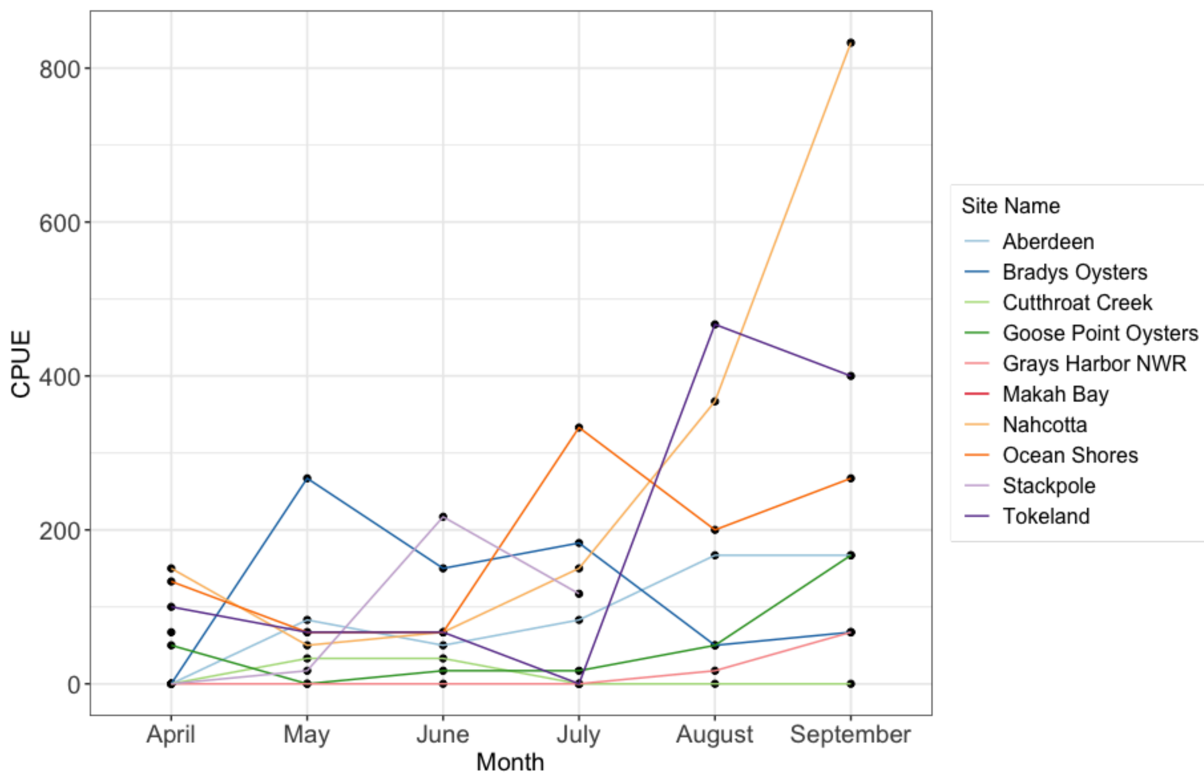

Figure 8. *Monthly catch-per-unit-effort (average number of crabs per 100 traps set) of European green crabs at sentinel sites. Note: Not all sites were sampled for the full six-month period. The single dot appearing in April represents Makah, which was sampled in that month only. Stackpole did not sample in August, so their CPUE in September also appears at the dot where CPUE = 33. The Tokeland CPUE for the months of August and September shows the Fukui capture rates only due to gear alterations to the minnow traps in those months.*

Annual Trends

The standardized protocol of the sentinel site trapping survey allows for robust evaluation of population change across time. While there are site-specific differences in magnitude of change, the relative abundance of green crabs grew dramatically between 2020 and 2021 (Figure 9). Based on sampling during the first two years of the sentinel site program, data are available for comparison at four sites: Ocean Shores (Grays Harbor) and Nahcotta, Stackpole, and Tokeland (Willapa Bay). Trapping observations from these sites show an increase in the abundance of green crabs in 2021, ranging from 67% and up to 800%. The three sites with the most dramatic increases are all located in Willapa Bay. While the sample size is small, these findings point to a larger trend of dramatic green crab population increases in just one year.

