First detection of the invasive European green crab *Carcinus maenas* (Linnaeus, 1758) on Lummi Nation reservation tidelands

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Lummi Natural Resources Department

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ABSTRACT

The European green crab (EGC), *Carcinus maenas* (Linnaeus, 1758), is one of the most widely distributed invasive marine species on Earth. Introductions of predatory EGC have resulted in a variety of environmental calamities, including habitat destruction, biotic community change, and collapses of local clam fisheries, just to name a few. While EGC have been established along the northeast Pacific coast for three decades, it was only in the last three years that the first live EGC were found in the San Juan Islands and Padilla Bay, Washington. And recently, three months ago, several live EGC were captured in Drayton Harbor, Whatcom County, Washington. The latest findings prompted Lummi Natural Resources Department (LNR) staff to perform a rapid EGC monitoring response, using established trapping protocols, on Lummi Nation reservation tidelands to the south of Drayton Harbor. This report details the LNR effort in both Lummi and Portage bays and describes the first detection of EGC in yet another location within the inland marine waters of the Salish Sea.

During October 7, 2019 through October 23, 2019, a total of 64 invasive EGC, 32 females and 32 males, were captured after 180 trap nights on Lummi Nation reservation tidelands within Lummi Bay. Forty-one EGC were collected from inside of the Lummi Sea Pond, whereas 23 EGC were sampled outside (west) of the tide gates at Sandy Point Heights. No EGC were captured at sampling locations in the barrier estuary behind the barrier beach of Lummi Bay, nor were any EGC detected at Portage Bay during the first week of November. Besides invasive EGC, more than 1,700 other animals were captured in Lummi and Portage bays during the study. Biotic resistance from native predators (e.g., Dungeness crab and staghorn sculpin), or the presence of a diverse, native benthic community, may provide some level of ongoing, natural control of the invasion on reservation tidelands.

Size frequency analyses revealed two EGC year classes being present at Lummi Bay: one dominated by individuals ranging from 30 mm to 50 mm “notch” carapace width, and the other, represented by a single crab measuring > 60 mm “notch” carapace width. No significant differences were detected in carapace width distributions between the sampling locations and sexes. The large individual, a male, was aged ≥ 1 year, suggesting an original settlement date during 2017/2018. The smaller EGC were considered 0-age, or young-of-year, and likely settled out of the plankton during 2018/2019. Given these results, the EGC expansion into Lummi Bay should be considered a relatively recent event.

Where EGC were captured, the relative abundances of female and male *C. maenas*, as indicated by mean (± SE) catch-per-unit-effort (CPUE), were generally consistent across sampling locations and trap styles, and ranged, by sex, from 0.25 ± 0.11 EGC/trap night to 0.75 ± 0.39 EGC/trap night. While the EGC catch rates reported here were lower than those reported for coastal British Columbia, Canada, the Lummi Bay CPUE (all sampling locations combined), when expanded to 100 trap nights (= 35.6 EGC/100 trap nights), is on par with the early invasion of Willapa Bay, Washington at its peak 20 years ago (35–43 EGC/100 trap nights), and currently

makes the relative abundance of the Lummi Bay population the second highest reported in the State of Washington.

In terms of an agency response, given the scope and scale of the problem here, there are simply no alternatives to coordinating with others across jurisdictional lines, sharing resources (if possible), and adopting an ethos of "many hands make light work". LNR should devote appropriate resources to gain a better understanding of, and to plan for, the following items pertaining to EGC on Lummi Nation reservation tidelands:

1) The Lummi Sea Pond as a potential sole source of EGC;
2) Potential impacts to crabs and clams, i.e., how EGC might regulate the local benthic community;
3) Potential impacts to habitat, i.e., how EGC might act as an ecosystem engineer;
4) Trapping and removal of EGC on Lummi Nation reservation tidelands; and
5) Novel uses for EGC should *C. maenas* become firmly established despite LNR and others' attempts to thwart the invasion.

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INTRODUCTION

The invasive European green crab, *Carcinus maenas*, colonized coastal, estuarine embayments of the western United States (U.S.) initially over 30 years ago, a likely result of transoceanic shipping and the maritime trades (Carlton and Cohen 2003). In the ensuing years, following a strong, large-scale El Niño–Southern Oscillation event in the Pacific Ocean off the U.S. West Coast, small populations of *C. maenas* were established in Willapa Bay and Grays Harbor, Washington. These populations originally derived from European green crab (hereafter, EGC) larvae dispersed naturally from reproducing ones in California (Tepolt et al. 2009). By the early 2010s, small pockets of EGC were detected along the Pacific Coast of British Columbia, Canada, and within the Sooke Basin at the southwestern tip of Vancouver Island inside of the Salish Sea (Gillespie et al. 2015). Not too surprisingly, in 2016, the first live Salish Sea EGC specimens found south of the U.S.–Canada Boundary were collected in the San Juan Islands and Padilla Bay, Washington (Behrens Yamada et al. 2017). These findings should be of concern to local natural resource managers because successful invasions of the crustacean predator elsewhere (e.g., Atlantic Coast of North America and Australia) have resulted in a variety of environmental calamities, including habitat destruction, biotic community change, and collapses of local clam fisheries, just to name a few (Grosholz et al. 2000; Walton et al. 2002; Whitlow 2010; Malyshev and Quijón 2011; Matheson et al. 2016; Howard et al. 2019).

In September 2019, following the late summertime discovery of *C. maenas* molts in Drayton Harbor, Whatcom County, Washington (Figure 1) by trained, volunteer beach walkers ("citizen scientists") from the Washington Sea Grant (WSG) Crab Team (Grason et al. 2018), the WSG Crab Team and EGC staff from the Washington Department of Fish and Wildlife (WDFW) mobilized and rapidly responded to the findings by deploying dozens of traps ($n > 80$) throughout Drayton Harbor, but especially between Dakotah and California creeks (Pleus 2019). At the end of the month, live EGC were indeed captured there in various locations (first author, personal observations, September 25, 2019; Pleus 2019) prompting Lummi Natural Resources Department (LNR) staff to perform a similar rapid response on Lummi Nation reservation tidelands to the south of Drayton Harbor (Figure 1) during the next tide series in early October 2019. This report details LNR's EGC monitoring efforts in both Lummi and Portage bays (Figure 1) and describes the first detection of EGC in yet another location within the inland marine waters of the Salish Sea.

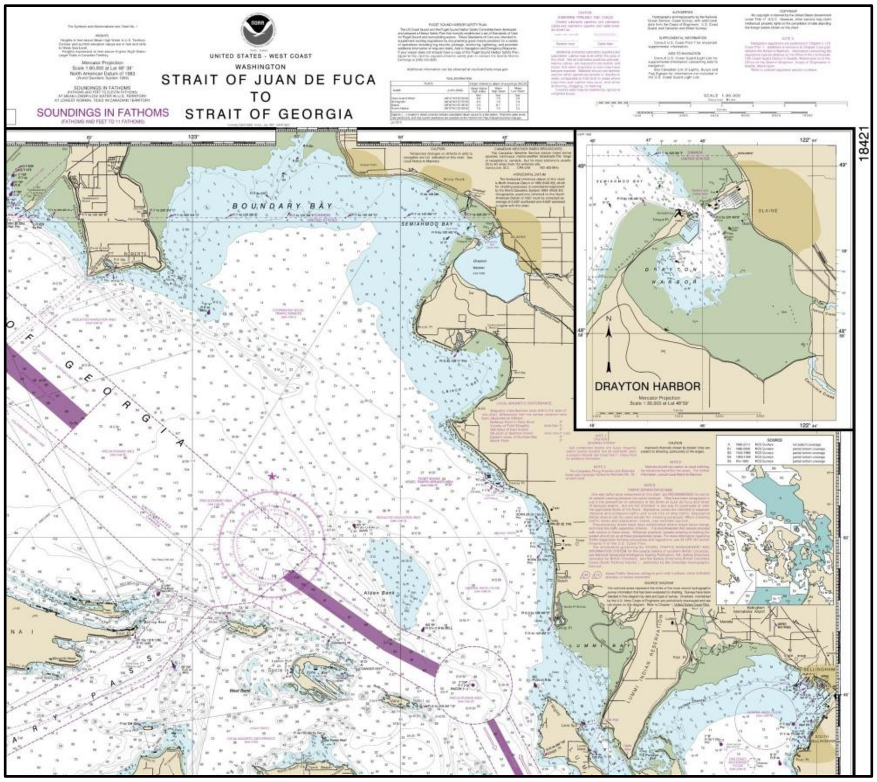

Figure 1. Nautical chart of study area showing locations of Drayton Harbor and Lummi Bay, Whatcom County, Washington, where invasive European green crab, *Carcinus maenas*, were captured during fall 2019. The Lummi Sea Pond dike/wall is located within Lummi Bay to the north of the Lummi Indian Reservation peninsula. Portage Bay and Portage Island lie off the southern tip of the peninsula, inside Bellingham Bay (source: National Oceanic and Atmospheric Administration).

MATERIALS AND METHODS

This study took place from October 7, 2019 through November 8, 2019 on Lummi Indian Reservation tidelands located in Lummi and Portage bays, Whatcom County, Washington (Figure 1). The sampling methods were adapted from standardized protocols used by EGC responders throughout the inland marine and coastal waters of Washington State (Grason et al. 2018; WSG 2019) which were based, in turn, on the earlier work of others (e.g., Behrens Yamada et al. 2005). Two styles of sampling devices were deployed: collapsible, fukui-style traps and standard minnow (or crayfish) traps (Figure 2). These were baited with frozen, oily fishes [in this case, Pacific herring (*Clupea pallasii*) or sardines (*Sardinops* sp.)] which have been used to successfully capture EGC throughout its introduced range (Behrens Yamada et al. 2005; Young et al. 2017; Grason et al. 2018). The traps were deployed in a variety of locations within Lummi (*n* sites = 8) and Portage (*n* sites = 3) bays (Figures 3 and 4) over two consecutive nights (or two "trap nights") during each of three tide series spanning a four week period (Figures 5–7). At each location, the traps were set and staked about 10 m to 30 m apart, alternating between the two styles, along convenient, traversable banks and shorelines (Figures 8 and 9) and in habitats preferred by EGC (i.e., tidal marshes, gently sloping mudflats, and tidal sloughs and channels) (Jensen et al. 2007; Behrens Yamada and Gillespie 2008; Grason et al.

2018; WSG 2019). For each trap set, besides recording the set/retrieval dates and times, the latitude and longitude were determined and recorded using a hand-held GPS unit. Tables 1 and 2 summarize the trapping efforts in both bays.

Figure 2. Trap styles used to monitor the presence/absence of the invasive European green crab, *Carcinus maenas*, on Lummi Nation reservation tidelands from October 7, 2019 through November 8, 2019. On the left is a standard minnow (or crayfish) trap; on the right, a collapsible, fukui-style trap. The two trap styles are commonly used together to capture a variety of EGC sizes. Individual traps were uniquely numbered (see tag at left) and baited with Pacific herring (*Clupea pallasii*) or sardines (*Sardinops* sp.) (Photo credits: second author).

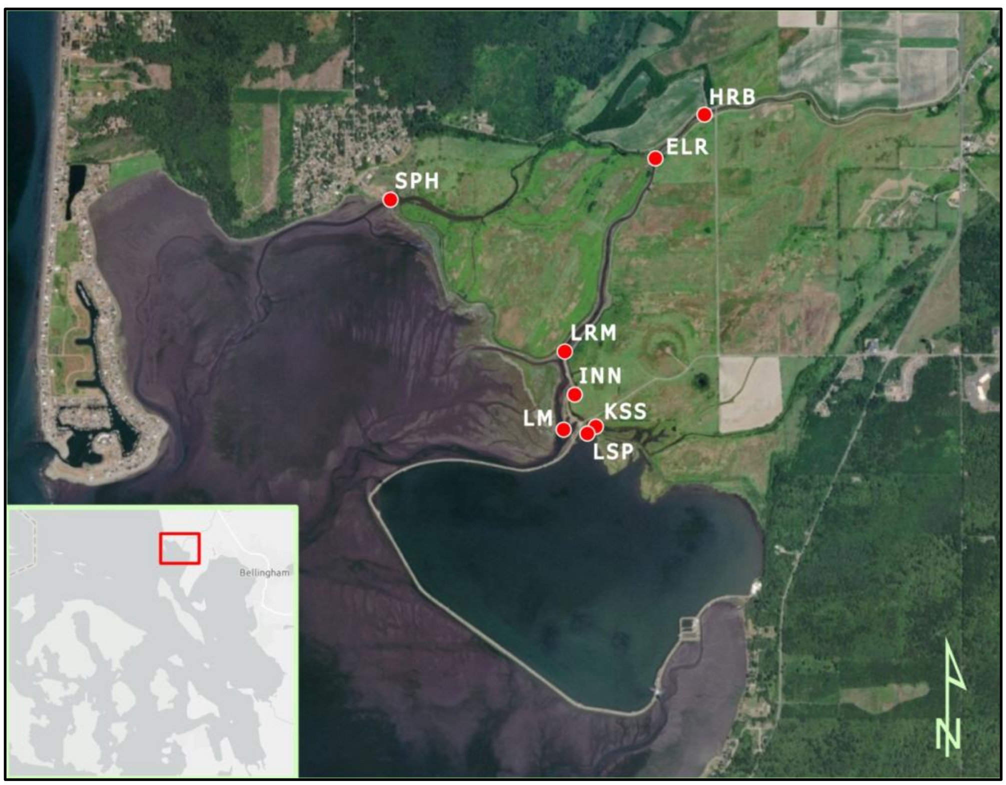

Figure 3. Satellite view and map of invasive European green crab, *Carcinus maenas*, sampling locations on Lummi Nation reservation tidelands within Lummi Bay, Whatcom County, Washington. Shown from the south are: Lummi Sea Pond (LSP), Kwina South Slough (KSS), Lummi River Mouth (LM), Inner Slough (INN), Lummi River Mid (LRM), Sandy Point Heights (SPH), East Lummi River (ELR), and Hillaire Road Bridge (HRB). A detailed view of each location can be found in Appendix 2.

Figure 4. Satellite view and map of invasive European green crab, *Carcinus maenas*, sampling locations on Lummi Nation reservation tidelands along Portage Island within Portage Bay, Whatcom County, Washington. Shown from the west are: Portage Bay West (PBW), Portage Bay South (PBS), and Portage Bay East (PBE). A detailed view of each location can be found in Appendix 2.

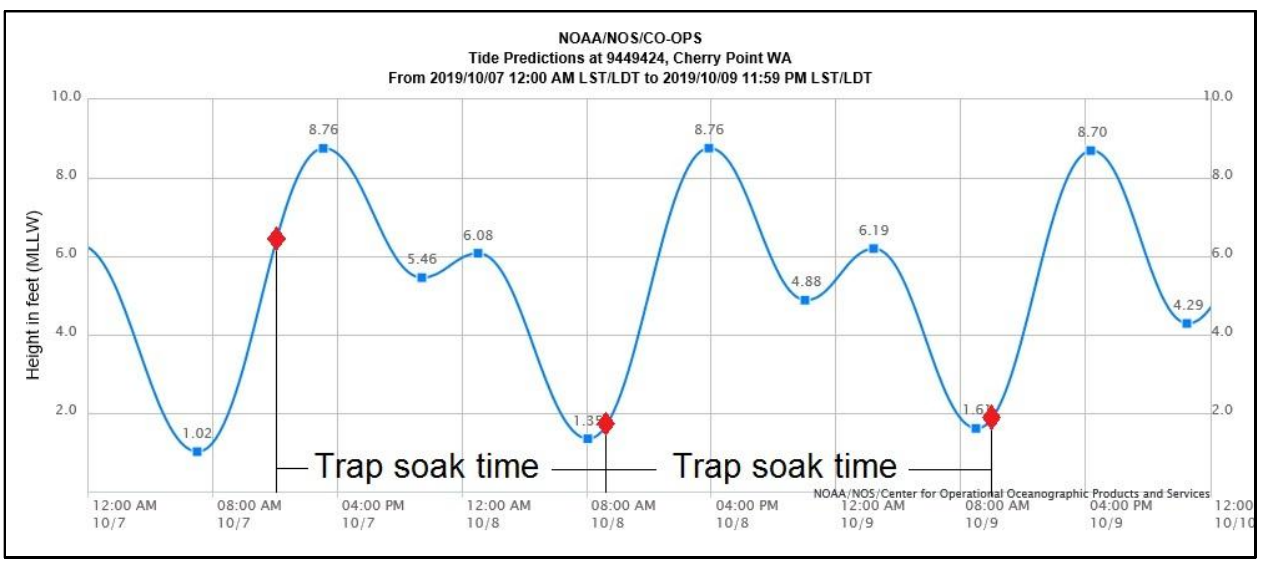

Figure 4. Tidal profiles (height in feet relative to mean lower low water, MLLW) for two consecutive "trap nights" in early October 2019. These represent the environmental conditions during the Lummi Natural Resources Department's invasive European green crab, *Carcinus maenas*, monitoring effort in Lummi Bay, Whatcom County, Washington (Source: National Oceanic and Atmospheric Administration).

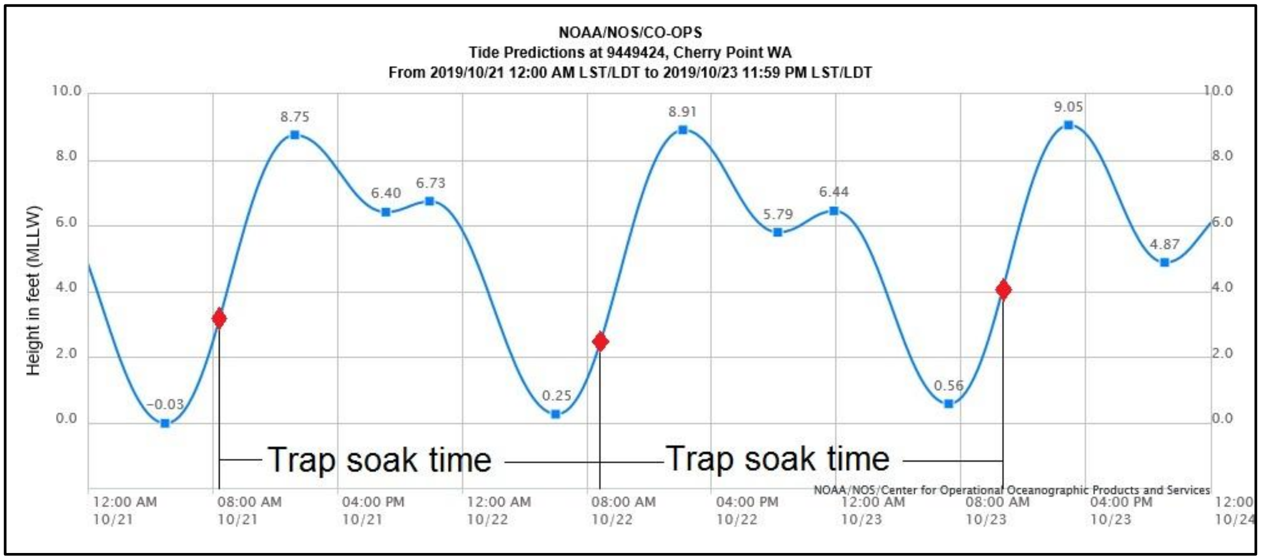

Figure 5. Tidal profiles (height in feet relative to mean lower low water, MLLW) for two consecutive "trap nights" in late October 2019. These represent the environmental conditions during the Lummi Natural Resources Department's invasive European green crab, *Carcinus maenas*, monitoring effort in Lummi Bay, Whatcom County, Washington (Source: National Oceanic and Atmospheric Administration).

