

CRAB TEAM IN WASHINGTON STATE

REPORT OF 2016 FINDINGS

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WASHINGTON SEA GRANT

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CONTENTS

INFOGRAPHIC	1
SUMMARY.....	2
1. MONITORING NETWORK.....	3
2. BAITED TRAPPING	4
3. MOLT SURVEYS	14
4. HABITAT TRANSECT SURVEYS	17
CLOSING THOUGHTS	20

Note: Data presented here are in summary form only.
Please contact Crab Team directly before reuse or for
access to the raw data for additional analysis.

2016



Crab Team

European Green Crab and Pocket Estuary Monitoring



26



108



1,899



153



Trapping

18,882



44,216



1



Surveys

Collection hours

Organisms observed

Green crab detected

Molt Hunts

47

13,150

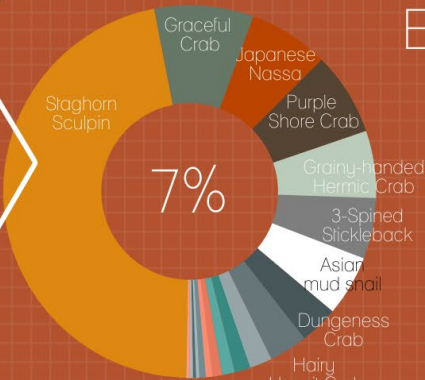


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What was found in traps?

Hairy Shore Crab
93%

5.5 males trapped for each female



Everything Else

Rare critters (<100)

- Prickly Sculpin
- Shiner Perch
- Bubble Shell
- Wrinkled Dove Snail
- Red Rock Crab
- Western Lean Nassa
- Eel-like Fishes
- Brokenback Shrimp
- Spider Crabs
- Tidepool Sculpin
- Helmet Crab
- Bay Pipefish
- European green crab
- Plainfin midshipman
- Black clawed Crab



WSG Green Crab



@WAGreenCrab

Superlative Sites!



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SUMMARY

Crab Team is a project of Washington Sea Grant in which volunteers conduct early-detection monitoring for European green crab (*Carcinus maenas*) across Washington's inland shorelines. Launched in 2015, Crab Team expanded to monitor 26 sites from Nisqually Reach to Bellingham, and as far west as the Dungeness River in 2016. Volunteers conduct monthly surveys that include baited trapping, molt searches and a habitat transect survey. While the primary goal of the project and monitoring protocols is to detect green crab at the earliest possible stage of invasion, volunteers collect data on all species observed during trapping and molt surveys. These data on native crabs, fishes and habitat features are the beginning of a longitudinal regional dataset on pocket estuary and salt marsh habitats in Washington's Salish Sea. Information from these sites will provide valuable insight into the health and dynamics of these understudied habitats and the impacts that green crab could have on them.

Here, we present a summary of Crab Team's monitoring data from 2016 intended to highlight the contributions of the volunteers and the value of the dataset. The most notable finding in 2016 was the capture of a European green crab by Crab Team volunteers in Westcott Bay, on San Juan Island. Fortunately, the single green crab was only one of more than 57,000 organisms observed during surveys. These data offer a broad and rich opportunity for exploring local shorelines from ecological, conservation and stewardship perspectives.

What follows are snapshots of Crab Team work during 2016, with brief interpretation of what the observed patterns might mean. As monitoring continues, and multiple years of data are assembled, we will be able to gain more insight into seasonal patterns and temporal trends. As Crab Team is a true collaboration with volunteers, we invite discussion. For more information on Crab Team, including survey protocols, visit the website: wsg.washington.edu/crabteam or email crabteam@uw.edu.

1. MONITORING NETWORK

Puget Sound, the Strait of Juan de Fuca and the San Juan Islands together constitute Washington's Salish Sea, which has nearly 2,500 miles of shoreline. It's no exaggeration to say that looking for a single, or even a few, green crab is like looking for

a needle in a haystack. Monitoring sites are selected based on suitability for green crab survival, availability of monitors and proximity to other sites. Crab Team monitored 26 sites in 2016, and identified 183 as potentially suitable habitat for green crab (**Figure 1**).

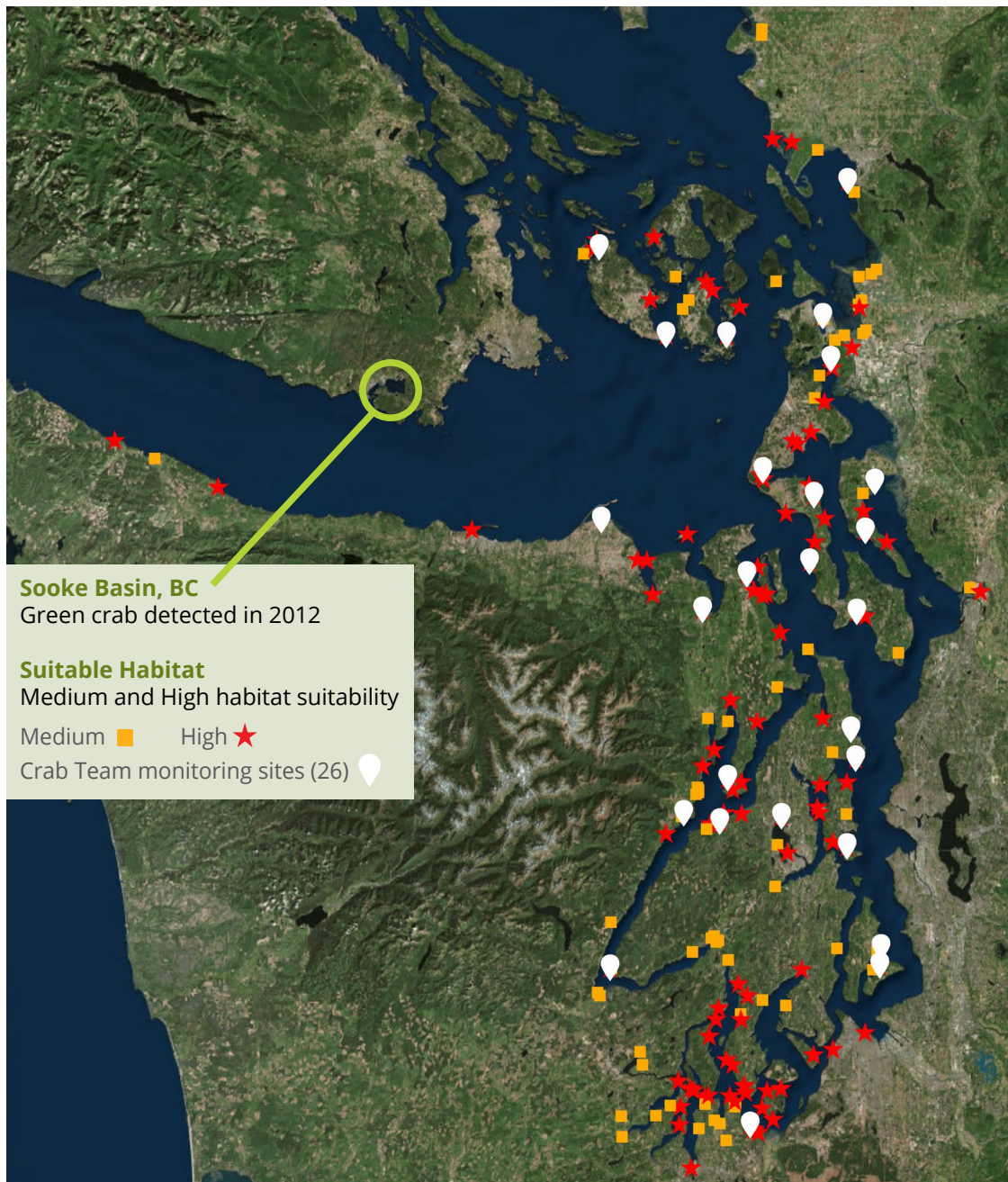


Figure 1. Map of suitable habitat for European green crab, and Crab Team monitoring sites during 2016.