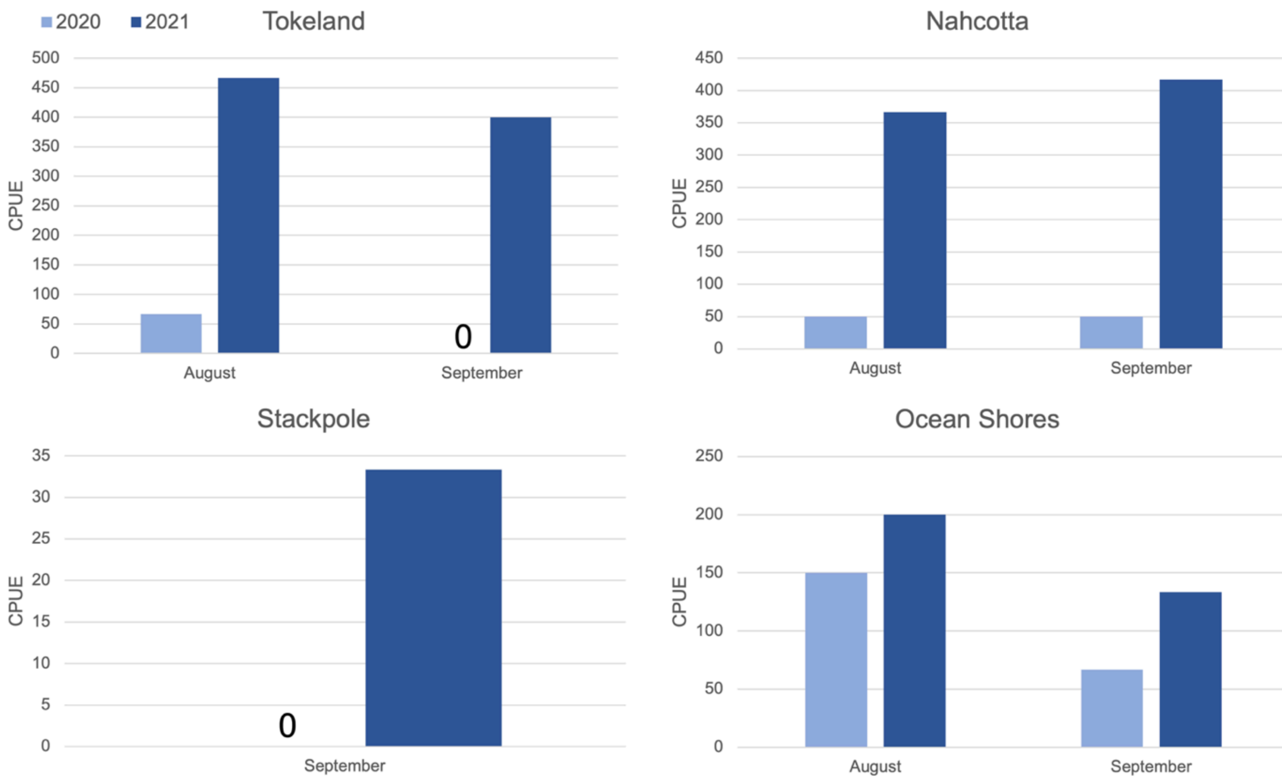

Figure 9. *Inter-annual comparisons of average green crab capture rates (CPUE is defined as number of green crabs captured per 100 trap sets). Notes: The scale for CPUE differs by site. Stackpole did not sample in August 2021, so the month of August is not included on this graph. The Tokeland graph shows only the CPUE of Fukui captures due to minnow trap alterations in August and September 2021.*

Concluding Remarks

Through standardized survey methods, the sentinel site network allows for the robust comparison of green crab trends over space and time, as well as tracking and observing community composition in habitats where green crabs are present, and often abundant. Currently, this network compiles the only data set that systematically tracks important green crab information across the Washington coast more broadly, including:

- Changes in green crab abundance, distribution, and seasonality
- Sex and size ratios of green crabs captured
- Patterns of community composition in places green crab inhabit

- Potential changes to community composition over time, in places where green crabs are present and abundant

Collectively, we still have a lot to learn about green crab movement, behavior, reproduction, and impacts. Some of these issues will require investigation beyond the sentinel network to identify the mechanisms at play. Yet, the consistency of the sentinel monitoring is at the core of understanding patterns at a regional scale.

Additionally, the findings from the sentinel site network have practical and important implications for green crab management in coastal Washington. This second consecutive year of data collection provides further evidence that this invasive species is now more abundant and more widespread than ever previously recorded in coastal estuaries, and some populations dramatically increased in the last year alone. Green crabs can now be found at all sites explored in Willapa Bay and Grays Harbor. In order to protect places of significant cultural, recreational, and economic value, intervention to suppress this invasive species is needed. The good news is that there is still time to intervene. We know that trapping is the best tool we currently have for green crab removal, yet it is also extremely resource intensive. Management decisions will require prioritizing resources to do the most effective and most efficient work. When considering management actions such as targeted removal efforts or resource allocation, science-informed decisions will have the greatest impact. From just two years of sentinel trapping, we have already gleaned some lessons that can inform smart management decisions. For example, we've detected highest catch rates of green crab from roughly July through September. Increasing trapping pressure and frequency during these months could produce the greatest returns on investment. We also see a decreased male bias in catch rates in later summer and early fall, meaning that trapping heavily during these months could serve to remove more female crabs. Although catch rates for adults are typically lower in May and June, we know that young-of-the-year crabs begin to emerge during these months, so directing targeted removal efforts at smaller crabs could be another strategy considered during that portion of the field season.

This work isn't without its challenges, however, and as monitors know, setting and retrieving traps requires navigating hazardous environments in often inclement weather, long travel times to and from sites, and a spirited sense of adventure. Partners noted difficulty scheduling around appropriate tide windows and planning logistics as one of the biggest obstacles to sentinel monitoring, constraints that are likely to similarly challenge all trapping work needed to successfully manage green crab. But, despite these challenges, and the ongoing difficulties created by the global pandemic, the network achieved a 90% sample rate in 2021. Their effort enables the continuation of this network and demonstrates the commitment of partners to monitoring efforts and to gathering the information needed to best manage the green crab invasion. Looking ahead to 2022, the data collected through the sentinel site network will contribute to an extended dataset, increasing in value over time, and furthering our collective knowledge to improve decision-making as it pertains to green crab control.