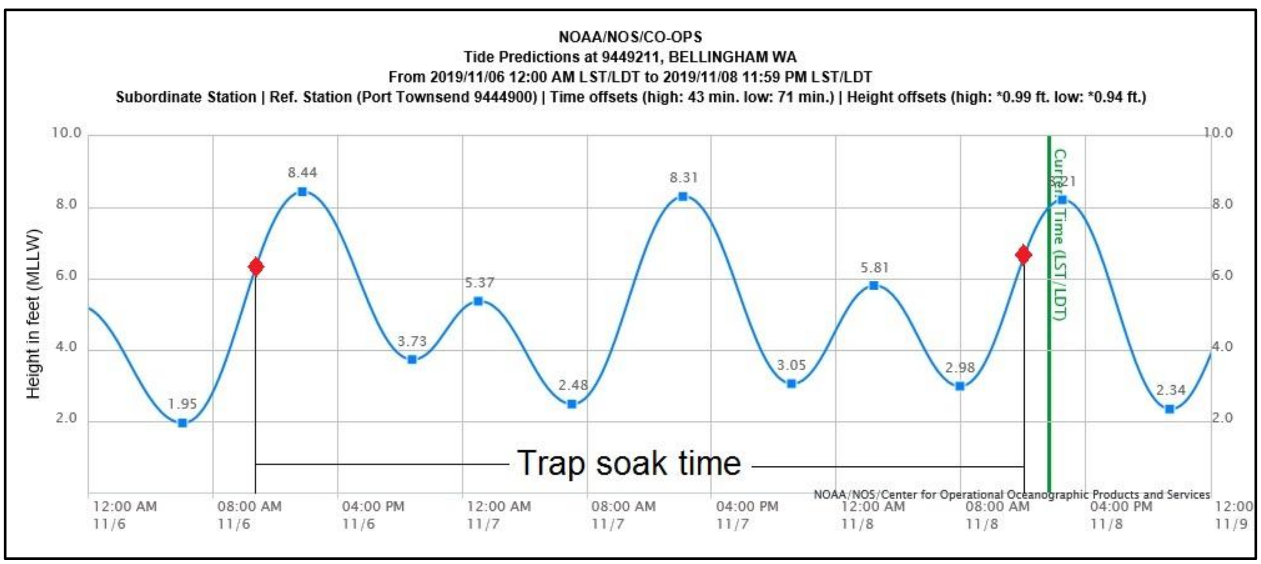

Figure 7. Tidal profiles (height in feet relative to mean lower low water, MLLW) for two consecutive "trap nights" in early November 2019. These represent the environmental conditions during the Lummi Natural Resources Department's invasive European green crab, *Carcinus maenas*, monitoring effort in Portage Bay, Whatcom County, Washington (Source: National Oceanic and Atmospheric Administration).

Figure 8. Personnel from the Lummi Natural Resources Department (LNR) and the Northwest Indian College (NWIC) setting and retrieving standard minnow traps (not pictured) and collapsible, fukui-style traps at the mouth of the Lummi River (left) and inside of the Lummi Sea Pond (right) on October 21, 2019 and October 23, 2019, respectively. For each trap set, besides recording the set/retrieval dates and times, the latitude and longitude were determined and recorded using a hand-held GPS unit [Photo credits: Chelsey Buffington, Washington Department of Fish and Wildlife (WDFW)].

Figure 9. Personnel from LNR and NWIC traversing tidal marshes and tidal sloughs, preferred habitat for the invasive European green crab, *Carcinus maenas*, on Portage Island within Portage Bay, Whatcom County, Washington during November 2019. Except for the Portage Bay monitoring effort, all traps were inspected and processed daily (Photo credit: first author).

Table 1. Lummi Natural Resources Department's 2019 monitoring effort for the invasive European green crab, *Carcinus maenas*, on Lummi Nation reservation tidelands within Lummi Bay, Whatcom County, Washington (see also Figure 3).

Location (S→N)	Trap Set Dates	Trap Style	Total # Traps	Trap Nights
Lummi Sea Pond	October 7, 8, 21 and 22, 2019	Fukui Minnow	12 12	24 24
Kwina South Slough	October 7 and 8, 2019	Fukui Minnow	2 2	4 4
Lummi River Mouth	October 21 and 22, 2019	Fukui Minnow	10 10	20 20
Inner Slough	October 7 and 8, 2019	Fukui Minnow	2 2	4 4
Lummi River Mid	October 7 and 8, 2019	Fukui Minnow	3 3	6 6
Sandy Point Heights	October 7 and 8, 2019	Fukui Minnow	6 6	12 12
East Lummi River	October 21 and 22, 2019	Fukui Minnow	5 5	10 10
Hillaire Road Bridge	October 21 and 22, 2019	Fukui Minnow	5 5	10 10
			Total	**180**

Table 2. Lummi Natural Resources Department's 2019 monitoring effort for the invasive European green crab, *Carcinus maenas*, on Lummi Nation reservation tidelands along Portage Island within Portage Bay, Whatcom County, Washington (see also Figure 4).

Location (W→E)	Trap Set Dates	Trap Style	Total # Traps	Trap Nights
Portage Bay West	November 6, 2019 (2-d soak)	Fukui Minnow	5 5	10 10
Portage Bay South	November 6, 2019 (2-d soak)	Fukui Minnow	5 5	10 10
Portage Bay East	November 6, 2019 (2-d soak)	Fukui Minnow	5 5	10 10
			Total	**60**

Sample processing.–Except for the Portage Bay monitoring effort, all traps were inspected and their contents processed daily (soak time for each trap night ~ 19 to 25 h). Regarding the former, in November 2019, field crew schedule conflicts precluded daily processing; hence, the Portage Bay traps were inspected and their contents processed at the end of two trap nights (soak time ~ 48 h). When processing a trap, the catch was sorted and all animals identified and enumerated. The invasive European green crab was distinguished from native crabs by the EGC's carapace conformation and carapace spine count (Figure 10). When EGC were detected, the invasive crabs were sexed and their size measured in two ways: the total carapace width (CW_{To}) and the "notch" carapace width (CW_{No}) (Figure 11). Across the relevant scientific literature to date, one measurement or the other has been used to characterize the size structure of EGC (Young and Allen 2018). The CW_{To} was measured using Vernier calipers to the nearest 1 mm between the tips of the fifth anterio-lateral spines of the carapace, whereas the CW_{No} was measured to the nearest 1 mm between the spaces or bases of, i.e., the notches between, the fourth and fifth anterio-lateral spines of the carapace (Figures 10 and 11). Whenever possible, all by-catch was identified to the species level then released alive, and all EGC were retained alive for subsequent genetic analysis (Tepolt and Zhang 2019). Finally, except for the Portage Bay monitoring effort, all bait was replaced daily and it should be noted that, after the first day of sampling, the bait was switched from frozen herring to frozen sardines due to ready availability of the latter.

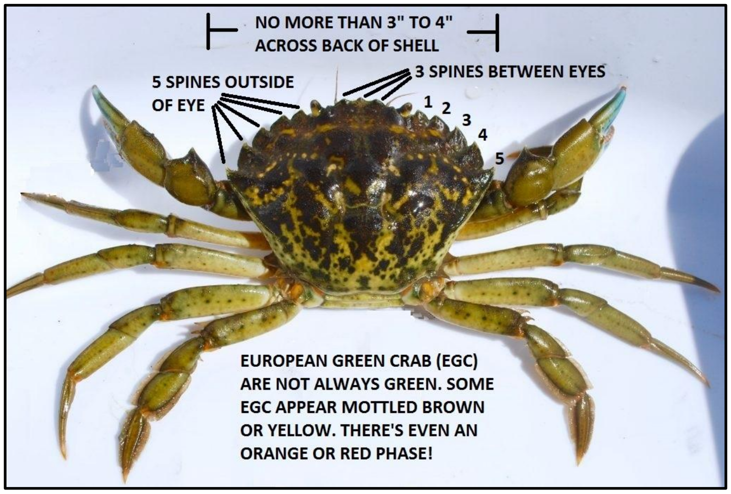

Figure 10. Characteristics used to identify the invasive European green crab (EGC), *Carcinus maenas*. Note the five lateral spines lying outside of each eye (Sources: Gillespie et al. 2015; Young et al. 2017; photo credit: Washington Sea Grant Crab Team).

Figure 11. Processing catch of invasive European green crab (EGC), *Carcinus maenas*, from baited traps set and retrieved on Lummi Nation reservation tidelands within Lummi Bay, Whatcom County, Washington during October 7, 2019 through October 23, 2019. Here, the carapace width of an EGC is being measured to the nearest 1 mm using Vernier calipers (Photo credit: first author).

Data analyses.–A variety of exploratory, descriptive statistics were used to assess the trap catches from Lummi and Portage bays. The relative abundances of foraging female and male EGC were examined by comparing their catch-per-unit-effort (CPUE), which was expressed as the number of female or male EGC per trap night, among sampling locations and trap styles. The CPUE data for female and male EGC were graphically presented (by sampling location and trap style) using box-and-whisker plots. According to Analytical Software (2013), the box "encloses the middle half of the data, bounded by the lower and upper quartiles (i.e., 25% and 75%, respectively). The box is bisected by a line at the value for the median. The vertical lines at the top and bottom of the box are called the whiskers, and they indicate the range of typical data values. Whiskers always end at the value of an actual data point and cannot be longer than 1½ times the size of the box. Extreme values above or below the whiskers are displayed as stars for possible outliers and as circles for probable outliers." Statistical comparisons were then made among data sources. In this case, differences in the mean ranks of CPUE for female and male EGC among sampling locations and trap styles were tested using a non-parametric ANOVA (Kruskal-Wallis test) followed by pair-wise comparisons with Dunn's test, if warranted. Finally, the CPUE data for Lummi Bay (all sampling locations and trap styles combined) were expanded to the number of EGC per 100 trap nights to facilitate tabulated comparisons with existing work elsewhere (e.g., Behrens Yamada and Gillespie 2008 or Pleus 2019).

A number of methods were used to explore how the size structure of EGC might vary over space on Lummi Nation reservation tidelands. Descriptive statistics (mean, measures of variation, median, etc.) for CW_{To} and CW_{No} of EGC (data combined from both trap styles by sample location) were tabulated for easy comparisons between carapace measurements and sampling locations. Furthermore, the size data were graphically presented (by sampling location and EGC sex) using box-and-whisker plots. Differences in the mean ranks of CW_{No} and CW_{To} among sampling locations and sex were then tested using a non-parametric ANOVA (Kruskal-Wallis test) followed by pair-wise comparisons with Dunn's test. The normality of size data was tested by constructing normal probability plots of CW_{To} and CW_{No} by EGC sex in conjunction with applying a Shapiro-Wilk (W) test at $\alpha = 0.05$. If the size data were not normally distributed, as would be indicated by a W statistic approaching 1 and $P > 0.05$, then the size data were natural log (Ln or $\log_e$)-transformed to normalize them. Regression techniques were then used to examine the relationship between the raw or transformed CW_{To} and CW_{No} data and plotted for easy visualization and comparison with other studies (e.g., Gillespie et al. 2015 or Young and Elliott 2018). Finally, at each location where EGC were detected, carapace width frequency histograms were constructed to gain insights on the age of animals captured *sensu* Behrens Yamada et al. (2005) and Behrens Yamada and Gillespie (2008), and for comparison between EGC sexes and sampling locations on Lummi Nation reservation tidelands and elsewhere (Behrens Yamada et al. 2005; McGaw et al. 2011; Gillespie et al. 2015). All statistical analyses were performed using Statistix 10 software (Analytical Software 2013).

Data on by-catch, or species other than the targeted EGC, collected in traps were not rigorously analyzed; rather, the species composition of by-catch was determined for both Lummi and Portage bays. Furthermore, the data were tabulated for comparisons with other studies (e.g., Gillespie et al. 2015) and for archive purposes should marine or estuarine community analyses in the study area be desired in the future.

RESULTS

During October 7, 2019 through October 23, 2019, a total of 64 invasive EGC, 32 females and 32 males, were captured after 180 trap nights on Lummi Nation reservation tidelands within Lummi Bay (all sampling locations and trap styles combined). Forty-one EGC were collected from inside of the Lummi Sea Pond (LSP), whereas 23 EGC were sampled outside (west) of the tide gates at Sandy Point Heights (SPH) (Figures 12 and 13, Table 3, and Appendices 1 and 2). No EGC were captured at sampling locations in the barrier estuary behind the barrier beach (geomorphic terms as defined by Shipman 2008) of Lummi Bay, nor were any EGC detected at Portage Bay in November 2019 (Figures 3 and 4, Tables 3 and 4, and Appendices 1 and 2).

Besides invasive EGC, more than 1,700 other animals were captured in Lummi and Portage bays during the study (Tables 3 and 4). Much of the samplers' time in the field was spent processing the by-catch (Figure 14) which consisted of 13 types of organisms representing multiple families and species of estuarine invertebrates and fishes (Figure 15, Table 3, Appendix 1). Of the 1,691 non-EGC animals collected in Lummi Bay, nearly 60% (*n* = 960) were native shore crabs of the genus *Hemigrapsus*. Staghorn sculpin, *Leptocottus armatus* (*n* = 292), juvenile Dungeness crab, *Metacarcinus magister* (*n* = 263), and unidentified pagurid hermit crabs, *Pagurus* sp. (*n* = 152), comprised the other ~40%. When compared to Lummi Bay, the by-catch diversity at Portage Bay, as indicated by the absolute number of species present (i.e., species richness), was very low. The only recorded by-catch in Portage Bay was the hairy or yellow shore crab, *Hemigrapsus oregonensis* (Table 4, Appendix 1). Not recorded were the abundant crustacean amphipods detected in a man-made channel at Portage Bay East (Figure A2-8, Appendix 2). These were not identified beyond suborder (Amphipoda: Gammaridea) nor were they quantified in the field.

Finally, trap nights resulting in no catch (i.e., empty traps upon inspection and processing) varied by embayment and trap style. For example, in Lummi Bay (all sampling locations combined), six of 90 minnow trap nights (6.7%) resulted in no catch, whereas 11 of 90 fukui trap nights (12.2%) resulted in no catch. Empty traps were even more common in Portage Bay where, all sampling locations combined, 5 of 30 minnow trap nights (16.7%) resulted in no catch and 13 of 30 fukui trap nights (43.3%) resulted in no catch. This variation was more pronounced at the level of individual sampling location. For example, at East Lummi River, only a single minnow trap resulted in no catch out of 20 trap nights (trap styles combined), whereas at Kwina South Slough, five of eight trap nights resulted in no catch, yet four of the five empty traps were the collapsible, fukui-style (Appendix 1).

Figure 12. Invasive European green crab, *Carcinus maenas*, collected on reservation tidelands inside of the Lummi Sea Pond, Lummi Bay, Whatcom County, Washington during October 2019 [Photo credits: Megan Hintz, Lummi Natural Resources Department (LNR), left; Chelsey Buffington, WDFW, right].

Figure 13. Invasive European green crab, *Carcinus maenas*, collected on reservation tidelands at Sandy Point Heights, Lummi Bay, Whatcom County, Washington during October 2019 (Photo credit: Megan Hintz, LNR).

Figure 14. Personnel from LNR and NWIC sorting by-catch along a tidal channel on Portage Island during LNR's monitoring effort of invasive European green crab, *Carcinus maenas*, within Portage Bay, Whatcom County, Washington during November 2019 (Photo credit: first author).

Figure 15. Examples of by-catch collected in baited minnow and fukui-style traps (see also Figure 2) during the Lummi Natural Resources Department's invasive European green crab, *Carcinus maenas*, monitoring effort in Lummi and Portage bays, Whatcom County, Washington. Pictured from left are: an unidentified pagurid hermit crab, *Pagurus* sp., staghorn sculpin, *Leptocottus armatus*, and saddleback gunnel, *Pholis ornata* (Photo credits: Megan Hintz, LNR, left and center; Chelsey Buffington, WDFW, right).