2. BAITED TRAPPING

Each month, monitors set six baited traps—three each of cylindrical minnow and square Fukui styles—for an overnight soak. All native organisms are identified and counted before being released, so Crab Team can compare the ecological communities of organisms that live at sites and how they change over the season.

This section provides some insight into what Crab Team captured in traps, as well as patterns of abundance and diversity across the 26 monitoring sites during 2016. We summarize the total catch by species for the year in different ways. A species might be abundant, meaning large numbers are trapped (**Table 1**), or it might be common (**Table 2**), meaning it is found at many of the sites, or it might be both abundant and common. Exploring species abundance and commonness across all sites (**Table 3**) enables us to get at questions of diversity and ecosystem productivity.



PHOTO CREDIT: CRAIG STAUDE

The first European green crab detected along Washington's inland shorelines was captured by Crab Team volunteers at Westcott Bay in August 2016, and appears along with the other fish captured in the same trap.

Highlights

- A total of 828 traps were set in 2016, totaling 18,696 soak hours (779 days).
- Of 44,216 organisms, and 25 species, only a single European green crab was captured.
- Trap catches were vastly dominated by native hairy shore crab (*Hemigrapsus oregonensis*), which were present at every single site.
- Staghorn sculpin was the distant second-most abundant organism, but still found at nearly every site.
- Both richness (number of species) and diversity are negatively correlated with total number of organisms trapped. That is, the more individual animals captured, the greater the dominance by hairy shore crab, and the fewer different types of animal captured.
- The number of organisms caught that were not hairy shore crabs was fairly consistent across all sites. Totaled over the season, each site caught slightly fewer than 200 critters other than hairy shore crab during 2016—regardless of how many hairy shore crab were caught.

Table 1. Trap Catch Totals by Species. Total number of each species captured in trapping surveys across all sites and months during the 2016 monitoring season.

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

Table 2. Commonness of Animals Trapped. Number of sites at which each species captured in trapping surveys was found during 2016 monitoring season.

Taxon Type	Species	Common Name	# Sites Where Captured (of possible 26)
Crab	<i>Hemigrapsus oregonensis</i>	Hairy shore crab	26
Fish	<i>Leptocottus armatus</i>	Staghorn sculpin	25
Crab	<i>Hemigrapsus nudus</i>	Purple shore crab	17
Fish	<i>Gasterosteus aculeatus</i>	Three-spined stickleback	13
Crab	<i>Pagurus hirsutiusculus</i>	Hairy hermit crab	12
Fish	<i>Cymatogaster aggregata</i>	Shiner perch	12
Crab	<i>Pagurus granosimanus</i>	Grainy-handed hermit crab	8
Crab	<i>Cancer (Metacarcinus) gracilis</i>	Graceful crab	6
Snail	<i>Batillaria attramentaria</i>	Asian mud snail	6
Crab	<i>Cancer (Metacarcinus) magister</i>	Dungeness crab	5
Fish	<i>Pholidae</i> and <i>Stichaeidae</i> spp.	Eel-like fishes (e.g. gunnels)	3
Crab	<i>Cancer productus</i>	Red rock crab	2
Crab	Multiple in <i>Majidae</i>	Spider crabs	2
Crab	<i>Telmessus cheiragonus</i>	Hairy helmet crab	2
Snail	<i>Haminoea</i> sp.	Bubble shell	2
Fish	<i>Oligocottus maculosus</i>	Tidepool sculpin	1
Fish	<i>Syngnathus leptorhynchus</i>	Bay pipefish	2
Crab	<i>Carcinus maenas</i>	European green crab	1
Crab	<i>Lophopanopeus bellus</i>	Black clawed crab	1
Shrimp	<i>Pandalidae</i> & <i>Hyppolytidae</i> spp.	Broken back shrimp	1
Snail	<i>Amphissa columbiana</i>	Wrinkled dove snail	1
Snail	<i>Nassarius fraterculus</i>	Japanese nassa	1
Snail	<i>Nassarius mendica</i>	Western lean nassa	1
Fish	<i>Cottus asper</i>	Prickly sculpin	1
Fish	<i>Porichthys notatus</i>	Plainfin midshipman	1
Fish	<i>Platichthys stellatus</i>	Starry flounder	1

Table 3. 2016 Trap Catch by Site. Total number of each species captured in trapping surveys by organism type and individual site during 2016 monitoring season.

Site	Site Name	Region	CRUSTACEANS												FISHES							GASTROPODS					TOTAL		
			<i>Hemigrapsus oregonensis</i>	<i>Hemigrapsus nudus</i>	<i>Cancer (Metacarcinus) gracilis</i>	<i>Cancer (Metacarcinus) magister</i>	<i>Cancer productus</i>	Majidae - Spider crabs	<i>Telmessus cheiragonus</i>	<i>Lophopanopeus bellus</i>	<i>Carcinus maenas</i>	<i>Pagurus hirsutissculus</i>	<i>Pagurus granosimanus</i>	Broken back shrimp	<i>Leptocottus armatus</i>	<i>Gasterosteus aculeatus</i>	<i>Cymatogaster aggregata</i>	<i>Cottus asper</i>	Eel-like fishes	<i>Oligocottus maculosus</i>	<i>Syngnathus leptorhynchus</i>	<i>Porichthys notatus</i>	<i>Batillaria atramentaria</i>	<i>Haminoea</i> spp.	<i>Amphissa columbiana</i>	<i>Nassarius fraterculus</i>		<i>Nassarius mendica</i>	Months Sampled
362	Post Point	Bellingham Bay	729	25	1							26	48	6	8								3				14	4	1,092
533	Westcott Bay	San Juan Island	337						1		2				414	2	7					8						6	771
536	Third Lagoon	San Juan Island	111	1	6	1									160	21	2											6	317
330	Mud Bay	San Juan Island	696	13	9					109	18				13		1								15			6	962
341	Crandall Spit	Fidalgo Bay	274							4	4				45													2	426
198	Discovery Bay	Strait of JDF	1,069	18	5										68	1	1											6	1,162
214	Dungeness River	Strait of JDF	971	1											74	1												3	1,047
323	Kiket Lagoon	Whidbey Basin	1,139	78	1					1					56													6	1,275
311	Penn Cove	Whidbey Basin	5,244												23	4	6											6	5,277
508	Race Lagoon	Whidbey Basin	1,716												7	50	3											6	1,776
516	Iverson Spit	Whidbey Basin	1,884	3											4	2	2											6	1,895
552	Elger Bay	Whidbey Basin	3,082	3											7													6	3,082
204	Kala Lagoon	Admiralty Inlet	3,185	4											31													6	3,221
306	Deer Lagoon	Admiralty Inlet	4,103	36											22		1											6	4,163
590	Lagoon Point	Admiralty Inlet	16					2			1				99	81												6	202
161	Zelatched Point	Hood Canal	2,605	2							4	9			7													6	2,649
138	Duckabush	Hood Canal	385												14		1	64										6	464
128	Nick's Lagoon	Hood Canal	522	6	1					32	5				55	2												6	652
74	Musquetti	Hood Canal	934	6						3					4	1												6	948
177	Carpenter Creek	Central Sound	4,360	2											39													5	4,401
173	Doe Kag Wats	Central Sound	2,059	18											78	2	2											6	2,163
133	Best Lagoon	Central Sound	2,327							3	14				3													6	2,368
553	Blakely Harbor	Central Sound	122		92	20	1								177		2						21					5	422
579	Heyer	Central Sound	416	11						1					5													2	433
581	Rabb's Lagoon	Central Sound	93		166						3				16	5	14								27			4	332
250	Butterball Cove	South Sound	2,627	1											76													6	2,706
TOTAL			41,006	228	270	110	22	5	4	1	1	188	101	6	1,505	172	42	64	10	4	3	1	167	34	27	231	14	44,216	