Table 3. Species composition of catches using two styles of baited traps [fukui (FKI) and minnow (MIN)] set overnight (number of trap nights subscripted) at eight locations (listed south to north; see also Figure 3) within Lummi Bay, Whatcom County, Washington during two different tide series from October 7, 2019 through October 23, 2019. LSP = Lummi Sea Pond, KSS = Kwina South Slough, LM = Lummi River Mouth, INN = Inner Slough, ELR = East Lummi River, LRM = Lummi River Mid, SPH = Sandy Point Heights, and HRB = Hillaire Road Bridge. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapside shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Loc. S→N	**BROK**	**CAMA**	**CYAG**	**GAAC**	**HEOR**	**HESP**	**LEAR**	**MEGR**	**MEMA**	**PASP**	**PHOR**	**PLST**	**SAND**	**TECH**	**Total**
LSP															
FKI_{24}	0	12	0	0	24	0	2	0	0	32	0	0	0	0	**70**
MIN_{24}	0	29	0	0	74	0	0	0	0	105	0	0	1	0	**209**
KSS															
FKI_{4}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MIN_{4}	0	0	0	2	2	0	0	0	0	0	0	0	0	0	**4**
LM															
FKI_{20}	0	0	0	0	17	0	26	0	123	2	0	1	0	0	**169**
MIN_{20}	1	0	0	0	63	0	16	0	12	4	1	0	0	1	**98**
INN															
FKI_{4}	0	0	0	0	9	0	5	0	0	0	0	0	0	0	**14**
MIN_{4}	0	0	0	0	3	0	1	0	0	0	0	0	0	0	**4**
ELR															
FKI_{10}	0	0	0	0	2	0	41	0	74	3	0	1	0	0	**120**
MIN_{10}	0	0	0	0	6	0	109	0	3	0	1	0	0	0	**120**
LRM															
FKI_{6}	0	0	0	0	15	0	7	0	6	0	0	0	0	0	**28**
MIN_{6}	0	0	0	0	21	0	2	0	7	2	0	0	0	0	**32**
SPH															
FKI_{12}	0	15	1	0	0	158	14	8	10	0	0	0	0	0	**206**
MIN_{12}	0	8	0	1	0	523	6	2	3	4	0	0	0	0	**547**
HRB															
FKI_{10}	0	0	0	0	22	0	35	0	18	0	0	2	0	0	**77**
MIN_{10}	0	0	0	0	21	0	28	0	7	0	0	1	0	0	**57**
Total	**1**	**64**	**1**	**3**	**279**	**681**	**292**	**10**	**263**	**152**	**2**	**5**	**1**	**1**	**1,755**

Table 4. Species composition of catches using two styles of baited traps [fukui (FKI) and minnow (MIN)] set overnight (number of trap nights subscripted) at three locations (listed west to east; see also Figure 4) along Portage Island within Portage Bay, Whatcom County, Washington during a single tide series from November 6, 2019 through November 8, 2019. PBW = Portage Bay West, PBS = Portage Bay South, and PBE = Portage Bay East. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Loc. W→E	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Total
PBW															
FKI_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
MIN_{10}	0	0	0	0	4	0	0	0	0	0	0	0	0	0	**4**
PBS															
FKI_{10}	0	0	0	0	2	0	0	0	0	0	0	0	0	0	**2**
MIN_{10}	0	0	0	0	50	0	0	0	0	0	0	0	0	0	**50**
PBE															
FKI_{10}	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**1**
MIN_{10}	0	0	0	0	41	0	0	0	0	0	0	0	0	0	**41**
Total	**0**	**0**	**0**	**0**	**98**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**98**

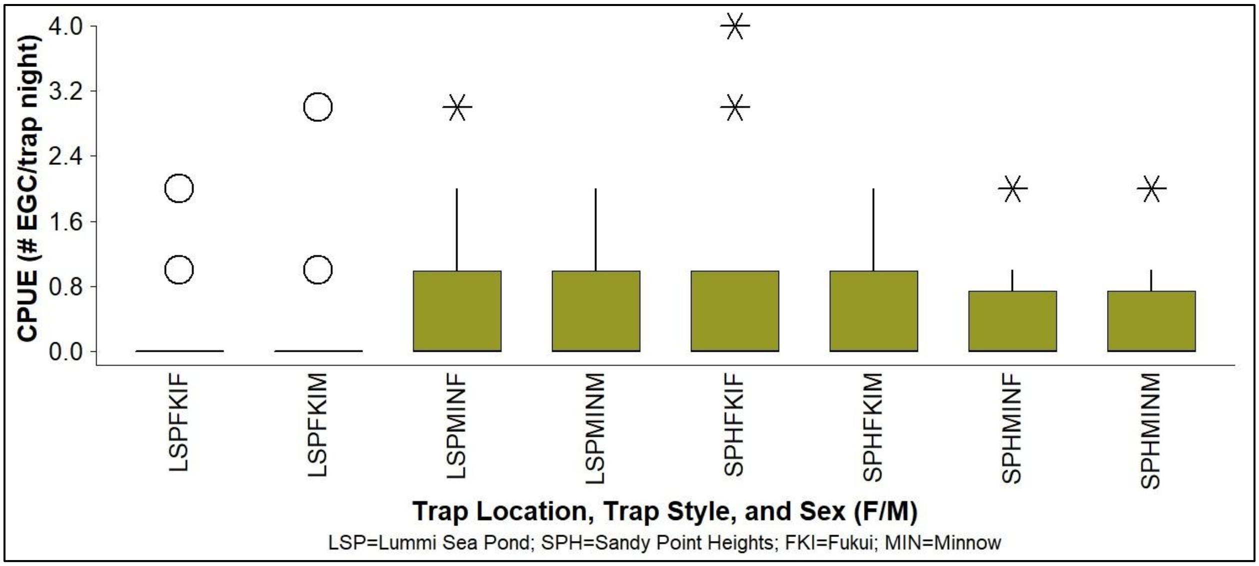

Figure 16. Box-and-whisker plots of relative abundance of female (F) and male (M) invasive European green crab (EGC), *Carcinus maenas*, as indicated by catch-per-unit-effort (CPUE), at two locations [Lummi Sea Pond (LSP) and Sandy Point Heights (SPH)] within Lummi Bay, Whatcom County, Washington using two styles of baited traps [fukui (FKI) and minnow (MIN)] during October 2019. There were no significant differences in the distributions of the groups above (Kruskal-Wallis one-way nonparametric ANOVA; H = 12.53; P = 0.0845). See Materials and Methods section for additional information on interpreting the results.

Table 5. Relative abundance of female (♀) and male (♂) invasive European green crab (EGC), *Carcinus maenas*, as indicated by mean (± SE) catch-per-unit-effort (CPUE; # EGC/trap night), at two locations (Lummi Sea Pond and Sandy Point Heights) within Lummi Bay, Whatcom County, Washington using two styles of baited traps (fukui and minnow) during October 2019.

Sampling Location and Sex	CPUE (# EGC/trap night) by Trap Style: Fukui	CPUE (# EGC/trap night) by Trap Style: Minnow
Lummi Sea Pond		
EGC ♀	0.25 ± 0.11	0.54 ± 0.16
EGC ♂	0.25 ± 0.14	0.67 ± 0.17
Sandy Point Heights		
EGC ♀	0.75 ± 0.39	0.33 ± 0.19
EGC ♂	0.50 ± 0.19	0.33 ± 0.19

Where EGC were captured, the relative abundances of foraging female (♀) and male (♂) *C. maenas*, as indicated by mean (± SE) catch-per-unit-effort (CPUE), were generally consistent across sampling locations and trap styles, ranging from 0.25 ± 0.11 EGC♀/trap night to 0.75 ± 0.39 EGC♀/trap night (Table 5). While collapsible, fukui-style traps did not appear to fish well in the Lummi Sea Pond, a non-parametric one-way ANOVA for CPUEs by sampling location-trap style-EGC sex revealed no significant differences in the mean ranks or distributions of the groups (Kruskal-Wallis test; H = 12.53; P = 0.0845) (Figure 16).

Figure 17. The sexes of invasive European green crab (EGC), *Carcinus maenas*, were distinguished from one another by the shape of their abdominal segments. In the female EGC (left), the segment is broad and rounded, whereas in the male EGC (right), the segment is narrow and shaped like a triangle. Pictured are EGC from the Lummi Sea Pond within Lummi Bay, Whatcom County, Washington (Photo credits: Megan Hintz, LNR).

Irrespective of sex (Figure 17), the sizes of EGC were also generally consistent across locations, with carapace widths averaging about 40 mm to 50 mm wherever the invasive species was sampled (Tables A3-1 and A3-2, Appendix 3). The greatest variation in carapace widths was observed in male EGC from Sandy Point Heights. Nonparametric one-way ANOVAs for both CW_{No} and CW_{To} by sampling location and sex revealed significant differences in mean ranks between the location-sex combinations [Kruskal-Wallis (K-W) test for CW_{No}; $H = 8.36$; $P = 0.0386$, whereas K-W test for CW_{To}; $H = 10.73$; $P = 0.0133$]. For both CW_{No} and CW_{To}, pair-wise comparisons of mean rank carapace widths showed that two groups of sampling location-sex combinations were not significantly different from one another (Figures 18 and 19). Nevertheless, irrespective of carapace width measurement type, the mean rank size of female EGC from Sandy Point Heights was significantly smaller than male EGC from the Lummi Sea Pond at the $\alpha = 0.05$ level (Dunn's test; $Z = 2.638$; Figures 18 and 19).

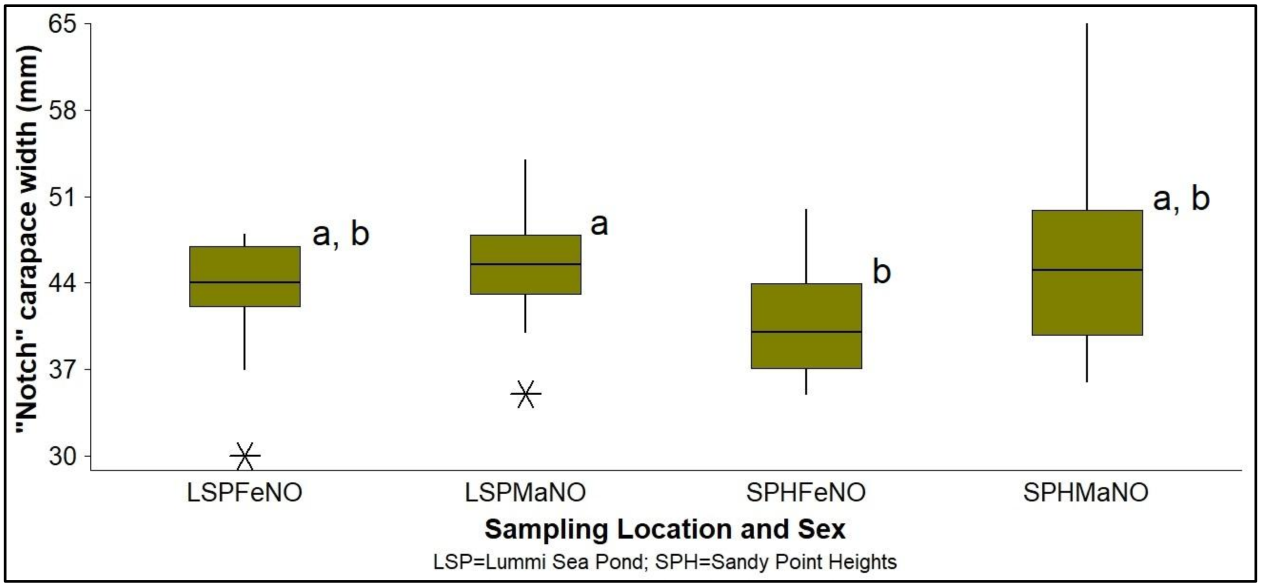

Figure 18. Box-and-whisker plots of "notch" carapace widths (mm) of female (Fe) and male (Ma) invasive European green crab, *Carcinus maenas*, from two sampling locations [Lummi Sea Pond (LSP) and Sandy Point Heights SPH)] within Lummi Bay, Whatcom County, Washington during October 2019. Boxes sharing letters indicate no significant differences at α = 0.05 (Dunn's pair-wise comparisons test; Z = 2.638). See Materials and Methods section for additional information on interpreting the results.

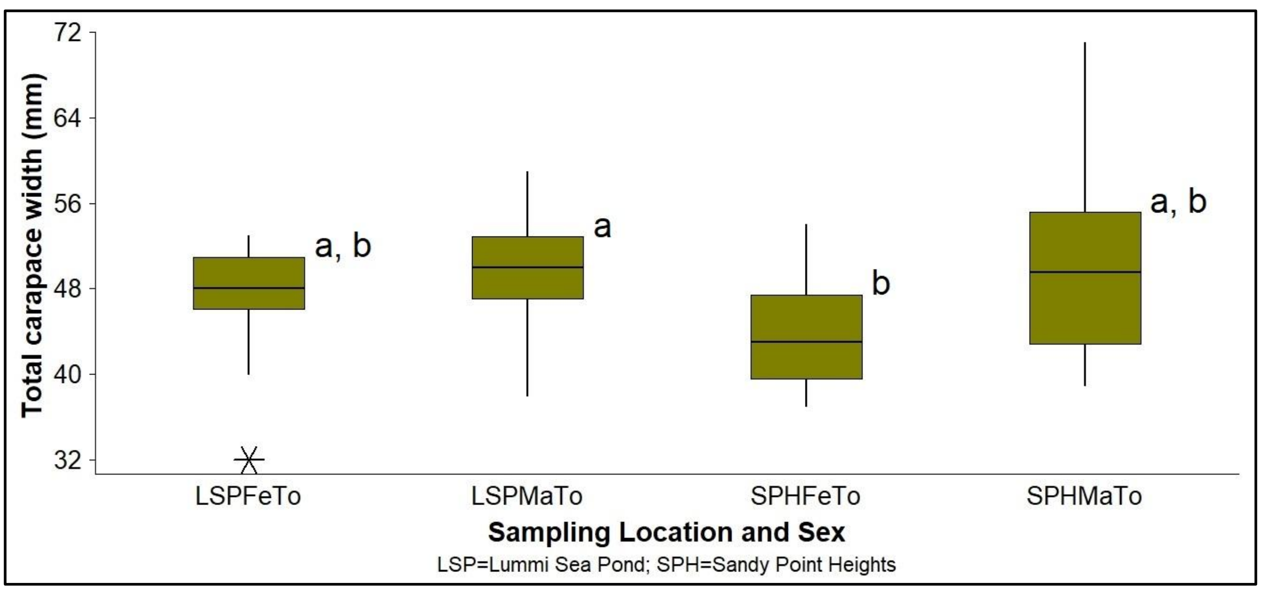

Figure 19. Box-and-whisker plots of total carapace widths (mm) of female (Fe) and male (Ma) invasive European green crab, Carcinus maenas, from two sampling locations [Lummi Sea Pond (LSP) and Sandy Point Heights SPH)] within Lummi Bay, Whatcom County, Washington during October 2019. Boxes sharing letters indicate no significant differences at α = 0.05 (Dunn's pair-wise comparisons test; Z = 2.638). See Materials and Methods section for additional information on interpreting the results.

As might be surmised from the previous two figures, the CW_{To} and CW_{No} of female and male EGC are similar and merely offset from each other by a few millimeters, the female EGC being slightly smaller. When the CW_{To} and CW_{No} for female and male EGC are pooled together for the Lummi Bay sampling locations (i.e., LSP and SPH data combined) and then plotted against each other by sex, a distinct linear relationship appears (Figure 20). After confirming normality in the female CW_{To} and CW_{No} data using a Shapiro-Wilk test ($W > 0.95$; $P > 0.14$), linear regression techniques revealed a very strong relationship between the metrics ($R^2 = 0.99$), one which was also highly significant ($F = 2277.5$; $P < 0.0001$). For female EGC at Lummi Bay (Figure 21), the resulting regression equation was as follows:

$$\text{Female } CW_{No} = 2.0620 + (0.8788 \times \text{Female } CW_{To})$$

On the other hand, the greater variation observed in the male CW_{To} and CW_{No} data (primarily from SPH) required transforming it before applying regression techniques. After natural log (Ln or $\log_e$)-normalizing the male carapace width data (also confirmed by a Shapiro-Wilk test, $W > 0.93$; $P > 0.05$), linear regression indicated a very strong relationship between the Ln- or $\log_e$-transformed metrics ($R^2 = 0.99$), one which was highly significant as well ($F = 2946.7$; $P < 0.0001$). For male EGC at Lummi Bay (Figure 22), the resulting regression equation was as follows:

$$\text{Ln (Male } CW_{No}) = 0.0654 + [0.9596 \times (\text{Ln (Male } CW_{To}))]$$

These equations will be useful for converting between CW_{To} and CW_{No} when comparing the results of this study with others (Gillespie et al. 2015; Young and Elliott 2018).

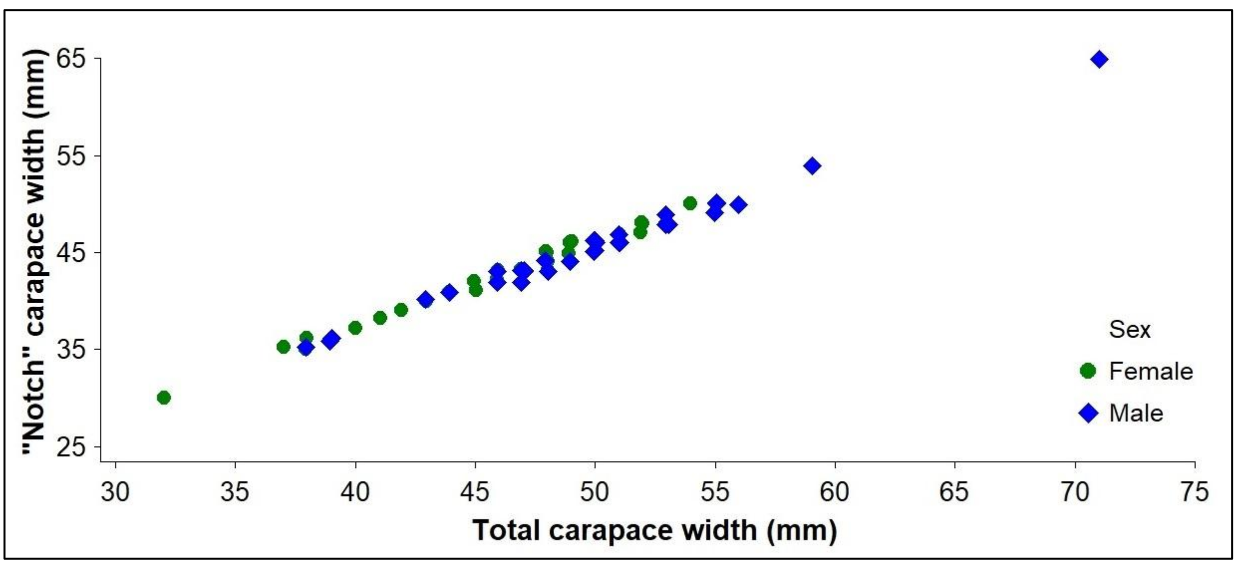

Figure 20. Relationship between the total carapace width (mm) and "notch" carapace width (mm) in female (green circle) and male (blue diamond) invasive European green crab, *Carcinus maenas*, collected within Lummi Bay, Whatcom County, Washington during October 2019. Total carapace width was measured between the tips of the fifth anterio-lateral spines to the nearest 1 mm, whereas the "notch" carapace width was measured between the spaces and bases of the fourth and fifth anterio-lateral spines (see also Figure 10).

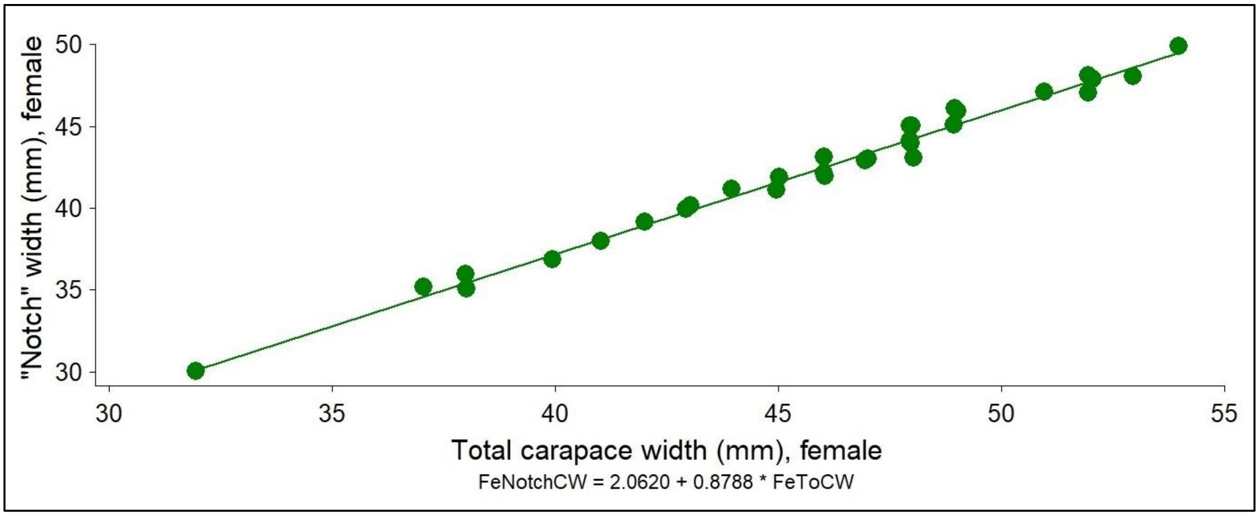

Figure 21. Relationship between the total carapace width (mm) and the "notch" carapace width (mm) in female invasive European green crab, *Carcinus maenas*, collected within Lummi Bay, Whatcom County, Washington during October 2019. After confirming normality in the carapace width data (*W* > 0.95; *P* > 0.14), the linear regression equation identified above indicated a very strong relationship between the metrics (R^2 = 0.99), one which was also highly significant (*F* = 2277.5; *P* < 0.0001).

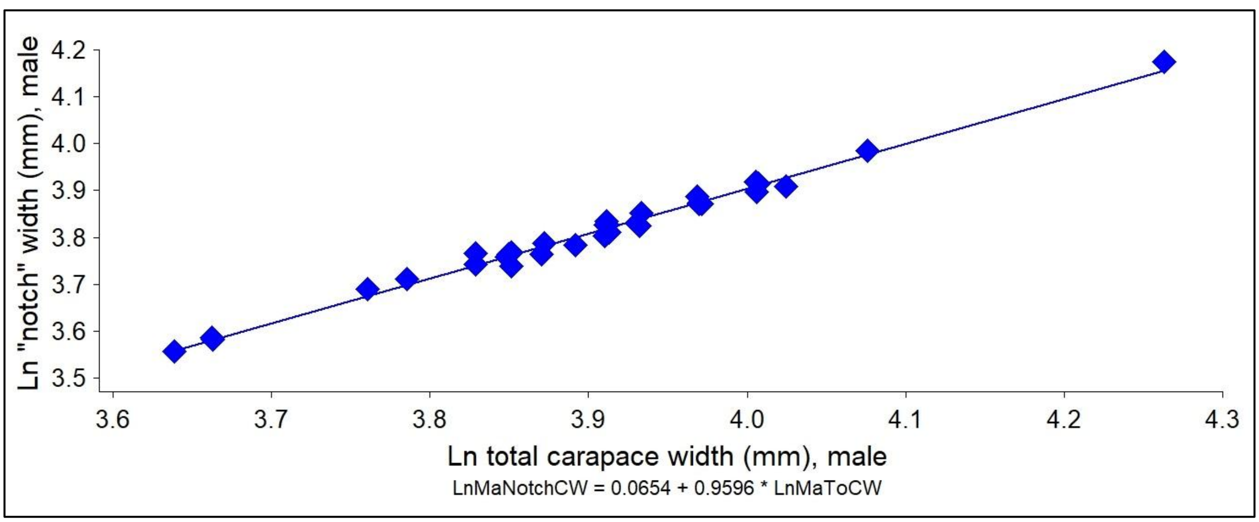

Figure 22. Relationship between the natural log (Ln or $\log_e$) of the total carapace width (mm) and the $\log_e$ "notch" carapace width (mm) in male invasive European green crab, *Carcinus maenas*, collected within Lummi Bay, Whatcom County, Washington during October 2019. After $\log_e$-normalizing the carapace width data (*W* > 0.93; *P* > 0.05), the linear regression equation identified above indicated a very strong relationship between the $\log_e$ metrics (R^2 = 0.99), one which was also highly significant (*F* = 2946.7; *P* < 0.0001).

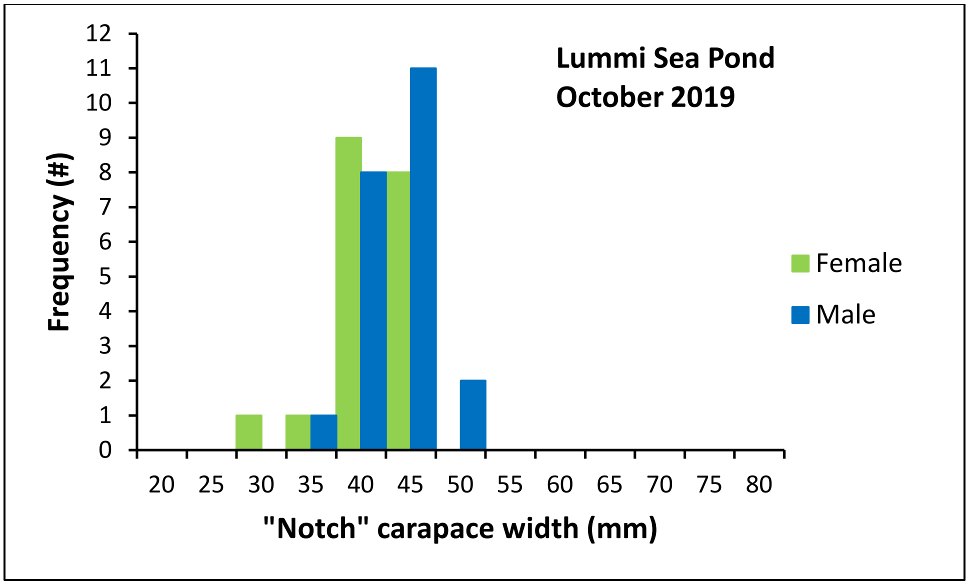

Figure 23. Frequency distribution for "notch" carapace widths (mm) of female (green) and male (blue) invasive European green crab (EGC), *Carcinus maenas*, collected inside of the Lummi Sea Pond during the Lummi Natural Resources Department's EGC monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019.

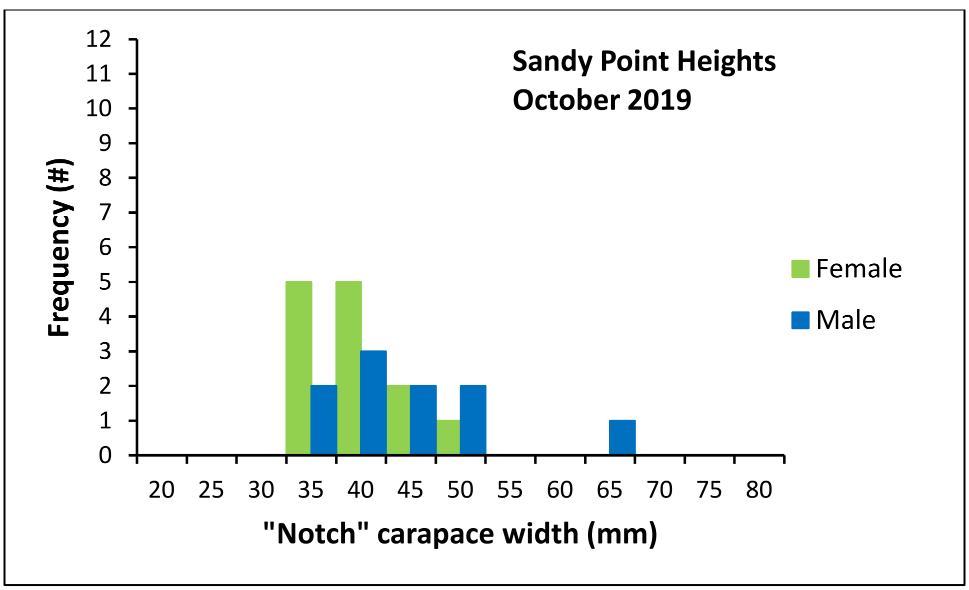

Figure 24. Frequency distribution for "notch" carapace widths (mm) of female (green) and male (blue) invasive European green crab (EGC), *Carcinus maenas*, collected at Sandy Point Heights during the Lummi Natural Resources Department's EGC monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019.

Size frequency histograms clearly revealed two EGC year classes being present at Lummi Bay: one dominated by individuals ranging from 30 mm to 50 mm CW_{No}, and the other, represented by a single crab measuring > 60 mm CW_{No} (Figures 23 and 24). No significant differences were detected in carapace width distributions (CW_{To} or CW_{No}) between the sampling locations and sexes (Kolmogorov-Smirnov tests, $P > 0.05$).

DISCUSSION

After more than a decade, Behrens Yamada and Gillespie's (2008) concerns have finally been realized: as predicted by Behrens Yamada et al. (2017), with increased vigilance and monitoring by experienced professionals and trained volunteers (e.g., Grason et al. 2018), additional concentrations of invasive EGC are now being detected in the Salish Sea (Pleus 2019), Lummi Bay being the most recent example (Mueller 2019; Neumeyer 2019). While the EGC catch rates reported here were lower than those reported for coastal British Columbia, Canada (Gillespie et al. 2015), the Lummi Bay CPUE (all sampling locations combined), when expanded to 100 trap nights, is on par with the early invasion of Willapa Bay, Washington at its peak 20 years ago (35–43 EGC/100 trap nights; Behrens Yamada and Gillespie 2008), and currently makes the relative abundance of the Lummi Bay population the second highest reported in the State of Washington (Table 6). These findings beg two questions: Where did the EGC in Lummi Bay come from? And how long has the invasive species been here?

Table 6. Relative abundance of invasive European green crab (EGC), *Carcinus maenas*, expressed as catch-per-unit-effort or CPUE (= number of EGC per 100 trap nights), within Lummi Bay, Whatcom County (shaded) compared to other inland marine and coastal areas of Washington State. Trap nights = combined number of fukui and minnow traps set overnight at selected locations [sources of data other than Lummi Bay: Akmajian (2018) and Pleus (2019)].

Capture location (listed north to south)	County	Trap nights	Number EGC captured	CPUE (# EGC/100 trap nights)
Drayton Harbor	Whatcom	553	38	6.87
Lummi Bay	**Whatcom**	**180**	**64**	**35.6**
Mud Bay, Chuckanut	Whatcom	251	3	1.19
Westcott Bay, San Juan Island	San Juan	895	6	0.67
Samish Bay	Skagit	36	4	0 *
Padilla Bay	Skagit	1,085	6	0.55
Wa'atch River Valley, Makah	Clallam	~2,000	968	~ 48
Dungeness Spit	Clallam	8,885	222	2.50
Sequim Bay	Clallam	957	3	0.31
Kala Point and Scow Bay	Jefferson	900	2	0.22
Lagoon Point, Whidbey Island	Island	412	3	0.73

*A CPUE (#EGC/100 trap nights) for Samish Bay was not calculated since these specimens were found incidentally by a shellfish grower on commercial shellfish bed(s).

As of this writing, the original source of the Lummi Bay EGC has yet to be determined. More information will become available in 2020 following rigorous genetic analysis of the Lummi Bay samples by Tepolt and Zhang (2019). Genetic connectivity of the Lummi Bay EGC to a source along the northeastern Pacific Coast is certain, especially given the body of evidence for oceanic current-driven larval dispersal linking reproducing concentrations or populations of EGC here at large spatial scales (Tepolt et al. 2009); however, it remains uncertain whether Tepolt and Zhang's (2019) upcoming work will provide finer resolution than the coastal level, in terms of spatial scale, on the question of where the Lummi Bay EGC originated from.

Physical oceanographic processes that could influence distribution of EGC at the local level have been well-documented for Lummi Bay and adjacent areas. In fact, multiple circulation studies were conducted by Heath et al. (1975) both inside and outside of the Lummi Sea Pond shortly after its construction. These authors found that, during certain springtime flood tides, surface water moves from Hale Passage, between Lummi Island and the Lummi Peninsula (Figure 1), in a north-northeasterly direction toward the northern and eastern shores of Lummi Bay. This would partially explain the occurrence of EGC at Sandy Point Heights (Figure 3). Inside of the Lummi Sea Pond, depending on the season, water circulation is affected by prevailing southerly winds and the incoming current (and tidal pressure behind it) through the southeastern inlet gates (Heath et al. 1975). Under prevailing conditions during summer, in just 22 hours, incoming EGC propagules could reach the northeastern corner of the pond, the location where immature and maturing EGC were trapped (Figures 3 and A2-7, Appendix 2). Moving forward, Heath et al.'s (1975) detailed review of the physical oceanographic processes affecting the Lummi Bay area should be used to inform LNR's EGC monitoring efforts.

Determining the temporal extent of the EGC invasion on Lummi Nation reservation tidelands is more tenable. To reiterate, irrespective of carapace width measurement, the size structures of EGC in Lummi Bay (Figures 26 and 27) suggest that there are two year classes present. The first, characterized by a single, sexually mature male EGC measuring ≥ 65 mm carapace width, is aged ≥ 1 year suggesting an original settlement date during 2017/2018 (Behrens Yamada et al. 2005, 2017; Gillespie et al. 2015; Young and Elliott 2018). The other, the dominant year class, is characterized by multiple individuals of both sexes ranging from 30 mm to 59 mm carapace width (Figures 26 and 27). These are considered 0-age or young-of-year and likely settled out of the plankton during 2018/2019 (Behrens Yamada et al. 2005, 2017; Gillespie et al. 2015). Given these results, the EGC expansion into Lummi Bay should be considered a relatively recent event.

The sizes of EGC observed in Lummi Bay (Figures 26 and 27) were consistent with EGC populations both inside its native range in Europe and those south of the U.S.–Canada Boundary in the northeast Pacific (Behrens Yamada et al. 2005; McGaw et al. 2011; Young and Elliott 2018), yet generally smaller than the sizes of EGC along coastal British Columbia (McGaw et al. 2011; Gillespie et al. 2015). Ostensibly, the latter finding is due to the "temperature-size rule" for cold-blooded animals, i.e., individuals of the same species existing under cooler temperature regimes tend to grow larger than individuals existing under warmer ones (Kelley et al. 2015).

The fact that no EGC were detected further inland, i.e., behind the barrier beach upstream of the mouth of the Lummi River, is both encouraging and somewhat expected. For example, the upstream hydrodynamics at Lummi River Mid (LRM), East Lummi River (ELR), and Hillaire Road Bridge (HRB) (Figure 3) are characterized by higher velocity flows compared to locations offshore of the barrier beach (personal observations). The conditions upstream would likely impair the ability of EGC to locate and handle prey (Robinson et al. 2011), possibly limiting the species expansion beyond its preferred habitat of "quiet" sloughs, tidal channels, and marshes (Jensen et al. 2007; Behrens Yamada and Gillespie 2008; Grason et al. 2018; WSG 2019).

Another possible reason why EGC failed to "fully realize their potential distribution" (*sensu* Jensen et al. 2007) in Lummi Bay is predation by and competition with native species such as the staghorn sculpin (Figure 15) and Dungeness crab, both conspicuously present (and often abundant) where EGC were absent in the bay and barrier estuary (Table 3, Appendix 1). Indeed, biotic resistance and the commensurate role of highly diverse, native benthic communities (Figure 25) have been documented throughout the introduced range of EGC in the continental U.S., and may provide some level of ongoing, natural control of the invasion on Lummi Reservation tidelands. On the other hand, if *C. maenas* colonizes Portage Bay, where no EGC have been detected (yet), the lack of a diverse community of organisms there might favor the invader to the detriment of native species (Hunt and Behrens Yamada 2003; de Rivera et al. 2005; Jensen et al. 2002, 2007; Kimbro et al. 2009).

Figure 25. Highly diverse, native benthic communities may provide biotic resistance to the invasion of the European green crab, *Carcinus maenas*, in the Salish Sea. The painting above depicts a native Olympia oyster, *Ostrea lurida*, reef somewhere in the northeast Pacific (Source: Partnership for Coastal Watersheds).

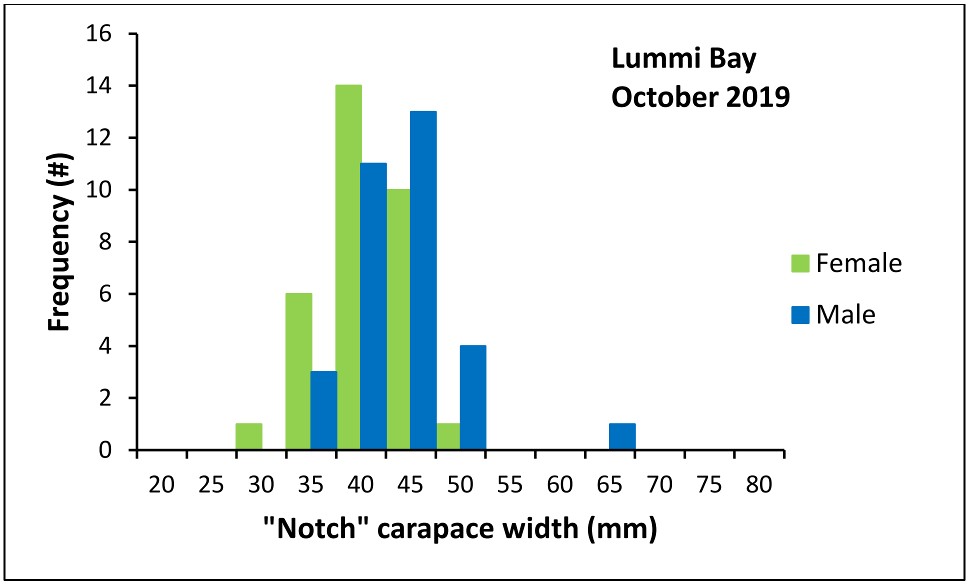

Figure 26. Frequency distribution for "notch" carapace widths (mm) of female (green) and male (blue) invasive European green crab (EGC), *Carcinus maenas*, collected within Lummi Bay, Whatcom County, Washington (Lummi Sea Pond and Sandy Point Heights combined) during the Lummi Natural Resources Department's EGC monitoring effort in October 2019.

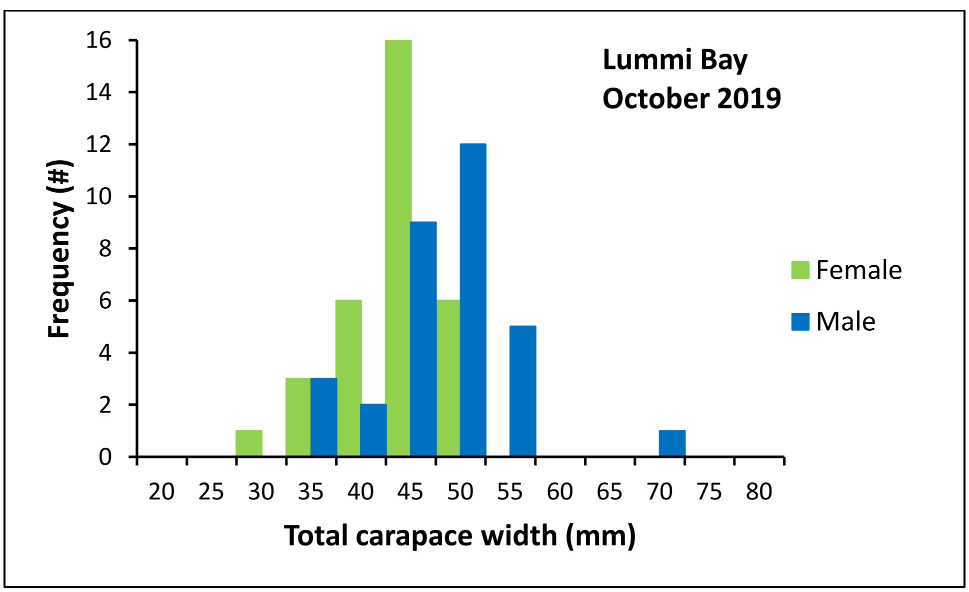

Figure 27. Frequency distribution for total carapace widths (mm) of female (green) and male (blue) invasive European green crab (EGC), *Carcinus maenas*, collected within Lummi Bay, Whatcom County, Washington (Lummi Sea Pond and Sandy Point Heights combined) during the Lummi Natural Resources Department's EGC monitoring effort in October 2019.