How “Diverse” Is Diverse? Patterns of Abundance and Diversity

A rank abundance curve (RAC) orders each species found in traps by their proportion of the total (Figure 2). The steepness of the line provides insight into how evenly organisms are divided among species. If the line is horizontal, all species are equally abundant. The RAC for trap contents of 2016 is extremely steep because hairy shore crab made up 93% of all organisms captured. This indicates that, **in general, the community of mobile animals in pocket estuaries that is sampled in baited traps is not a very “even” one.** Keep in mind, however, that not all organisms that live in these habitats will come to a baited trap.

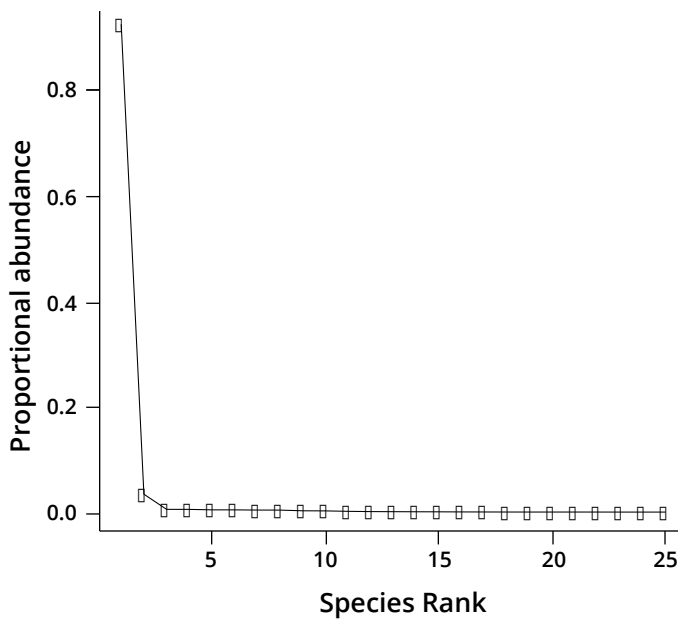


Figure 2. This rank abundance curve (RAC) puts each species captured across the entire network in order from most to least abundant and shows what proportion of the total of 44,216 animals captured in 2016 each made up.

Another way to look at ecological communities of pocket estuaries is how widespread each species is across all of the sites sampled. Figure 3 is a histogram, where each species is listed by the number of sites at which it was trapped. So, for example, the furthest left grey bar indicates that 10 of the species captured were found only at one site—they are rare species, uncommon in these habitats. On the other end, two species were found at nearly all of the sites: staghorn sculpin was found at 25 sites, and hairy shore crab was found at all 26 sites. **This shows us that most species we found are uncommon in pocket estuaries, limited to one or two sites.** A handful, such as purple shore crab, stickleback and hermit crabs, are intermediate. Only a very few species are common in traps.

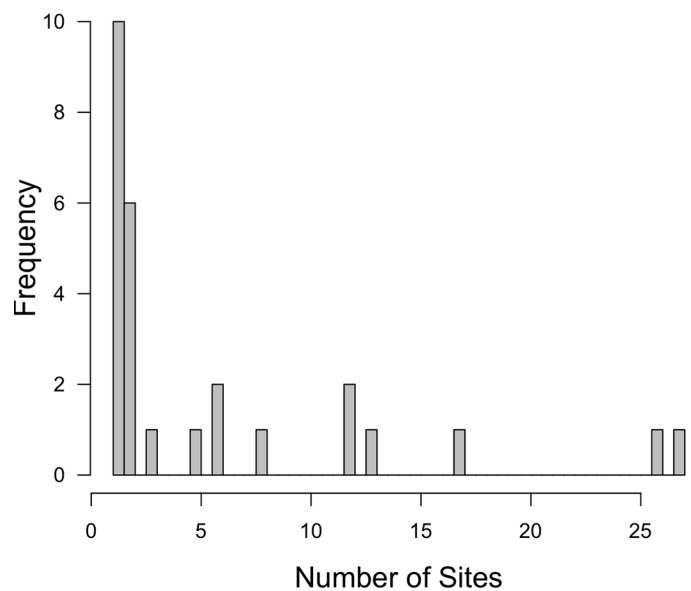


Figure 3. Species commonness histogram showing how many species were found at one or more sites. Each bar is the total number of species that was found at the number of sites indicated by the horizontal axis. Rare species, those found only at a single site or a few sites, are on the right side of the plot, and common species, those found at many sites, appear on the right side of the plot.

* Technically, because some of our observations group multiple species together (e.g., spider crabs, brokenback shrimp), the appropriate term is “taxa” (or taxon for singular), which means groups of organisms of a type, rather than species.

Does Diversity and Abundance Change Across the Salish Sea?

We found large differences in the number of individual animals and the number of species (or “taxa”*) observed across all our sites. Some sites had only a handful of organisms in their traps each month, while others had thousands. **Figure 4** gives some insight into the scale of that variation. The marker for each site is coded by size, where larger markers indicate a greater total number of animals found in traps during 2016, and by color, where a darker marker indicates a greater number of taxa found at that site in traps during 2016.