MANAGEMENT IMPLICATIONS

Lummi Nation policy makers and LNR managers have much to consider with respect to the recent findings of EGC on reservation tidelands. Local authorities, the research and maritime business communities, including commercial fishermen, and the public should remain vigilant, especially given the multiple pathways in which *C. maenas* has expanded its range (Carlton and Cohen 2003). Indeed, a review of the history of the spread of EGC worldwide suggests that it is not a matter of questioning if negative impacts occur once the invader is detected; rather, it is a case of understanding when or how the negative impacts will occur once EGC is established (Kulhanek et al. 2011). Furthermore, the nature and degree of these impacts will differ from one location to another, reducing the ability of natural resource managers and scientists to accurately predict the outcomes of responses to the EGC invasion (Howard et al. 2018).

In terms of responding, given the scope and scale of the problem in the northeast Pacific (e.g., Tepolt et al. 2009), there are simply no alternatives to coordinating with others across jurisdictional lines, sharing resources (if possible), and adopting an ethos of "many hands make light work". For example, WDFW, the Department of Fisheries and Oceans Canada, and the Puget Sound Partnership recently developed a cross-border agreement to coordinate and collaborate on their agency responses to findings of EGC that might affect the shared waters of the Salish Sea (Drinkwin et al. 2019). Expanding on this collaborative model to include the Puget Sound Treaty Tribes, British Columbia's First Nations, or other equally relevant government entities will improve the chances of a successful response to the EGC invasion. In the meantime, LNR should devote appropriate resources to gain a better understanding of, and to plan for, the following items pertaining to Lummi Nation reservation tidelands:

1) The Lummi Sea Pond as a potential sole source of EGC;
2) Potential impacts to crabs and clams, i.e., how EGC might regulate the local benthic community;
3) Potential impacts to habitat, i.e., how EGC might act as an ecosystem engineer;
4) Trapping and removal of EGC on Lummi Nation reservation tidelands; and
5) Novel uses for EGC should *C. maenas* become firmly established despite LNR and others' attempts to thwart the invasion.

The remainder of this document will address each of the items above and provide some actions for consideration by Lummi Nation policy makers and LNR managers.

The Lummi Sea Pond: larval retention and the incubator effect.–The Lummi Sea Pond, which is visible from space, is an artificial impoundment within Lummi Bay that encompasses an area of about 750 acres (Figures 1 and 3). At the time of its construction (late 1960s), the Lummi Sea Pond was a coastal engineering feat – one that would not likely be repeated today – and was originally intended for commercial aquaculture purposes (EDA 1970; Sampson 2018). Two production-scale hatcheries lie along the dike road encompassing the Lummi Sea Pond: one is for rearing bivalve shellfish, the other is dedicated to the husbandry of Pacific salmon, *Oncorhynchus* sp. Seawater enters and exits the system through four different gated sections of the earthen, dike wall that surrounds the pond (Heath et al. 1975). More than 20 individual tide gates (>10 "mirrored" pairs) are distributed among the four sections; approximately half of these are not functioning properly or are in need of repairs. In the past, Lummi Nation tribal members regularly dredged the Lummi Sea Pond to commercially harvest shellfish, e.g., hard-shell clams (Family Veneridae), growing on the bottom (Dolphin 2002). The fishermen's dredge spoils, mostly empty shells, were habitually deposited in a limited number of locations inside of the Lummi Sea Pond where they remain today (Flavian Point, Lummi Shellfish Hatchery Manager; personal communication, December 13, 2019).

What relevance do the existing conditions and shellfish growing history at the Lummi Sea Pond have on EGC there? Without significant or efficient flushing of its contents, EGC larvae will likely be retained in the Lummi Sea Pond, and will be subject to increased spring- and summertime temperatures, promoting rapid larval development and growth of the species (Behrens Yamada et al. 2005, 2008). In essence, the Lummi Sea Pond will act as a very large incubator for EGC, especially given its water quality, the ample available shelter and habitat, and the ready source of bivalve food from decades of shellfish aquaculture and natural shellfish production in the pond (Dolphin 2002). If left unchecked, the EGC in Lummi Sea Pond might therefore become a single source population that spreads seed to appropriate habitats in neighboring inland marine areas (Behrens Yamada and Gillespie 2008; Banas et al. 2009; Tepolt et al. 2009; Behrens Yamada et al. 2017).

Several years ago, an analogous situation arose in northern California where a similarly isolated system exists near San Francisco, the location of the West Coast's original founder population of EGC (Carlton and Cohen 2003; Tepolt et al. 2009; Kelley et al. 2015). The Seadrift Lagoon in Bolinas, Marin County is an artificial impoundment (~30 acres) that abuts Stinson Beach, the barrier separating Bolinas Lagoon, a barrier estuary, from Bolinas Bay (Figure 28). *Carcinus maenas* first colonized the system in the early 1990s and within 20 years, the Seadrift and Bolinas lagoons had two of the highest densities of EGC ever observed in the northeast Pacific (Tepolt et al. 2009; Kelley et al. 2015). Despite a recent effort by researchers and local volunteers to reduce the EGC population there, the Seadrift Lagoon population boomed, reaching ~300,000 individual crab (or a density of ~2.5 crab/m^2), mostly due to unexpected ecological outcomes benefitting the invader, but also in part because of the years-long delay between first documenting the presence of EGC and taking appropriate, timely action to reduce its impact (Fimrite 2017).

Following is a partial list of management options and responses to consider, in no particular order or priority ranking, for addressing the colonization of EGC inside of the Lummi Sea Pond. Of course, any response on the water must be evaluated by assessing its potential impact to existing Lummi shellfish and finfish hatchery operations and production schedules at the pond:

1) Drain or partially drain the Lummi Sea Pond, preferably during winter, for a sufficient period of time to maximize mortality of EGC left dewatered in the pond;
2) Monitor presence of EGC at artificial or complex habitats left over from historic aquaculture practices at the Lummi Sea Pond, e.g., old oyster beds, underwater structures, or empty shell piles and rubble;
3) If warranted (and if possible), reduce or remove aforementioned artificial or complex habitats that might serve as shelter for EGC inside of the pond;
4) Replace or repair non-functioning tide gates, returning them to their original condition and efficiency *sensu* Heath et al. 1975, to reduce the incubator effect at the Lummi Sea Pond and to promote the establishment of a highly-diverse, native benthic community, increasing the resilience to EGC (Conkerton et al. 2017); and
5) Conduct study of most effective sampling/removal method(s) inside of the pond, especially one(s) that target female EGC or ovigerous crab.

Figure 28. Seadrift Lagoon (at left), an artificial impoundment of approximately 30 acres within the larger Bolinas Lagoon (center right), Marin County, California. This coastal system is analogous to the Lummi Sea Pond and Lummi Bay, Whatcom County, Washington with respect to the invasion of European green crab (EGC), *Carcinus maenas*. The history, environmental conditions, and EGC status at Seadrift Lagoon can inform the Lummi Natural Resources Department's response to EGC at the Lummi Sea Pond and elsewhere on Lummi Nation reservation tidelands (Photo credit: U.S. Army Corps of Engineers).

EGC as benthic community regulator: impacts to clams and crabs.–While the ecological implications of the northeast Pacific EGC invasion have been understood for over 20 years (Jamieson et al. 1998; Grosholz et al. 2000), it has only been in the last decade or so that researchers have attempted to shed light on how EGC might disrupt normal predator-prey interactions and ecosystem function in the region (e.g., Kimbro et al. 2009). Predictably, the invasion history of EGC demonstrates that native bivalve molluscs and crabs will be significantly impacted, through predation or competition, if the invader becomes established and is left unchecked (Grosholz et al. 2000; Kulhanek et al. 2011). For example, in Bodega Bay Harbor, California, significant decreases in the abundances of native clams, *Nutricola* spp., were observed only three years after the introduction of EGC (Grosholz et al. 2000). Likewise, in Tasmania, Australia, experimental out-planting of juvenile hard-shell clams, *Katelysia scalarina* (Family Veneridae), resulted in significantly lower survival of the economically-valuable *K. scalarina* in areas where invasive EGC occurred compared to areas without the predator. The increase in clam mortality was attributed, reasonably, to the invader since native clam predators were already present in both areas (Walton et al. 2002). But perhaps nowhere is the impact to clam fisheries more apparent than on the Atlantic coast of the U.S., where *C. maenas* was not only implicated in widespread declines of the commercially-harvested Eastern soft-shell clam, *Mya arenaria* (Conkerton et al. 2017), but also in phenotypic changes in "life-saving" traits of the prey species (Whitlow 2010).

Unlike the impacts to clams, the empirical evidence for negative impacts to northeast Pacific crabs is somewhat mixed. For example, besides the reduction in native clams, *Nutricola* spp., Grosholz et al. (2000) reported a several-fold decline in abundance of the native hairy or yellow shore crab, *Hemigrapsus oregonensis*, after EGC became established in Bodega Bay, California. Alternatively, the results of other field and laboratory research on competitive interactions between EGC and native crabs for food and shelter generally favor the latter (e.g., Jensen et al. 2002, 2007; de Rivera et al. 2005), which is encouraging. Both extrinsic and intrinsic factors influence the outcomes of such competitive interactions, though, and of course, whether or not the crabs even overlap in real time and space (McDonald et al. 2001; Jensen et al. 2007; Behrens Yamada et al. 2010). For example, in competitive interactions between similar size EGC and the native *H. oregonensis*, when dueling for hard, complex shelter (e.g., bivalve shell), the native species consistently dominated the contests; but, the invasive EGC is more adept at burrowing in soft sediments compared to *H. oregonensis*, prompting the question of whether EGC is necessarily dependent on hard, complex shelter for protection from predators in the first place (Jensen et al. 2002). Furthermore, when assessing feeding trials that examined differences between EGC and northeast Pacific crabs, prey type (e.g., hard- or thick-shelled molluscs vs. soft- or thin-shelled molluscs) ostensibly had a greater influence over the outcomes vs. the contestants themselves (Kimbro et al. 2009; Behrens Yamada et al. 2010). In the end, irrespective of the resource (or quality thereof) being dueled over, the outcome of any contest will likely depend on body size, physical attributes (e.g., claw size), or age differences between crabs, with the larger or more experienced individual having a superior advantage over the smaller or naïve one, but only if their distributions overlap in the wild (McDonald et al. 2001; Jensen et al. 2007; Behrens Yamada et al. 2010).

EGC as ecosystem engineer: impacts to nearshore habitat.–The invasive EGC is a pernicious burrower and is capable of excavating large quantities of soft sediments while seeking food or shelter (Ropes 1968; Young et al. 2017). Although EGC were not actually observed digging or residing in burrows within Lummi Bay during LNR's monitoring effort, there was ample evidence of these activities in the upper intertidal habitats where EGC were captured in October 2019 (Figures 29 and 30). Burrowing activity and sediment excavation were also apparent in sampling locations where EGC were not captured; after all, these behaviors are common in native crabs, too (e.g., McGaw 2005). While normal or natural biotic perturbations to marine sediment processes are not likely to unduly impair ecosystem function on Lummi Nation reservation tidelands, the escalation of burrowing activities by a bourgeoning population of EGC could lead to changes in sediment chemistry and altered nutrient dynamics (Grundmanis and Murray 1977), ultimately affecting water quality in the area. Furthermore, the corresponding increases in suspended sediments near shore could place stressors on valued ecosystem components like forage fishes (Families Clupeidae and Osmeridae) (Parks et al. 2013) and eelgrass, *Zostera marina* (Thom et al. 2011).

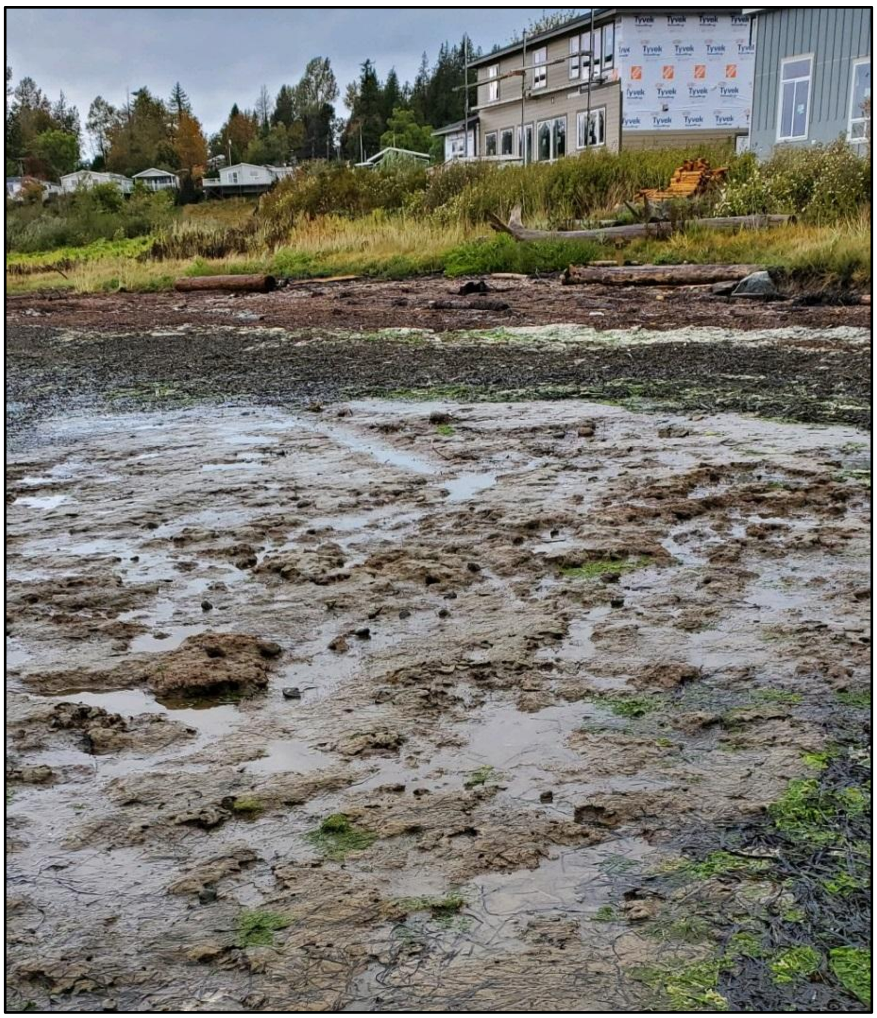

Figure 29. Evidence of burrowing or excavating (holes, etc.) in the soft sediments of the upper intertidal zone at Sandy Point Heights, Whatcom County, Washington where invasive European green crab (EGC), *Carcinus maenas*, were captured during October 2019. It was not possible to attribute the pictured features to EGC or to native crabs without further destroying the habitat (Photo credit: Daniel Washington, Northwest Indian College).

Figure 30. Evidence of burrowing or excavating (holes, etc.) in the soft sediments of an intertidal marsh bank within the Lummi Sea Pond, Whatcom County, Washington where invasive European green crab (EGC), *Carcinus maenas*, were captured during October 2019. It was not possible to attribute the pictured features to EGC or to native crabs without destroying the habitat (Photo credit: second author).

Concerning EGC impacts to eelgrass, perhaps more troubling than future changes to its growing environment is the invader's destructive behavior of uprooting eelgrass shoots within eelgrass beds (Malyshev and Quijón 2011). For example, in the southern Gulf of St. Lawrence, Canada, Garbary et al. (2014) detected a 75% reduction in eelgrass shoot density within a single eelgrass bed over a three-month period, the result of EGC cutting and tearing its way through the basal ends of eelgrass shoots within the bed. And now, closer to home, during the course of this writing, Howard et al. (2019) reported similar habitat destruction and losses of eelgrass across the U.S.–Canada Boundary in coastal British Columbia where EGC is abundant. Left unchecked, losses of eelgrass due to the destructive behavior of EGC will send ripple effects through nearshore ecosystems ultimately affecting fish communities that rely on such habitat for some or all of their life histories (Matheson et al. 2016). Within the Salish Sea, these findings have particular relevance to Pacific salmon restoration efforts (Kennedy et al. 2018).

To summarize, should EGC become firmly established on Lummi Nation reservation tidelands, there will be negative impacts: some subtle, others, completely glaring (Kulhanek et al. 2011). For example, Walton et al.'s (2002) work suggests that shellfish stock enhancement efforts by the Lummi Shellfish Hatchery could be greatly impaired by EGC predation. Similarly, any nearshore habitat restoration projects undertaken by LNR must account for the influence of EGC predation on the perceived success of such projects (Conkerton et al. 2017). Following is a partial list of management options and responses to consider, in no particular order or priority ranking, for addressing the potential impacts of EGC on the biotic community and nearshore habitats of Lummi Nation reservation tidelands:

1) Revisit Dolphin et al.'s (2010) Lummi Intertidal Baseline Inventory, or LIBI study, to inform Before-After Control-Impact (BACI) style assessments (Smokorowski and Randall 2017) of valued resources on reservation tidelands. Some examples of updated baseline information could include, but are not limited to, current databases or maps of the distribution and densities of:
    a. Eelgrass beds, geo-referenced via aerial surveys (e.g., drone or airplane);
    b. Bivalve molluscs (clams, mussels, and oysters), geo-referenced using established LNR foot surveyor protocols (e.g., Dolphin 2013 or Hintz 2018) and with particular attention paid to vulnerable life stages (i.e., juveniles) subject to EGC predation *sensu* Walton et al. (2002); and
    c. Forage fishes, or forage fish spawning habitat, and juvenile Pacific salmonids, geo-referenced using established LNR beach seining protocols or similar (e.g., Dolphin et al. 2010).
2) Conduct analyses of impacts to Lummi shellfish and salmon hatchery operations and production schedules from EGC predation/behavior and/or LNR's response to the species. For example, were EGC to consume hatchery-produced and out-planted Manila clam (*Venerupis philippinarum*) seed, what are the true costs – in terms of time, people, utilities, and materials – associated with that loss? Or, if in response to EGC, were the department to shut down either hatchery (or both) at the Lummi Sea Pond for any length of time, what are the true costs associated with that measure?
3) Conduct success/benefit assessment of plausible LNR responses to EGC using a risk matrix (e.g., IS 2018), or similar ranking procedure, to evaluate potential outcomes of the department's activities based on the level of its response (low to high) and the probability of controlling EGC (low to high) (Table 7).

Table 7. Example of a risk matrix adapted for assessing the success/benefit of Lummi Natural Resources Department's (LNR) responses to the invasion of European green crab (EGC), *Carcinus maenas*, on Lummi Nation reservation tidelands based on the level of LNR response (low to high) and the probability of controlling EGC (low to high). Table cell colors are scaled for both financial and environmental liabilities as well. For example, red cells = little cost to LNR resulting in the least control of EGC with the least benefit to the environment, whereas green cells = high cost to LNR resulting in the most control of EGC with the greatest benefit to the environment (Source: adapted from IS 2018).

		LNR Level of Response			
Probability of EGC being Contained or Controlled	**Score**	1	2	3	4
	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	4	4	8	12	16
	5	5	10	15	20

Trapping and removal.–Previous studies of introduced populations of EGC on the Pacific and Atlantic coasts have shown declines in trap catches of the species during fall and winter (McDonald et al. 2006; Young et al. 2017). Accordingly, Grason et al. (2018) and WSG (2019) recommend setting traps in Washington State from April through September. The LNR study occurred immediately after the end-of-season catches of EGC in Drayton Harbor (Pleus 2019). Given the time of year of LNR's rapid response (October/November), the CPUEs reported here likely underestimated the true relative abundance of EGC in Lummi Bay; therefore, future monitoring efforts on reservation tidelands should, at a minimum, match the season identified in the current protocols (Grason et al. 2018; WSG 2019). Furthermore, Heath et al.'s (1975) and Dolphin's (2002) studies should be reviewed to inform possible trapping locations within Lummi Bay, including the Lummi Sea Pond. In this way, the department's field crews will maximize their catches of EGC, and their results will better reflect the scale of the problem in the bay and elsewhere. Finally, besides expanding the monitoring effort throughout Lummi Bay, including Sandy Point and its tidal channel system, LNR staff should target the Nooksack River Delta in Bellingham Bay (Figure 1) and continue monitoring appropriate habitat in Portage Bay.

On a related note, some trap styles and catch methods work more effectively than others in attracting and retaining feeding or foraging EGC; hence, LNR may choose to explore the efficacy of other gear types, e.g., commercial shrimp pots or small bottom trawls (Young et al. 2017; Waser 2018), besides the commonly-used collapsible, fukui-style traps and standard minnow traps. Engaging Lummi commercial fishermen or volunteer tribal members in a community-wide response *sensu* Grason et al. (2018), especially if the primary goal becomes one of rapidly reducing the EGC population on reservation tidelands, would likely be effective (Fimrite 2017); however, Turner et al. (2016) caution against the possibility of overcompensation occurring, an ecological process related to increases in adult reproduction, juvenile survival, and juvenile maturation rates, paradoxically, following a reduction in population size of the target species. Overcompensation likely contributed to the recent EGC population boom observed at Seadrift Lagoon in Bolinas, Marin County, California (Figure 28; Fimrite 2017).

Novel uses for EGC.–Unlike some introduced marine species, e.g., the commercially-valuable Manila clam, there are currently no positive effects identified for the invasive EGC (Kulhanek et al. 2011); still, food scientists and entrepreneurs alike, especially those in areas most impacted by EGC, such as the U.S. East Coast and northeastern Canada, are working rapidly to find creative solutions to the problem. Young and Elliott (2018) review many of these, including works outlining possible fishery development (McNiven et al. 2013), use as bait in existing recreational finfish fisheries, industrial uses (Ghosh and Urban 2009), including fertilizer, and not surprisingly, market development and recipes for human consumption (Galetti et al. 2017) (Figure 31). Regarding human consumption, much of the research has been directed at the suitability and nutritional qualities of EGC (Skonberg and Perkins 2002; Kang et al. 2018), and most recently, additional advances have been made in pharmaceutical applications (Wrobel et al. 2019) as well as the development of high-quality snacks for the pet food trade (Staples 2019).

While progress is being made on novel uses for EGC, e.g., visit https://www.greencrab.org or view Recipe for Disaster: Green Crabs in the Great Marsh at http://www.walkercreekmedia.com, Lummi policy makers and LNR managers should not yet resign themselves to this fate or be reassured by untested economic prospects that could lead to complacency in proactive management of EGC at this early stage of the invasion; rather, the tribe should be resolved in its efforts to control EGC on Lummi Nation reservation tidelands and, when possible, do likewise elsewhere along its usual-and-accustomed fishing grounds and stations within the Salish Sea.

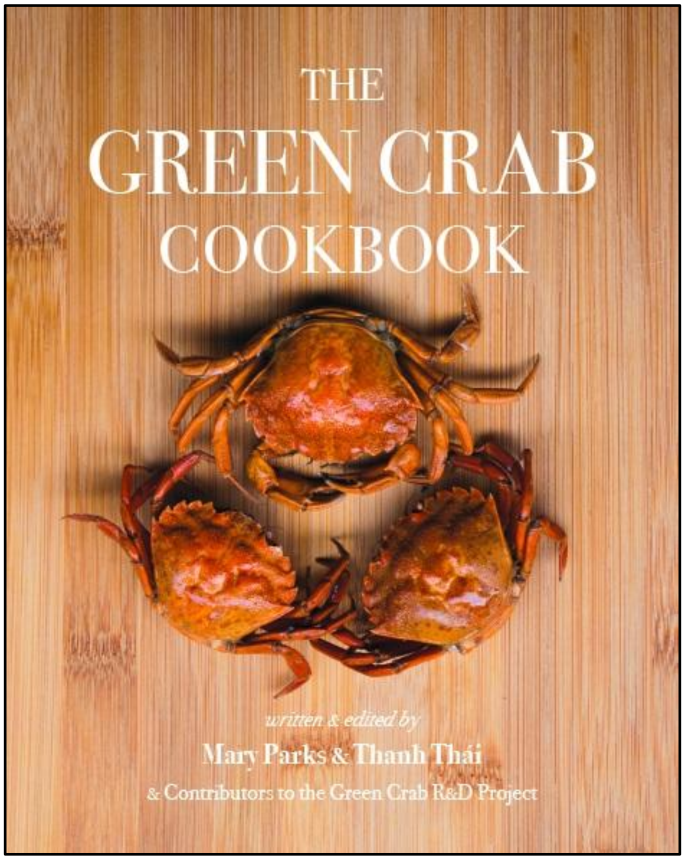

Figure 31. Desperate times call for desperate measures. Novel uses for invasive European green crab, *Carcinus maenas*, are being explored in coastal marine areas impacted by the species. While some advances are being made, the documented successes should not be considered substitutes for proactive management and early detection, rapid response, and containment of EGC within the Salish Sea (Source: The Green Crab R & D Project).

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APPENDIX 1

Sampling Locations and Catch Summary Data

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Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
EAST LUMMI RIVER																	
10/21/2019																	
Fukui																	
56	48.805920	-122.655100	0	**0**	0	0	0	0	22	0	12	0	0	0	0	0	**34**
57	48.804800	-122.655600	0	**0**	0	0	0	0	1	0	10	0	0	0	0	0	**11**
58	48.805070	-122.655540	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
59	48.805700	-122.655300	0	**0**	0	0	0	0	1	0	12	0	0	0	0	0	**13**
60	48.805360	-122.655480	0	**0**	0	0	0	0	1	0	19	0	0	0	0	0	**20**
Minnow																	
41	48.805810	-122.655200	0	**0**	0	0	2	0	25	0	0	0	0	0	0	0	**27**
42	48.805540	-122.655440	0	**0**	0	0	0	0	24	0	0	0	0	0	0	0	**24**
45	48.804920	-122.655580	0	**0**	0	0	1	0	14	0	0	0	0	0	0	0	**15**
47	48.806040	-122.655040	0	**0**	0	0	1	0	12	0	2	0	0	0	0	0	**15**
50	48.805180	-122.655530	0	**0**	0	0	1	0	7	0	0	0	0	0	0	0	**8**
10/22/2019																	
Fukui																	
56	48.805920	-122.655100	0	**0**	0	0	0	0	3	0	10	0	0	0	0	0	**13**
57	48.804800	-122.655600	0	**0**	0	0	1	0	2	0	8	0	0	0	0	0	**11**
58	48.805070	-122.655540	0	**0**	0	0	0	0	0	0	0	3	0	0	0	0	**3**
59	48.805700	-122.655300	0	**0**	0	0	0	0	1	0	0	0	0	0	0	0	**1**
60	48.805360	-122.655480	0	**0**	0	0	0	0	10	0	3	0	0	1	0	0	**14**
Minnow																	
41	48.805810	-122.655200	0	**0**	0	0	0	0	1	0	0	0	1	0	0	0	**2**
42	48.805540	-122.655440	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
45	48.804920	-122.655580	0	**0**	0	0	0	0	8	0	0	0	0	0	0	0	**8**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
47	48.806040	-122.655040	0	**0**	0	0	0	0	10	0	1	0	0	0	0	0	**11**
50	48.805180	-122.655530	0	**0**	0	0	1	0	8	0	0	0	0	0	0	0	**9**
HILLAIRE ROAD BRIDGE																	
10/21/2019																	
Fukui																	
8	48.807933	-122.651800	0	**0**	0	0	0	0	7	0	4	0	0	0	0	0	**11**
9	48.808183	-122.650817	0	**0**	0	0	4	0	3	0	1	0	0	0	0	0	**8**
15	48.808100	-122.651150	0	**0**	0	0	2	0	9	0	6	0	0	0	0	0	**17**
17	48.808050	-122.651483	0	**0**	0	0	2	0	1	0	0	0	0	0	0	0	**3**
18	48.808283	-122.650383	0	**0**	0	0	0	0	2	0	5	0	0	0	0	0	**7**
Minnow																	
21	48.808133	-122.651000	0	**0**	0	0	7	0	0	0	1	0	0	0	0	0	**8**
25	48.807967	-122.651617	0	**0**	0	0	1	0	4	0	2	0	0	0	0	0	**7**
27	48.808233	-122.650650	0	**0**	0	0	1	0	0	0	2	0	0	0	0	0	**3**
29	48.808067	-122.651283	0	**0**	0	0	3	0	0	0	0	0	0	0	0	0	**3**
30	48.808283	-122.650267	0	**0**	0	0	3	0	2	0	1	0	0	0	0	0	**6**
10/22/2019																	
Fukui																	
8	48.807933	-122.651800	0	**0**	0	0	1	0	2	0	0	0	0	0	0	0	**3**
9	48.808183	-122.650817	0	**0**	0	0	1	0	3	0	0	0	0	1	0	0	**5**
15	48.808100	-122.651150	0	**0**	0	0	4	0	2	0	1	0	0	1	0	0	**8**
17	48.808050	-122.651483	0	**0**	0	0	5	0	0	0	0	0	0	0	0	0	**5**
18	48.808283	-122.650383	0	**0**	0	0	3	0	6	0	1	0	0	0	0	0	**10**
Minnow																	
21	48.808133	-122.651000	0	**0**	0	0	0	0	11	0	0	0	0	0	0	0	**11**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
25	48.807967	-122.651617	0	**0**	0	0	0	0	0	0	1	0	0	1	0	0	**2**
27	48.808233	-122.650650	0	**0**	0	0	3	0	0	0	0	0	0	0	0	0	**3**
29	48.808067	-122.651283	0	**0**	0	0	0	0	7	0	0	0	0	0	0	0	**7**
30	48.808297	-122.650257	0	**0**	0	0	3	0	4	0	0	0	0	0	0	0	**7**
INNER SLOUGH																	
10/7/2019																	
Fukui																	
4	48.791367	-122.662817	0	**0**	0	0	0	0	2	0	0	0	0	0	0	0	**2**
6	48.791567	-122.662750	0	**0**	0	0	3	0	2	0	0	0	0	0	0	0	**5**
Minnow																	
21	48.791300	-122.662933	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
23	48.791467	-122.662750	0	**0**	0	0	1	0	1	0	0	0	0	0	0	0	**2**
10/8/2019																	
Fukui																	
4	48.791367	-122.662817	0	**0**	0	0	0	0	1	0	0	0	0	0	0	0	**1**
6	48.791567	-122.662750	0	**0**	0	0	6	0	0	0	0	0	0	0	0	0	**6**
Minnow																	
21	48.791300	-122.662933	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
23	48.791467	-122.662750	0	**0**	0	0	2	0	0	0	0	0	0	0	0	0	**2**
KWINA SOUTH SLOUGH																	
10/7/2019																	
Fukui																	
2	48.789683	-122.661150	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
7	48.789567	-122.660833	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
Minnow																	
13	48.789633	-122.661050	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
14	48.789733	-122.661267	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
10/8/2019																	
Fukui																	
2	48.789683	-122.661150	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
7	48.789417	-122.660583	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Minnow																	
13	48.789633	-122.661050	0	**0**	0	2	0	0	0	0	0	0	0	0	0	0	**2**
14	48.789733	-122.661267	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
LUMMI RIVER MID																	
10/7/2019																	
Fukui																	
5	48.793983	-122.663267	0	**0**	0	0	5	0	1	0	0	0	0	0	0	0	**6**
10	48.793600	-122.663617	0	**0**	0	0	5	0	1	0	0	0	0	0	0	0	**6**
11	48.793733	-122.663533	0	**0**	0	0	3	0	0	0	0	0	0	0	0	0	**3**
Minnow																	
25	48.794117	-122.663133	0	**0**	0	0	6	0	1	0	0	1	0	0	0	0	**8**
27	48.793667	-122.663567	0	**0**	0	0	3	0	1	0	0	0	0	0	0	0	**4**
29	48.793867	-122.663383	0	**0**	0	0	8	0	0	0	0	0	0	0	0	0	**8**
10/8/2019																	
Fukui																	
5	48.794167	-122.663550	0	**0**	0	0	1	0	1	0	1	0	0	0	0	0	**3**
10	48.793667	-122.663917	0	**0**	0	0	0	0	4	0	2	0	0	0	0	0	**6**
11	48.793900	-122.663750	0	**0**	0	0	1	0	0	0	3	0	0	0	0	0	**4**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
Minnow																	
25	48.794350	-122.663383	0	**0**	0	0	3	0	0	0	0	1	0	0	0	0	**4**
27	48.793783	-122.663800	0	**0**	0	0	1	0	0	0	4	0	0	0	0	0	**5**
29	48.794033	-122.663650	0	**0**	0	0	0	0	0	0	3	0	0	0	0	0	**3**
LUMMI RIVER MOUTH																	
10/21/2019																	
Fukui																	
1	48.788517	-122.663750	0	**0**	0	0	2	0	1	0	3	0	0	0	0	0	**6**
2	48.789450	-122.662733	0	**0**	0	0	0	0	1	0	10	0	0	0	0	0	**11**
3	48.789800	-122.663767	0	**0**	0	0	0	0	2	0	4	0	0	0	0	0	**6**
4	48.789483	-122.663483	0	**0**	0	0	0	0	0	0	4	0	0	0	0	0	**4**
5	48.788667	-122.663567	0	**0**	0	0	3	0	2	0	7	0	0	0	0	0	**12**
6	48.788850	-122.663367	0	**0**	0	0	1	0	3	0	9	0	0	0	0	0	**13**
7	48.789533	-122.663817	0	**0**	0	0	2	0	4	0	0	0	0	0	0	0	**6**
10	48.789167	-122.663033	0	**0**	0	0	1	0	0	0	2	1	0	0	0	0	**4**
11	48.789633	-122.663317	0	**0**	0	0	0	0	0	0	5	0	0	0	0	0	**5**
12	48.789840	-122.663450	0	**0**	0	0	1	0	1	0	21	0	0	0	0	0	**23**
Minnow																	
13	48.788750	-122.663433	0	**0**	0	0	1	0	0	0	1	0	0	0	0	0	**2**
14	48.789000	-122.663200	0	**0**	0	0	6	0	1	0	2	1	0	0	0	0	**10**
16	48.788433	-122.663817	0	**0**	0	0	0	0	1	0	1	0	0	0	0	0	**2**
19	48.789383	-122.663750	0	**0**	0	0	1	0	2	0	0	0	0	0	0	0	**3**
20	48.789383	-122.663750	0	**0**	0	0	0	0	0	0	1	0	0	0	0	0	**1**
22	48.789767	-122.663433	0	**0**	0	0	7	0	1	0	0	0	0	0	0	0	**8**
23	48.789550	-122.663317	0	**0**	0	0	0	0	2	0	1	0	0	0	0	0	**3**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
24	48.789650	-122.663733	0	**0**	0	0	3	0	0	0	0	0	0	0	0	0	**3**
26	48.788583	-122.663650	0	**0**	0	0	9	0	0	0	0	0	0	0	0	0	**9**
28	48.789717	-122.662600	0	**0**	0	0	6	0	0	0	0	2	0	0	0	0	**8**
10/22/2019																	
Fukui																	
1	48.788517	-122.663750	0	**0**	0	0	0	0	0	0	5	0	0	0	0	0	**5**
2	48.789450	-122.662733	0	**0**	0	0	0	0	1	0	19	0	0	0	0	0	**20**
3	48.789800	-122.663767	0	**0**	0	0	0	0	6	0	4	0	0	0	0	0	**10**
4	48.789483	-122.663483	0	**0**	0	0	5	0	0	0	0	0	0	0	0	0	**5**
5	48.788667	-122.663567	0	**0**	0	0	0	0	1	0	3	0	0	0	0	0	**4**
6	48.788850	-122.663367	0	**0**	0	0	1	0	0	0	5	0	0	0	0	0	**6**
7	48.789533	-122.663817	0	**0**	0	0	0	0	2	0	6	0	0	1	0	0	**9**
10	48.789167	-122.663033	0	**0**	0	0	0	0	1	0	0	0	0	0	0	0	**1**
11	48.789633	-122.663317	0	**0**	0	0	1	0	0	0	3	0	0	0	0	0	**4**
12	48.789840	-122.663450	0	**0**	0	0	0	0	1	0	13	1	0	0	0	0	**15**
Minnow																	
13	48.788750	-122.663433	0	**0**	0	0	2	0	1	0	1	0	0	0	0	0	**4**
14	48.789000	-122.663200	0	**0**	0	0	8	0	1	0	1	0	0	0	0	0	**10**
16	48.788433	-122.663817	0	**0**	0	0	2	0	3	0	1	0	0	0	0	0	**6**
19	48.789383	-122.663750	0	**0**	0	0	2	0	2	0	0	1	0	0	0	0	**5**
20	48.789767	-122.663433	0	**0**	0	0	6	0	0	0	0	0	0	0	0	0	**6**
22	48.789550	-122.663317	1	**0**	0	0	1	0	0	0	1	0	0	0	0	1	**4**
23	48.789650	-122.663733	0	**0**	0	0	0	0	1	0	1	0	0	0	0	0	**2**
24	48.788583	-122.663650	0	**0**	0	0	1	0	1	0	1	0	1	0	0	0	**4**
26	48.789717	-122.662600	0	**0**	0	0	3	0	0	0	0	0	0	0	0	0	**3**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
28	48.789600	-122.663667	0	**0**	0	0	5	0	0	0	0	0	0	0	0	0	**5**
LUMMI SEA POND																	
10/7/2019																	
Fukui																	
1	48.788500	-122.662667	0	**2**	0	0	4	0	0	0	0	6	0	0	0	0	**12**
3	48.788750	-122.662233	0	**4**	0	0	0	0	2	0	0	3	0	0	0	0	**9**
Minnow																	
16	48.788600	-122.662417	0	**1**	0	0	1	0	0	0	0	2	0	0	0	0	**4**
19	48.788800	-122.662217	0	**0**	0	0	5	0	0	0	0	4	0	0	0	0	**9**
10/8/2019																	
Fukui																	
1	48.788500	-122.662667	0	**1**	0	0	3	0	0	0	0	2	0	0	0	0	**6**
3	48.788750	-122.662233	0	**3**	0	0	0	0	0	0	0	14	0	0	0	0	**17**
Minnow																	
16	48.788600	-122.662417	0	**1**	0	0	5	0	0	0	0	24	0	0	0	0	**30**
19	48.788800	-122.662217	0	**1**	0	0	8	0	0	0	0	27	0	0	0	0	**36**
10/21/2019																	
Fukui																	
43	48.788970	-122.661240	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
44	48.788640	-122.660780	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
46	48.788990	-122.661100	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
48	48.788420	-122.660660	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
49	48.789160	-122.661460	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
51	48.788000	-122.660390	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
52	48.787700	-122.660200	0	**0**	0	0	0	0	0	0	0	2	0	0	0	0	**2**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
53	48.788860	-122.660790	0	**1**	0	0	1	0	0	0	0	0	0	0	0	0	**2**
54	48.789040	-122.660870	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
55	48.789090	-122.661270	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Minnow																	
31	48.789120	-122.661330	0	**2**	0	0	2	0	0	0	0	0	0	0	0	0	**4**
32	48.789050	-122.661220	0	**1**	0	0	6	0	0	0	0	0	0	0	0	0	**7**
33	48.788920	-122.661190	0	**1**	0	0	2	0	0	0	0	1	0	0	0	0	**4**
34	48.788970	-122.660750	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
35	48.789020	-122.661010	0	**3**	0	0	1	0	0	0	0	2	0	0	0	0	**6**
36	48.788750	-122.660770	0	**0**	0	0	1	0	0	0	0	4	0	0	0	0	**5**
37	48.787840	-122.660280	0	**1**	0	0	0	0	0	0	0	4	0	0	0	0	**5**
38	48.788240	-122.660540	0	**0**	0	0	3	0	0	0	0	9	0	0	0	0	**12**
39	48.788510	-122.660820	0	**3**	0	0	3	0	0	0	0	14	0	0	0	0	**20**
40	48.789150	-122.661610	0	**2**	0	0	0	0	0	0	0	0	0	0	0	0	**2**
10/22/2019																	
Fukui																	
43	48.788970	-122.661240	0	**0**	0	0	2	0	0	0	0	0	0	0	0	0	**2**
44	48.788640	-122.660780	0	**0**	0	0	0	0	0	0	0	1	0	0	0	0	**1**
46	48.788990	-122.661100	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
48	48.788420	-122.660660	0	**0**	0	0	5	0	0	0	0	0	0	0	0	0	**5**
49	48.789160	-122.661460	0	**1**	0	0	3	0	0	0	0	0	0	0	0	0	**4**
51	48.788000	-122.660390	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
52	48.787700	-122.660200	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
53	48.788860	-122.660790	0	**0**	0	0	2	0	0	0	0	1	0	0	0	0	**3**
54	48.789040	-122.660870	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
55	48.789090	-122.661270	0	**0**	0	0	0	0	0	0	0	3	0	0	0	0	**3**
Minnow																	
31	48.789120	-122.661330	0	**2**	0	0	1	0	0	0	0	1	0	0	0	0	**4**
32	48.789050	-122.661220	0	**4**	0	0	6	0	0	0	0	0	0	0	0	0	**10**
33	48.788920	-122.661190	0	**2**	0	0	11	0	0	0	0	0	0	0	0	0	**13**
34	48.788970	-122.660750	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
35	48.789020	-122.661010	0	**1**	0	0	1	0	0	0	0	1	0	0	0	0	**3**
36	48.788750	-122.660770	0	**0**	0	0	2	0	0	0	0	0	0	0	0	0	**2**
37	48.787840	-122.660280	0	**0**	0	0	4	0	0	0	0	4	0	0	1	0	**9**
38	48.788240	-122.660540	0	**1**	0	0	4	0	0	0	0	5	0	0	0	0	**10**
39	48.788510	-122.660820	0	**0**	0	0	4	0	0	0	0	2	0	0	0	0	**6**
40	48.789150	-122.661610	0	**3**	0	0	4	0	0	0	0	1	0	0	0	0	**8**
PORTAGE BAY EAST																	
11/6/2019																	
Fukui																	
2	48.706833	-122.618050	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
4	48.706850	-122.617733	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
7	48.706833	-122.617417	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
10	48.706950	-122.617067	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
17	48.707383	-122.617083	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Minnow																	
20	48.706917	-122.617267	0	**0**	0	0	3	0	0	0	0	0	0	0	0	0	**3**
21	48.706817	-122.617583	0	**0**	0	0	4	0	0	0	0	0	0	0	0	0	**4**
23	48.706850	-122.617867	0	**0**	0	0	33	0	0	0	0	0	0	0	0	0	**33**
26	48.706867	-122.618217	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
29	48.707100	-122.617067	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
PORTAGE BAY SOUTH																	
11/6/2019																	
Fukui																	
3	48.706733	-122.618367	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
8	48.706717	-122.618717	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
11	48.706633	-122.618150	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
12	48.706600	-122.619033	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
15	48.706650	-122.617800	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
Minnow																	
19	48.706633	-122.619117	0	**0**	0	0	22	0	0	0	0	0	0	0	0	0	**22**
22	48.706733	-122.618450	0	**0**	0	0	11	0	0	0	0	0	0	0	0	0	**11**
25	48.706717	-122.618217	0	**0**	0	0	3	0	0	0	0	0	0	0	0	0	**3**
27	48.706667	-122.618900	0	**0**	0	0	13	0	0	0	0	0	0	0	0	0	**13**
28	48.706617	-122.617917	0	**0**	0	0	1	0	0	0	0	0	0	0	0	0	**1**
PORTAGE BAY WEST																	
11/6/2019																	
Fukui																	
1	48.706700	-122.624317	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
5	48.706233	-122.622500	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
6	48.706267	-122.622517	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
9	48.706450	-122.622283	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
18	48.706683	-122.624267	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Minnow																	
13	48.706183	-122.622517	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
14	48.706700	-122.624200	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
16	48.706217	-122.622550	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
24	48.706283	-122.622533	0	**0**	0	0	4	0	0	0	0	0	0	0	0	0	**4**
30	48.706667	-122.624300	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	**0**
SANDY POINT HEIGHTS																	
10/7/2019																	
Fukui																	
8	48.802783	-122.679467	0	**0**	0	0	0	0	1	5	0	0	0	0	0	0	**6**
9	48.802550	-122.679883	0	**0**	0	0	0	0	1	0	0	0	0	0	0	0	**1**
12	48.803267	-122.679400	0	**5**	0	0	0	45	0	0	0	0	0	0	0	0	**50**
15	48.803067	-122.679817	0	**1**	0	0	0	20	1	0	0	0	0	0	0	0	**22**
17	48.802933	-122.680150	0	**3**	0	0	0	8	0	0	0	0	0	0	0	0	**11**
18	48.802917	-122.679133	0	**0**	0	0	0	1	0	3	0	0	0	0	0	0	**4**
Minnow																	
20	48.802950	-122.679150	0	**0**	0	0	0	27	1	1	0	0	0	0	0	0	**29**
22	48.803250	-122.679550	0	**0**	0	0	0	95	0	1	0	0	0	0	0	0	**96**
24	48.802867	-122.680400	0	**0**	0	0	0	8	1	0	0	0	0	0	0	0	**9**
26	48.802983	-122.679917	0	**2**	0	0	0	35	0	0	0	0	0	0	0	0	**37**
28	48.802883	-122.679300	0	**0**	0	0	0	4	0	0	0	1	0	0	0	0	**5**
30	48.802650	-122.679633	0	**0**	0	0	0	1	1	0	0	1	0	0	0	0	**3**
10/8/2019																	
Fukui																	
8	48.803183	-122.679467	0	**2**	1	0	0	17	1	0	2	0	0	0	0	0	**23**
9	48.803067	-122.679400	0	**1**	0	0	0	4	2	0	4	0	0	0	0	0	**11**
12	48.803267	-122.679400	0	**0**	0	0	0	15	0	0	2	0	0	0	0	0	**17**