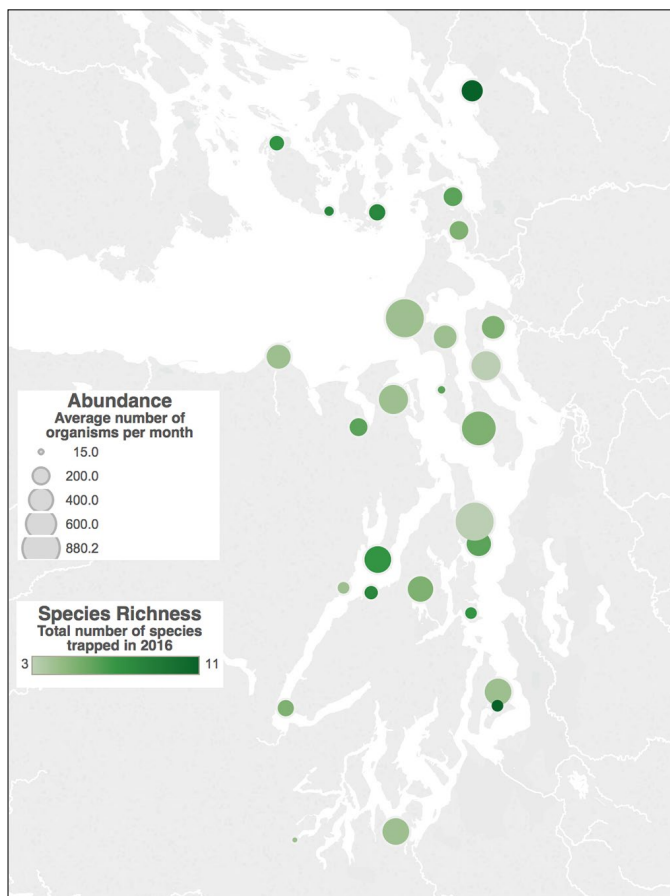


Figure 4. Map of total abundance and species richness (number of taxa) of animals captured in traps across 26 Crab Team monitoring sites during 2016. Larger circles mark sites with more total animals trapped, and darker circles indicate that more taxa were found at that site.

Note that the measure of abundance is the average number of organisms trapped per month, which allows us to adjust for the fact that some sites weren't sampled for the full six-month period. We made this adjustment because we would expect if you sample more times, you're likely to capture not only more organisms, but also more types of organisms, just because you sampled more, and not necessarily because there are more types of organisms at that spot. Sites characterized by greater diversity were scattered across the region, with the most diverse sites being the northernmost (Post Point Lagoon in Fairhaven) and one nearly southernmost (Rabb's Lagoon, Vashon Island). Even sites that were close to each other seemed to be very dissimilar in abundance and diversity of critters.

This suggests that local factors that apply specifically to each site, such as temperature, or salinity, or tidal regime, could be more important than regional factors in influencing these two characteristics of ecological communities.



PHOTO CREDIT: P. SEAN MCDONALD

Two European green crabs captured at Padilla Bay during 2016 rapid response trapping. Crab Team launched monitoring sites in Padilla Bay in 2017 in response to these detections.

Who and How Many? Does Abundance Influence Diversity?

When looking at the map (Figure 4), we noticed that larger circles seemed generally lighter in color (i.e., sites that had a great abundance of organisms had fewer taxa). To explore whether this was just a trick of the eye, or a true pattern, we took the sites out of geographic space and plotted them on XY axes. On the plot in Figure 5, the color of the markers from the map denoting the total number of taxa observed at each site during 2016 trapping has been translated to the vertical axis, and the abundance of organisms—again as the average number per month—is plotted on the horizontal axis. Thus, the total for each site is a dot on this plot. To find a particular site, use Table 3.

You'll see there is a fair amount of scatter but, generally, the **sites with the most critters in their traps also had very few taxa, while the sites with the most taxa trapped fewer critters**. The line on the plot draws the 'best-fit' relationship between the number of taxa and the number of critters*—the line that is

simultaneously closest to all the points or data. The number in the top right corner of the plot indicates the distance from the data to the line, or how well the estimated relationship (line) predicts the data we actually observe (dots). This value can range from 0–1, and a higher value means the data are close to the line, and the equation for the line has more accurate predictive power. A lower value doesn't necessarily mean the relationship doesn't exist, however. In ecology, such scatter often means that factors that aren't measured in the equation for the line also influence the outcome (taxa richness). So, if one site is below the line—fewer species than expected based on the abundance—perhaps it is because that site is heavily impacted by humans or experiences extremely high temperatures. Interpreting relationships like this is at the heart of ecology, and it often gives starting points for future questions.

The fit for the relationship between the number of taxa (richness) and the average number of individuals trapped per month, or the r^2 , is 0.35. This sounds low, but actually isn't bad for an ecological relationship,

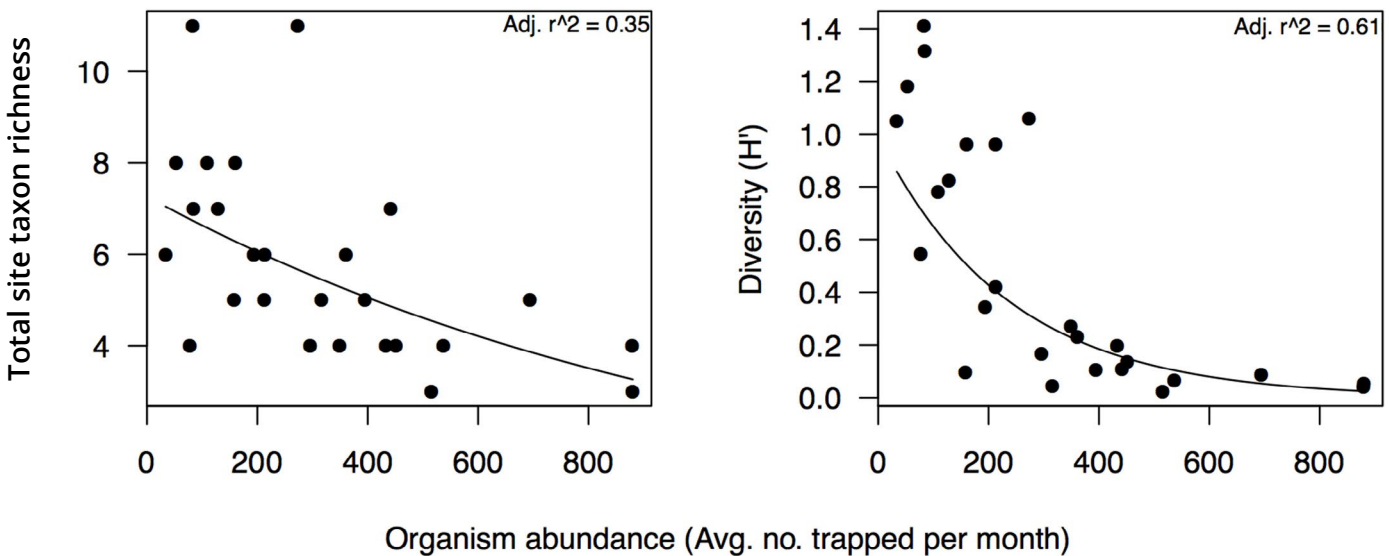


Figure 5. Relationship of taxa richness (left) and Diversity (H' , right) with average organism abundance per month in 2016 trapping surveys. Each point indicates a separate site. The lines plotted show the best fit of the data to a relationship with the natural log of organism abundance.

* If it looks like the line curves slightly, you have a good eye! The relationship was modeled not as a straight line, but using the natural log of abundance, which varies on an order of magnitude larger scale than taxon richness.

which is influenced by a lot of different contexts simultaneously, and thus data often have a lot of spread.

The plot in **Figure 5** has the same horizontal axis—abundance—but measures a different characteristic of the community: true **Diversity** (with a capital D). We often think of diversity (in common usage), as being simply the number of species (or taxa). That measure is usually called **richness** by ecologists and it is only one way diversity can be measured. The **evenness** (relative abundance) with which each of the species is represented also matters. Intuitively, we think that a cornfield is less diverse than a mixed forest because it is dominated by a single species; however, there may be just as many or more species present in the cornfield if you count the “weeds.” The measure of **Diversity** used here is the Shannon Index (denoted as H'), which includes both **richness** and **evenness** in the calculation. Increased **richness** and **evenness** will increase the Shannon Index for a site. This plot shows the same 26 sites by the same abundances on the horizontal axis, but with a new measure of “diversity” on the vertical axis.

Given the fact that hairy shore crab comprise 93% of trap catch, it’s no surprise that there is an even stronger negative relationship (steeper line) of H' with abundance. In large part, this is because the sites that have the highest trap catches have the most hairy shore crab, and therefore the lowest evenness. Want to see the data?

In **Figure 6**, we’ve shown the total number of all organisms at a site (no longer the average per month, but the total for all of 2016), which is now on the vertical axis, and the total number of hairy shore crab only on the horizontal axis. Each point still represents a single site. In this case, the data are very, very close to the line. (Editorial Note: it is rare to see such a high value of r^2 on ecological plots!) That means that the number of shore crabs is a very accurate predictor of the total number of organisms of all species that were trapped at the site. Note that the line doesn’t

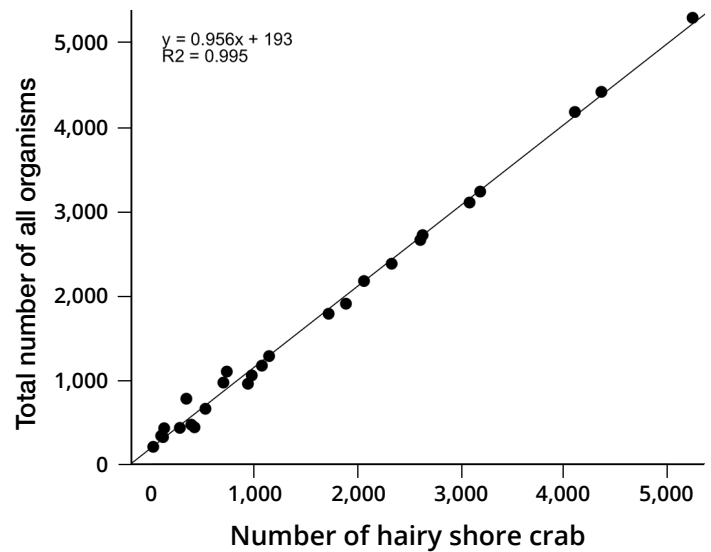


Figure 6. Relationship of the total number of all organisms in traps with the total number of hairy shore crab across all sites in Crab Team monitoring network during 2016. Line is estimated line of best fit.

go through the point (0, 0), but hits the vertical axis slightly above the horizontal axis. This means that even when there aren’t any hairy shore crab at a site (which in this case is only a prediction because every single site had at least one hairy shore crab in 2016), there are at least a few other organisms; to be precise, that’s estimated to be 193 other organisms.

Lower evenness at sites with high abundance of critters explains why there is a steeper decline in Diversity (H') with abundance, but it doesn’t explain why taxa richness apparently declines with abundance: **Why would more individual animals mean fewer types of animal?** Shouldn’t it be the opposite? However, a different face on the same question might be: why would more hairy shore crab mean fewer types of animal, because let’s face it, when we have more individual animals, it really means that we have more hairy shore crab.

This is an intriguing question that Crab Team doesn’t have an answer to—at the moment. After all, it’s only our first year. Here are some possibilities:

- Conditions that shore crabs are very good at surviving, and where they do best, are not suitable for many other species.
- Shore crabs decrease the diversity of other species in places where they live, potentially by out-competing for resources, or even eating other species directly.
- Or, it could be related to sampling technique: at sites with many hairy shore crab, they fill up a trap quickly. A trap of agitated pinchers might be less appealing for some of the shy species to enter, so those species might be present in the habitat, but not observed in the traps.

This is an excellent demonstration of how observational studies like Crab Team can provide hypotheses about how the world works. These ideas are potential starting points for future study.



PHOTO CREDIT: JEFF ADAMS

A female hairy shore crab bearing eggs under her abdominal flap.

When Do Crabs Celebrate Valentine’s Day? And Other Observations on Behavior

In addition to learning about ecological communities as a whole, we can learn about individual species from trapping data. For instance, volunteers often report how many gravid (egg-bearing) females they find. We can use this opportunistically collected information to identify peak reproductive times. Because we have the most data for hairy shore crab, our conclusions are strongest for that species. **Figure 7** is the total number of gravid females collected at all sites for each month during 2016. Reproduction measured this way shows two peaks, one in May and one in July/August. This is supported by previous research, which has found that each female hairy shore crab can bear two broods of eggs in a single summer. The timing of those peaks might change from year to year depending on temperature.

We can also learn about the crabs’ behavior by assessing the ratio of male to female crabs that enter traps. Many volunteers have noticed that the number of male hairy shore crab captured in traps is often, but not always, much greater than the number of females.

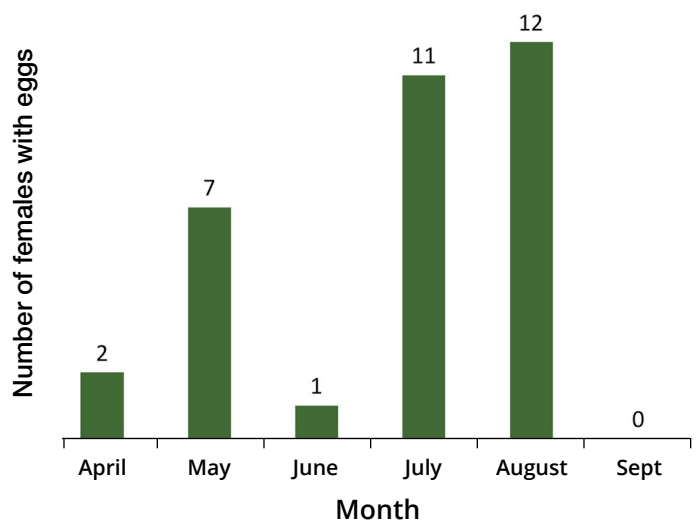


Figure 7. Total number of female hairy shore crab (*Hemigrapsus oregonensis*) captured in traps bearing eggs by month during 2016.