Table A1-1. Sampling locations and catch summaries for two styles of baited traps (fukui and minnow) set overnight at several locations (listed alphabetically by name) within Lummi and Portage bays, Whatcom County, Washington during multiple tide series from October 7, 2019 through November 8, 2019. BROK = Broken back shrimp (Family Hippolytidae), CAMA = *Carcinus maenas* (European green crab; shaded), CYAG = *Cymatogaster aggregata* (shiner perch), GAAC = *Gasterosteus aculeatus* (three-spine stickleback), HEOR = *Hemigrapsus oregonensis* (yellow shore crab), HESP = *Hemigrapsus* sp. (unidentified grapsid shore crab), LEAR = *Leptocottus armatus* (staghorn sculpin), MEGR = *Metacarcinus gracilis* (graceful crab), MEMA = *Metacarcinus magister* (Dungeness crab), PASP = *Pagurus* sp. (unidentified pagurid hermit crab), PHOR = *Pholis ornata* (saddleback gunnel), PLST = Platichthys stellatus (starry flounder), SAND = Sand shrimp (Family Crangonidae), and TECH = *Telmessus cheiragonus* (hairy helmet crab).

Location; Set Date; Trap	Latitude	Longitude	BROK	CAMA	CYAG	GAAC	HEOR	HESP	LEAR	MEGR	MEMA	PASP	PHOR	PLST	SAND	TECH	Sub-Total
15	48.803017	-122.679800	0	**1**	0	0	0	13	2	0	0	0	0	0	0	0	**16**
17	48.802883	-122.680150	0	**0**	0	0	0	7	6	0	1	0	0	0	0	0	**14**
18	48.803083	-122.679500	0	**2**	0	0	0	28	0	0	1	0	0	0	0	0	**31**
Minnow																	
20	48.803033	-122.679550	0	**1**	0	0	0	40	0	0	0	0	0	0	0	0	**41**
22	48.803217	-122.679517	0	**1**	0	0	0	54	1	0	0	0	0	0	0	0	**56**
24	48.802833	-122.680367	0	**0**	0	0	0	28	2	0	0	1	0	0	0	0	**31**
26	48.802983	-122.679917	0	**2**	0	0	0	61	0	0	0	1	0	0	0	0	**64**
28	48.803217	-122.679450	0	**2**	0	1	0	144	0	0	1	0	0	0	0	0	**148**
30	48.803117	-122.679467	0	**0**	0	0	0	26	0	0	2	0	0	0	0	0	**28**
		Total	**1**	**64**	**1**	**3**	**377**	**681**	**292**	**10**	**263**	**152**	**2**	**5**	**1**	**1**	**1,853**

APPENDIX 2

Satellite Imagery of Sampling Locations

(Listed alphabetically by name of sampling location)

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Figure A2-1. Satellite view of trap locations at **East Lummi River (ELR)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

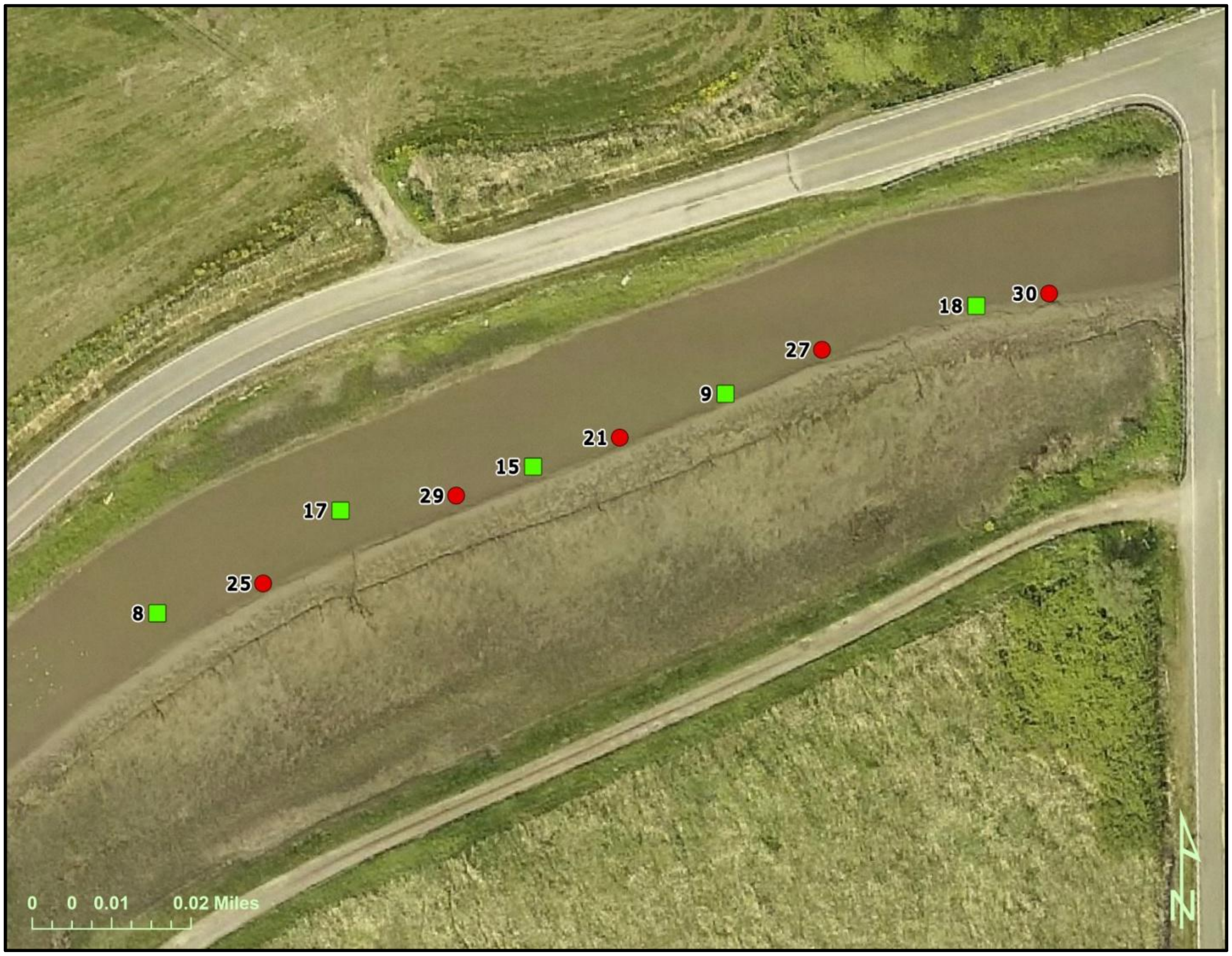

Figure A2-2. Satellite view of trap locations at **Hillaire Road Bridge (HRB)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

Figure A2-3. Satellite view of trap locations at **Inner Slough (INN)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

Figure A2-4. Satellite view of trap locations at **Kwina South Slough (KSS)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1. Duplicate numbers indicate traps that were set and retrieved on different dates within a two-day sampling period.

Figure A2-5. Satellite view of trap locations at **Lummi River Mid (LRM)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1. Duplicate numbers indicate traps that were set and retrieved on different dates within a two-day sampling period.

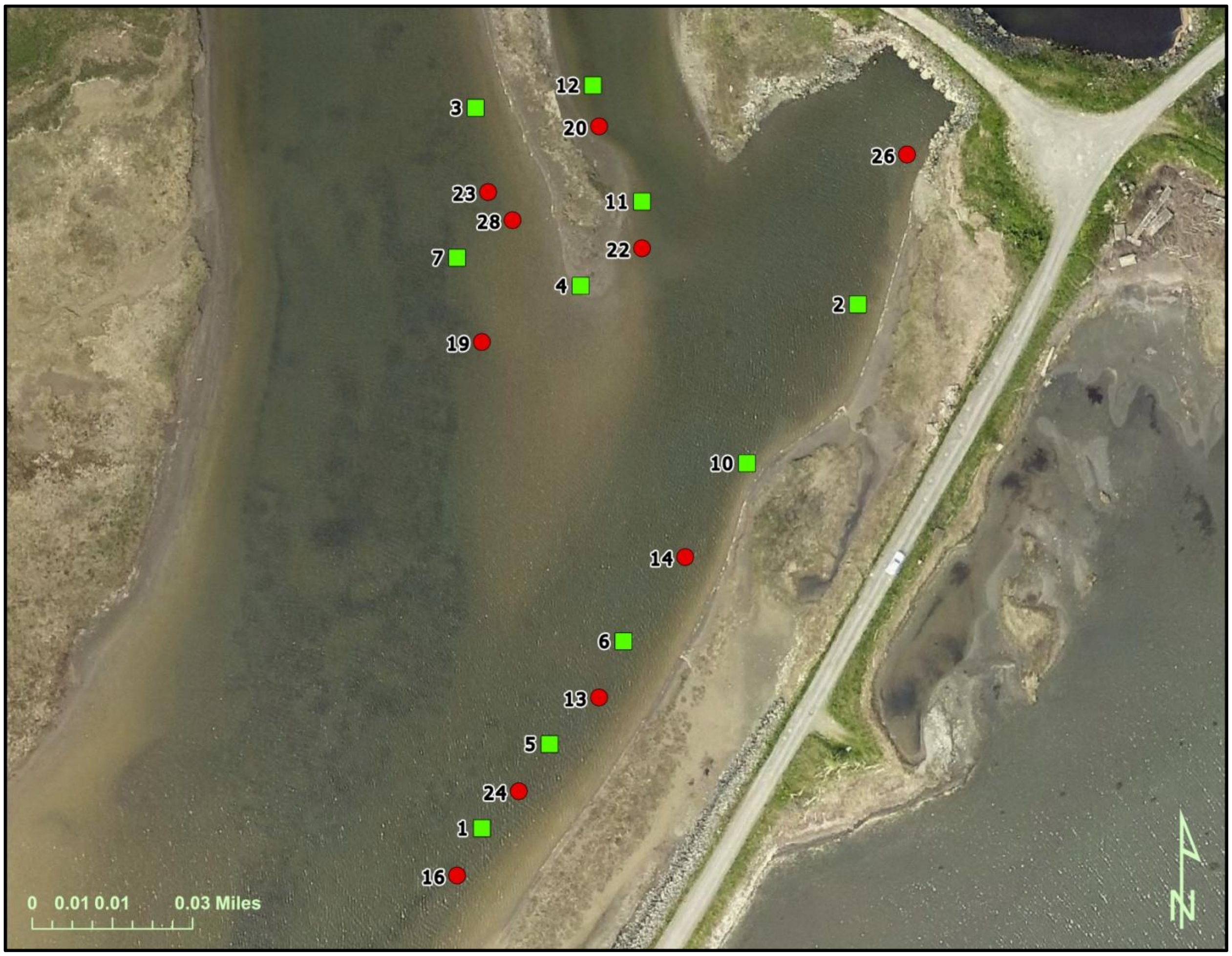

Figure A2-6. Satellite view of trap locations at **Lummi River Mouth (LM)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