The predominance of males does not hold true for all species, however. **Figure 8** is a scale of the seven most common crab species in trapping surveys, arrayed along a gradient based on the sex ratio averaged across the entire 2016 trapping season. Note that the circles representing each species are different sizes—they have been scaled to reflect how many of that species were captured total. Thus, as with egg-bearing females,

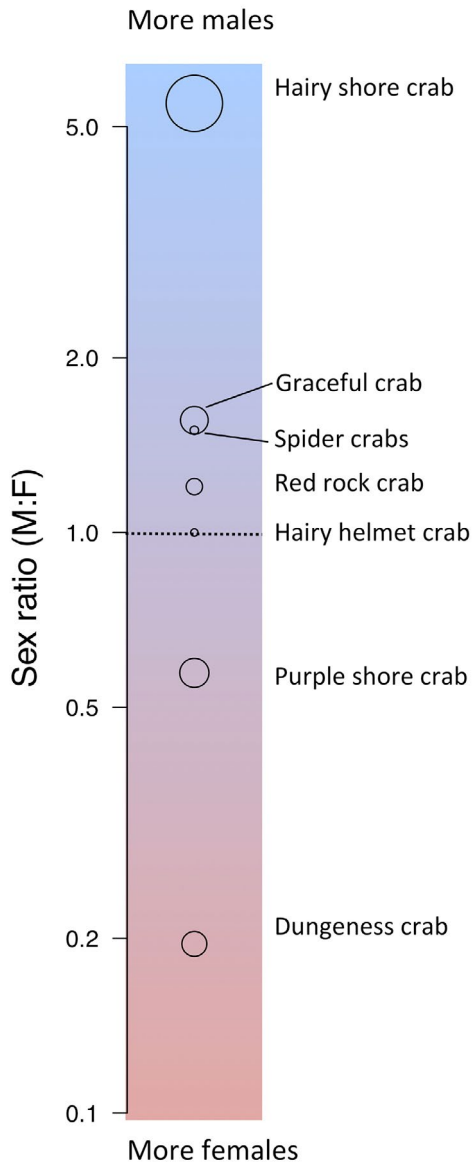


Figure 8. Sex ratio (male:female) of all crab species captured in traps during 2016. Size of circle indicates total number of individuals for that species/taxon captured.

our conclusions for hairy shore crab are stronger than for hairy helmet crab, of which only four individuals were found. The gradient is scaled logarithmically because the value for each species is a ratio. The dotted line at 1 indicates an equal number of males and females. A sex ratio of five means that there are five times more males than females, but a sex ratio of 0.2 means that there is one male for every five females—or five times as many females as males.

When we think about a species or population as a whole, we typically expect that the sex ratio should be closer to 1:1, so why would most of our crabs deviate from that ratio? Though for some organisms, there are behavioral, ecological, or biological factors that might cause an imbalanced sex ratio in the population, we suspect that the sex bias we observe is likely due to the effect of sampling and might occur for two reasons:

- 1) there are more crabs of one sex in the habitats we sample and/or
- 2) there are the same number of males as females in the habitat, but more of one sex enter traps.

If, for instance, female Dungeness crab disproportionately prefer the protected pocket estuaries where we sample, our result of a female-biased sex ratio reflects that habitat choice, rather than an assessment of the entire Dungeness crab population in the Salish Sea. For Dungeness crab, this seems most likely, as the females, being smaller, are often found in more protected habitats than the males.

A male-biased sex ratio might instead reflect behavior. The thought is that more males enter traps because they engage in greater risk-taking behavior in seeking food, because large size enables greater reproductive success. Entering a trap that is already full of pinchy claws is a risky proposition for a small crab. There is some evidence that, for hairy shore crab, males do take more risks than females.

One way we could test this question is by looking at the sex ratio of crab molts (which is an observation we don't currently collect); if it is closer to 1:1 averaged

over the season, then we could rule out the first explanation. However, this method could also be biased if one sex grows faster than the other, producing more molts per individual. A second way to test this is to use a type of trap that doesn't require crabs to make a decision to enter, such as a pitfall trap. A pitfall trap is a bucket buried so the top is level with the sediment surface—crabs fall in as they walk across the mud.

Sex ratio can also change over the course of the season, and that change can be different for different species—even for similar species. Comparing the two species of native shore crab (Figure 9), we see that not only is the overall average sex ratio different, but the trend over time is nearly opposite. Purple shore crab has a pronounced dip in June, then increases to a peak in September, while hairy shore crab decreases slightly, but steadily, over the course of the summer.

A lower sex ratio can occur either because fewer males, or more females, are entering traps. In order to figure out why these species differ, we can take a look at each sex separately. Figure 10 shows trend in abundance for both species over the course of the

season. Even though purple shore crabs are overall much less numerous in traps than hairy shore crabs, comparing the change over time can still show similar trends if changes in season are affecting the species similarly. In this case, male hairy and purple shore crabs appear in traps at similar relative abundances for most of the season, with the exception of June. Females of the two shore crabs species, however, show very different patterns. Female hairy shore crabs increase fairly consistently over the summer, but female purple shore crabs show a “hump-shaped” pattern: low in April and September, but consistent in the middle of the season. Why do females of these two species show a markedly different pattern? This remains an intriguing question for future study.

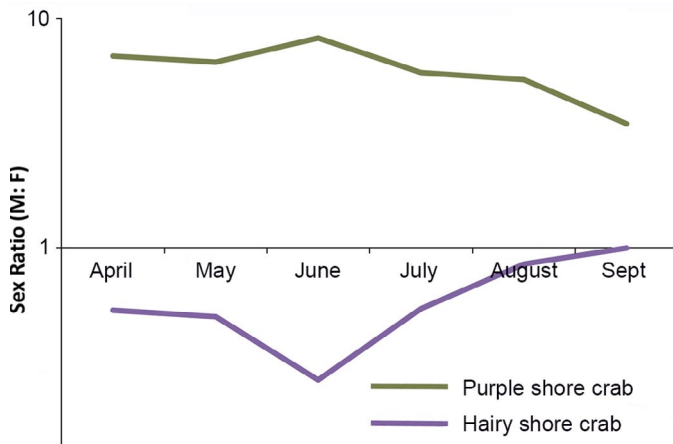


Figure 9. Sex ratio (male:female) of hairy (*Hemigrapsus oregonensis*) and purple (*H. nudus*) shore crabs trapped by month.

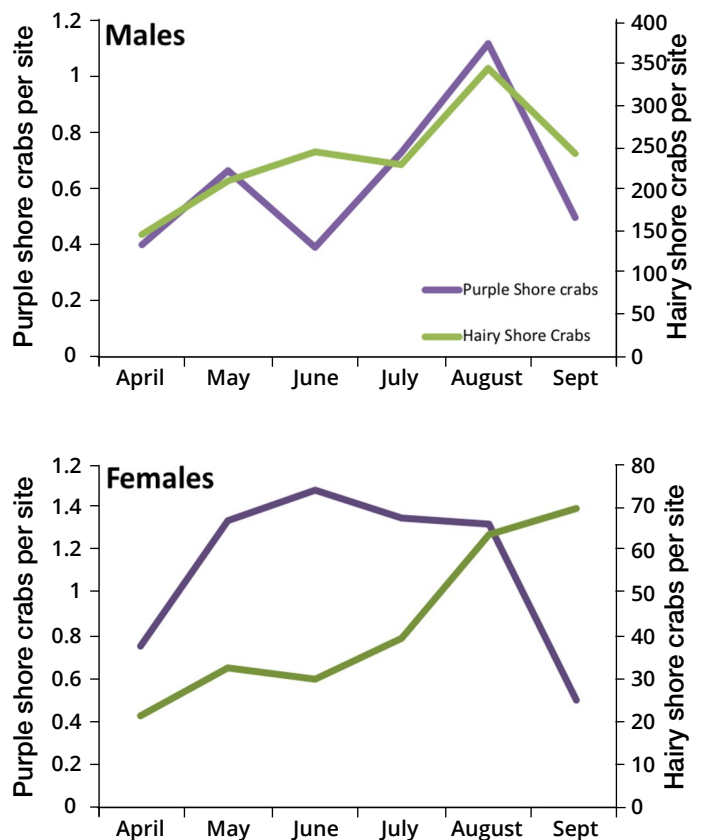


Figure 10. Total number of male (top panel) and female (bottom panel) hairy (*Hemigrapsus oregonensis*, right axis) and purple (*H. nudus*, left axis) shore crab captured by month.

3. MOLT SURVEYS

Another way to learn about the crustacean communities that live in the habitats we sample is by looking at their molts. Volunteers conduct standardized molt searches each month. By looking at molts we can find evidence of species that live in the area, but might not come to traps. We can also assess seasonality of growth for various species.

During 2016, a total of 12 taxa of crustacean was found in the molt surveys (Table 4). That’s close, indeed only one greater than, the number of crustacean species that were found in traps, but the species were not the same. Some species were found only as molts, including pea crabs, burrowing shrimp and amphipods. We know that burrowing shrimp are common in and around pocket estuaries, but because they are either filter or deposit feeders, we don’t expect them to come to our mackerel bait. The only crab that was captured live that did not also appear as a molt was the European green crab. Funnily enough, in Crab Team’s rapid assessment trapping in Westcott Bay following the capture of the single European green crab, we did find a green crab molt, albeit not in a location we expected to find molts.

The order of crustacean species abundance is similar in the trapping and molt data (Table 5), but large crabs, like Dungeness and rock crab, are found relatively more frequently as molts than they were in traps, probably because their molts are easier to find and degrade more slowly than those of smaller species or individuals, for instance, hermit crabs.

Table 4. Total Molts Collected by Species. Total number of each taxon collected in molt surveys across all sites and months during the 2016 monitoring season

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

Table 5. Commonness of Molts Collected. Number of sites at which each crustacean taxon was found in mmolt surveys during the 2016 monitoring season.

Molt Species	Common Name Where Found	# Sites
<i>Hemigrapsus oregonensis</i>	Hairy shore crab	26
<i>Hemigrapsus nudus</i>	Purple shore crab	19
<i>Cancer (Metacarcinus) magister</i>	Dungeness crab	18
<i>Cancer (Metacarcinus) gracilis</i>	Graceful crab	11
<i>Cancer productus</i>	Red rock crab	10
Multiple in <i>Majidae</i>	Spider Crabs	5
<i>Telmessus cheiragonus</i>	Helmet crab	5
Multiple in <i>Amphipoda</i>	Amphipods	2
Multiple in <i>Thalassinidea</i>	Burrowing shrimp	2
<i>Pagurus</i> spp.	Hermit crabs	2
<i>Lophopanopeus bellus</i>	Black clawed crab	2
Multiple in <i>Pinnotheridae</i>	Pea crabs	1

Learning How Communities Change Over Time And In Different Places, From Molts

We can learn about patterns of how many, and how many types of, crustaceans there are by looking at data on molts. **Figure 11** is a map of molt surveys, similar to the Figure 4 map, which is based on trapping data. The marker for each site is coded by size, where larger markers indicate a greater total number of molts found in hunts during 2016, and by color, where a darker marker indicates a greater number of molt taxa found during 2016.

Interestingly, sites that captured the most live crabs (**Figure 4**) didn't always have the most molts. Deer Lagoon, the southern-most site on Whidbey Island, for instance, was second out of all our sites in capturing the most live organisms. Yet, very few molts were ever found at this site. This is likely because site-related factors like wind and shoreline shape affect how many molts wash up on beaches.



PHOTO CREDIT: EMILY GRASON

Molts of the purple shore crab collected during the Crab Team molt survey.

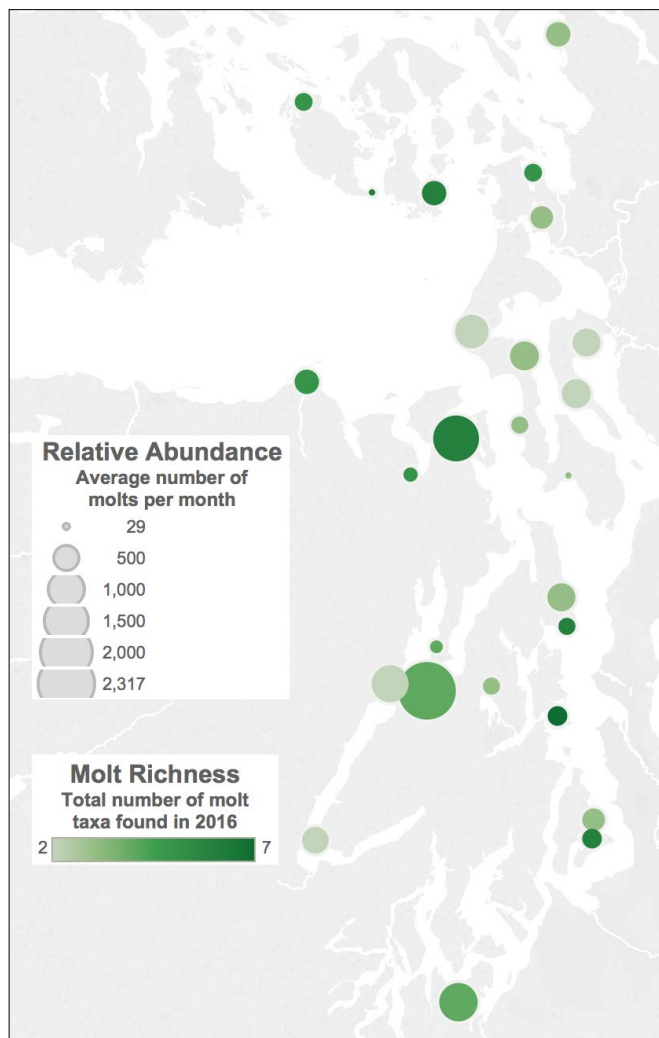


Figure 11. Map of total abundance and species richness (number of taxa) of molts collected across 26 Crab Team monitoring sites during 2016. Larger circles mark sites with more total molts, and darker circles indicate that more taxa were found at that site.

Examining patterns of peaks in molts can tell us about periods of growth. **Figure 12** shows the average number of molts of each species found per month at a typical site. While the numbers of each species vary (the darker lines indicate more molts of that species), peaks for a given species might indicate times of the year when that species is growing most rapidly. For hairy shore crab this appears to be May and September, while June was a clear peak for purple shore crab. When we find more molts overall, we can be more confident that a peak represents a change in growth rates for the species. However, species for which we found only a very few molts (hermit crabs, black-clawed crab and pea crabs) don't really give us enough information to tell if observations represent a peak or just a rare sighting.



PHOTO CREDIT: P. SEAN MCDONALD

Volunteers Caitlin Kenney and Gail Trotter tally the molts found during survey at Butterball Cove near Lacey.