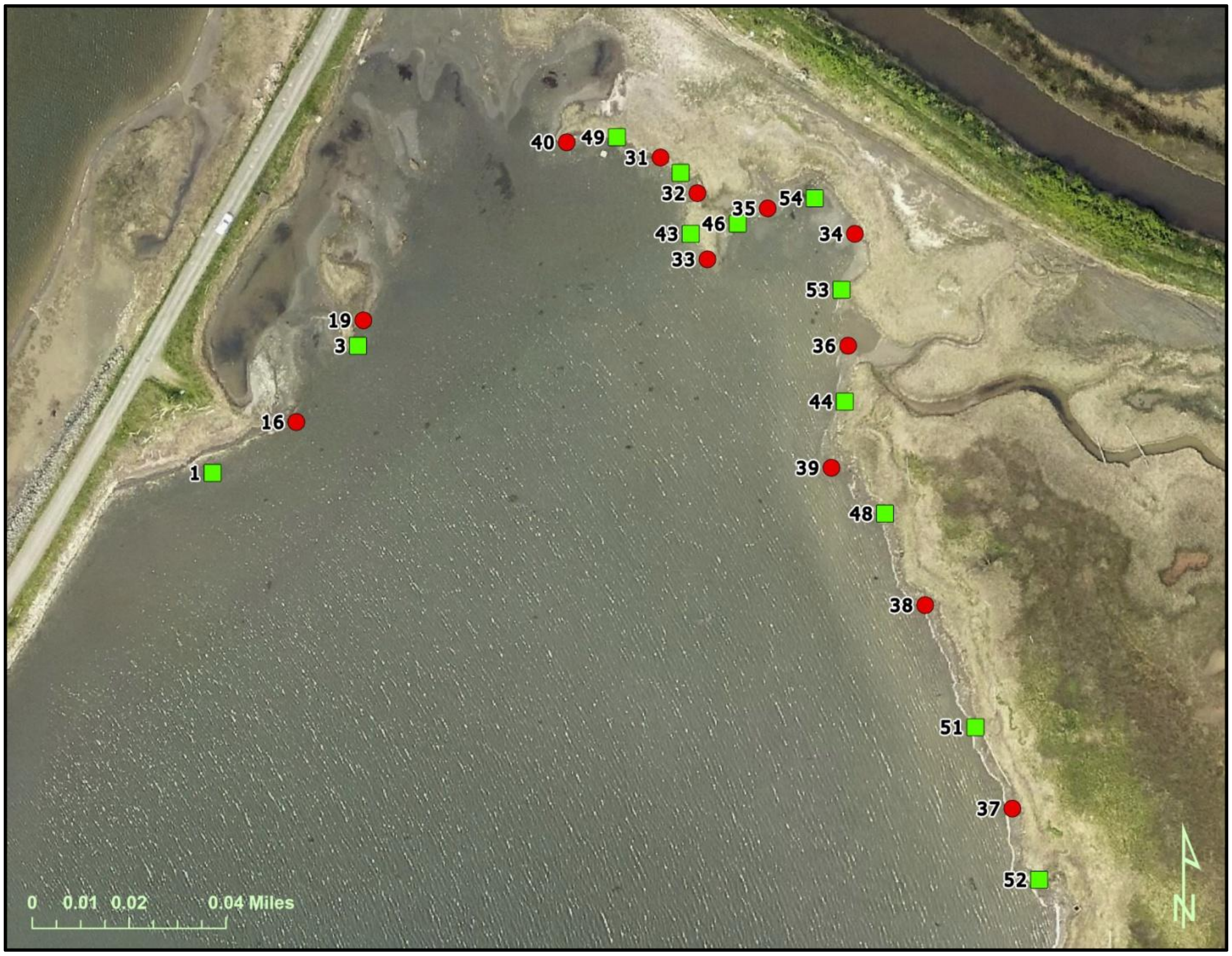

Figure A2-7. Satellite view of trap locations at **Lummi Sea Pond (LSP)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

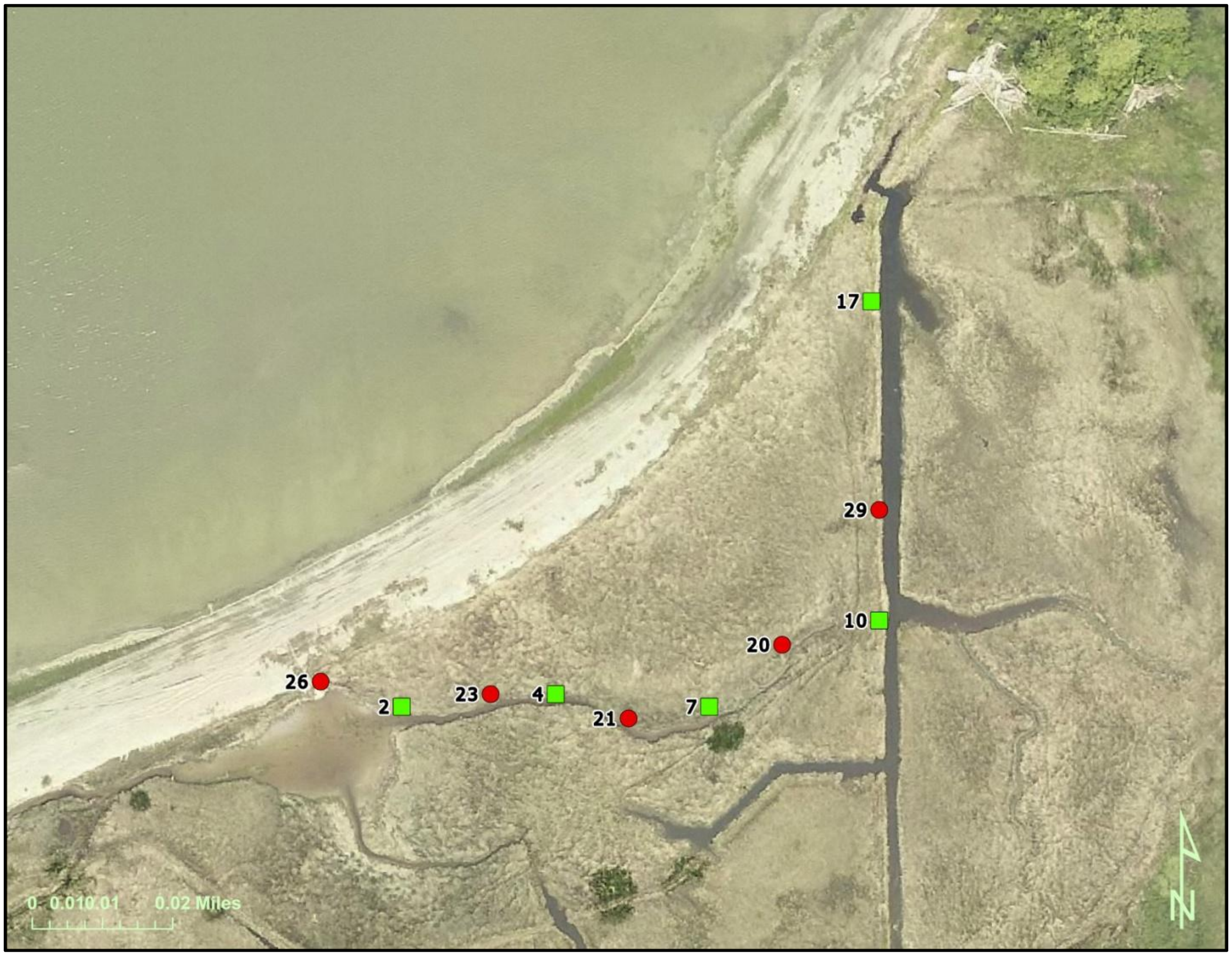

Figure A2-8. Satellite view of trap locations at **Portage Bay East (PBE)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Portage Bay, Whatcom County, Washington in November 2019. Note the man-made channels at right. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

Figure A2-9. Satellite view of trap locations at **Portage Bay South (PBS)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Portage Bay, Whatcom County, Washington in November 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

Figure A2-10. Satellite view of trap locations at **Portage Bay West (PBW)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Portage Bay, Whatcom County, Washington in November 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1.

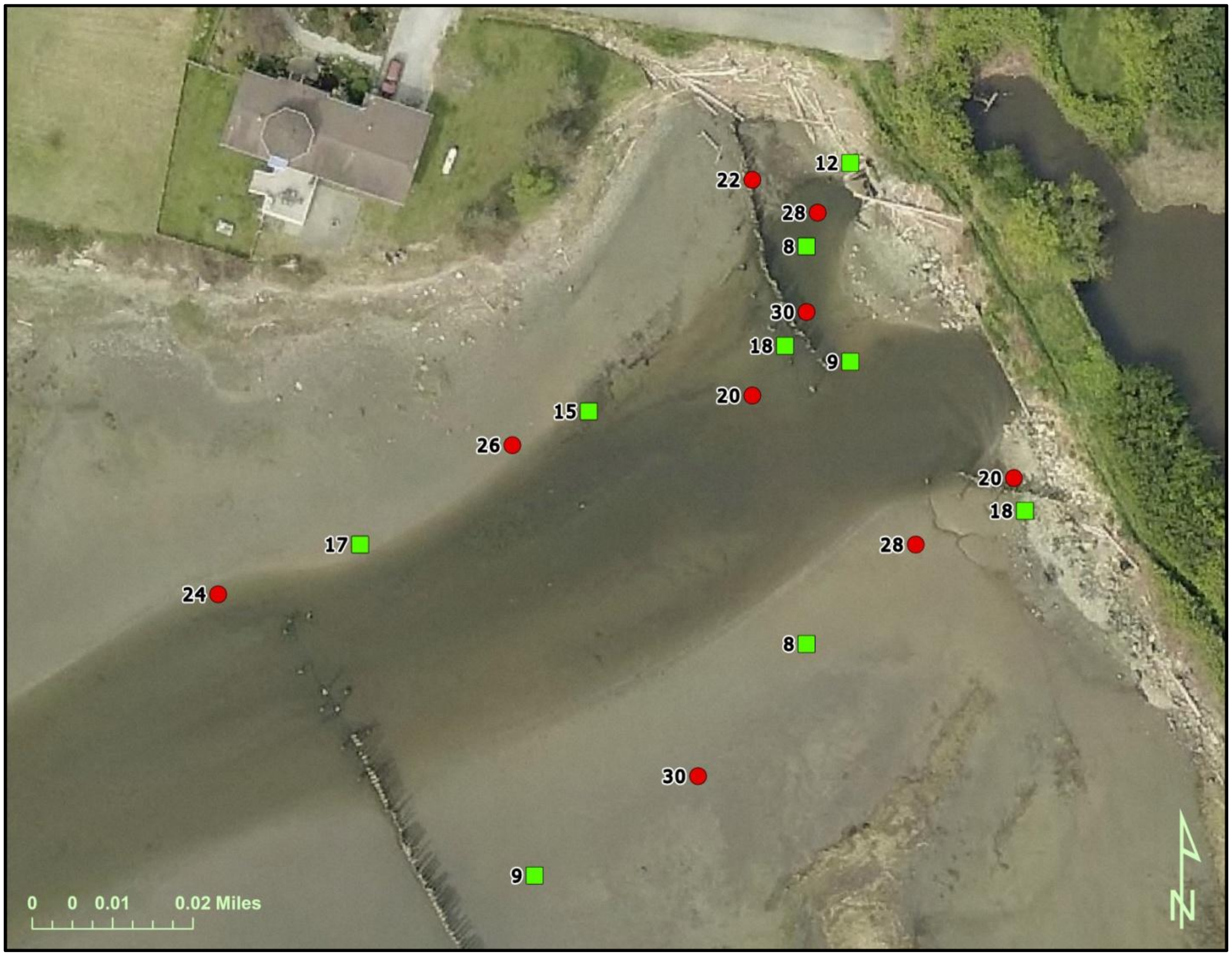

Figure A2-11. Satellite view of trap locations at **Sandy Point Heights (SPH)** during the Lummi Natural Resources Department's invasive European green crab (EGC), *Carcinus maenas*, monitoring effort within Lummi Bay, Whatcom County, Washington in October 2019. Locations of fukui-style traps are indicated by green squares, whereas minnow trap locations are indicated by red circles. Trap numbers correspond with sampling location and catch summary data in Table A1-1. Duplicate numbers indicate traps that were set and retrieved on different dates within a two-day sampling period.

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APPENDIX 3

Analyses and Transformations of European Green Crab Size Data

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Table A3-1. Comparison of descriptive statistics for "notch" carapace widths (CW_{No}, mm) of invasive European green crab (*Carcinus maenas*) captured at two locations (Lummi Sea Pond and Sandy Point Heights) within Lummi Bay, Whatcom County, Washington during October 7, 2019 through October 23, 019.

	Lummi Sea Pond		Sandy Point Heights	
Statistic	**Female CW_{No}**	**Male CW_{No}**	**Female CW_{No}**	**Male CW_{No}**
N	19	22	13	10
Lo 95% CI	41.4	43.5	38.1	39.8
Mean	43.5	45.2	40.8	45.8
Up 95% CI	45.6	46.9	43.5	51.8
SD	4.3	3.9	4.5	8.4
Variance	18.7	15.6	19.9	70.2
SE Mean	0.99	0.84	1.2	2.6
C.V.	9.9	8.7	10.9	18.3
Minimum	30	35	35	36
Median	44	46	40	45
Maximum	48	54	50	65

Table A3-2. Comparison of descriptive statistics for total carapace widths (CW_{To}, mm) of invasive European green crab (*Carcinus maenas*) captured at two locations (Lummi Sea Pond and Sandy Point Heights) within Lummi Bay, Whatcom County, Washington during October 7, 2019 through October 23, 019.

	Lummi Sea Pond		Sandy Point Heights	
Statistic	**Female CW_{To}**	**Male CW_{To}**	**Female CW_{To}**	**Male CW_{To}**
N	19	22	13	10
Lo 95% CI	44.9	47.6	40.9	43.5
Mean	47.3	49.6	43.9	50.2
Up 95% CI	49.6	51.6	46.9	56.9
SD	4.9	4.5	4.9	9.4
Variance	23.8	20.3	24.2	87.7
SE Mean	1.1	0.96	1.4	2.9
C.V.	10.3	9.1	11.2	18.7
Minimum	32	38	37	39
Median	48	50	43	49
Maximum	53	59	54	71

Table A3-3. Carapace width (CW, mm) measurements ["Notch" (No) and Total (To)] and their transformations (natural log, ln, and log_{10}) for female and male invasive European green crab, *Carcinus maenas*, captured at two locations (Lummi Sea Pond and Sandy Point Heights, combined) within Lummi Bay, Whatcom County, Washington from October 7, 2019 through October 23, 2019.

FEMALE →						**MALE →**					
CW_{No}	Ln CW_{No}	Log_{10} CW_{No}	CW_{To}	Ln CW_{To}	Log_{10} CW_{To}	CW_{No}	Ln CW_{No}	Log_{10} CW_{No}	CW_{To}	Ln CW_{To}	Log_{10} CW_{To}
30	3.401197	1.477121	32	3.465736	1.505150	35	3.555348	1.544068	38	3.637586	1.579784
35	3.555348	1.544068	37	3.610918	1.568202	36	3.583519	1.556303	39	3.663562	1.591065
35	3.555348	1.544068	38	3.637586	1.579784	36	3.583519	1.556303	39	3.663562	1.591065
36	3.583519	1.556303	38	3.637586	1.579784	40	3.688879	1.60206	43	3.761200	1.633468
37	3.610918	1.568202	40	3.688879	1.602060	41	3.713572	1.612784	44	3.784190	1.643453
38	3.637586	1.579784	41	3.713572	1.612784	42	3.737670	1.623249	46	3.828641	1.662758
39	3.663562	1.591065	42	3.737670	1.623249	42	3.737670	1.623249	47	3.850148	1.672098
40	3.688879	1.602060	43	3.761200	1.633468	43	3.761200	1.633468	46	3.828641	1.662758
40	3.688879	1.602060	43	3.761200	1.633468	43	3.761200	1.633468	47	3.850148	1.672098
41	3.713572	1.612784	44	3.784190	1.643453	43	3.761200	1.633468	47	3.850148	1.672098
41	3.713572	1.612784	45	3.806662	1.653213	43	3.761200	1.633468	47	3.850148	1.672098
42	3.737670	1.623249	46	3.828641	1.662758	43	3.761200	1.633468	48	3.871201	1.681241
42	3.737670	1.623249	45	3.806662	1.653213	44	3.784190	1.643453	49	3.891820	1.690196
42	3.737670	1.623249	46	3.828641	1.662758	44	3.784190	1.643453	48	3.871201	1.681241
43	3.761200	1.633468	46	3.828641	1.662758	45	3.806662	1.653213	50	3.912023	1.698970
43	3.761200	1.633468	47	3.850148	1.672098	45	3.806662	1.653213	50	3.912023	1.698970
43	3.761200	1.633468	48	3.871201	1.681241	46	3.828641	1.662758	50	3.912023	1.698970
43	3.761200	1.633468	47	3.850148	1.672098	46	3.828641	1.662758	50	3.912023	1.698970
44	3.784190	1.643453	48	3.871201	1.681241	46	3.828641	1.662758	50	3.912023	1.698970
44	3.784190	1.643453	48	3.871201	1.681241	46	3.828641	1.662758	51	3.931826	1.707570
44	3.784190	1.643453	48	3.871201	1.681241	46	3.828641	1.662758	51	3.931826	1.707570
45	3.806662	1.653213	48	3.871201	1.681241	47	3.850148	1.672098	51	3.931826	1.707570
45	3.806662	1.653213	49	3.891820	1.690196	48	3.871201	1.681241	53	3.970292	1.724276
45	3.806662	1.653213	48	3.871201	1.681241	48	3.871201	1.681241	53	3.970292	1.724276

Table A3-3. Carapace width (CW, mm) measurements ["Notch" (No) and Total (To)] and their transformations (natural log, ln, and log_{10}) for female and male invasive European green crab, *Carcinus maenas*, captured at two locations (Lummi Sea Pond and Sandy Point Heights, combined) within Lummi Bay, Whatcom County, Washington from October 7, 2019 through October 23, 2019.

FEMALE →						**MALE →**					
CW_{No}	**Ln CW_{No}**	**Log_{10} CW_{No}**	**CW_{To}**	**Ln CW_{To}**	**Log_{10} CW_{To}**	**CW_{No}**	**Ln CW_{No}**	**Log_{10} CW_{No}**	**CW_{To}**	**Ln CW_{To}**	**Log_{10} CW_{To}**
46	3.828641	1.662758	49	3.89182	1.690196	48	3.871201	1.681241	53	3.970292	1.724276
46	3.828641	1.662758	49	3.89182	1.690196	49	3.891820	1.690196	53	3.970292	1.724276
47	3.850148	1.672098	51	3.931826	1.707570	49	3.891820	1.690196	55	4.007333	1.740363
47	3.850148	1.672098	52	3.951244	1.716003	50	3.912023	1.698970	55	4.007333	1.740363
48	3.871201	1.681241	52	3.951244	1.716003	50	3.912023	1.698970	55	4.007333	1.740363
48	3.871201	1.681241	52	3.951244	1.716003	50	3.912023	1.698970	56	4.025352	1.748188
48	3.871201	1.681241	53	3.970292	1.724276	54	3.988984	1.732394	59	4.077537	1.770852
50	3.912023	1.698970	54	3.988984	1.732394	65	4.174387	1.812913	71	4.262680	1.851258

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