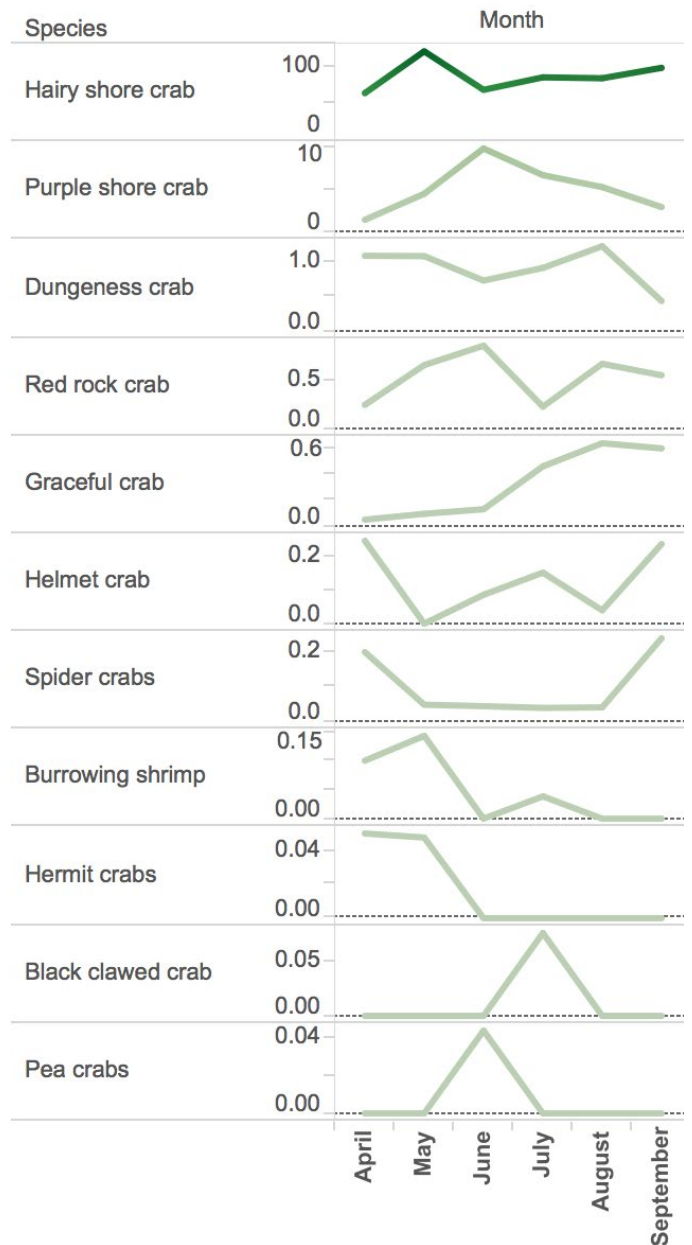


Figure 12. Total number of molts collected by survey month for each species found across 26 Crab Team monitoring sites during 2016. Species are ordered by most molts found (top) to fewest molts found (bottom).

4. HABITAT TRANSECT SURVEYS

Of the three Crab Team protocols implemented at each site—trapping, molt hunt and shoreline transect—only the first two actually involve looking for European green crab. The shoreline transect protocol is designed to collect information about the sampling site itself, how much of it is anchored by vegetation, what the washed up debris (wrack) can tell us about the surrounding habitat, etc. Collected over time, this information could help us understand how habitat influences green crab, and vice versa. We know that green crab do well in pocket estuaries, but can we get more specific than that? Can

we predict where green crab will show up and do well based on how much vegetation, or eelgrass or trash, is present? Or, can we see changes in the vegetation, or eelgrass, as a result of green crab population growth? By comparing sites with and without green crab, before and after arrival, we could start to disentangle the relationships with habitat factors that could help us prioritize other sites for protection.

Figure 13 is a map of 2016 sampling sites, showing how much wrack each site had monthly, on average, and what that wrack was made up of. The “wrackiest” site

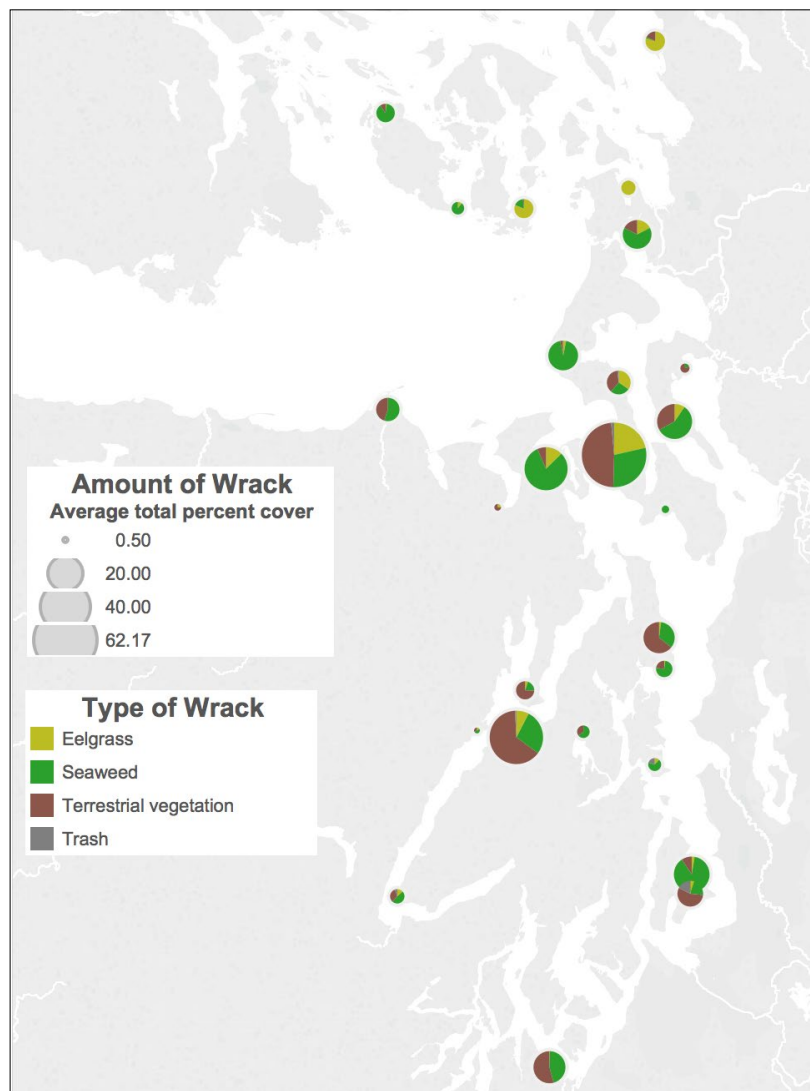


Figure 13. Map of average wrack percent cover (size of circle) and composition (colors) by site.

was Lagoon Point on Whidbey Island. On average, each month more than half of its shoreline was covered with some kind of washed up debris, mostly terrestrial vegetation. The three sites that were dominated by eelgrass in the wrack were all up north.

Learning How Sites Change Over Time And In Different Places, From Transect Surveys

Collecting habitat information monthly enables us to explore seasonal patterns in shorelines. As environmental factors such as nutrients wave intensity, temperature and the amount of time the intertidal zone is exposed at low tide change over the course of the year, they likely trigger changes in shoreline features. For instance, in late summer, we might expect to see more barnacles and mussels dying from heat or long exposure to the air. We might also expect to see evidence of an increase in “primary production” (growth by photosynthesizing organisms like eelgrass and seaweed) in the earliest months of sampling, when nutrients are most available in the water. We might even detect a shift from sand to mud as beaches settle out after winter storms.

Green crab could alter not only the habitat itself, but also the seasonal patterns in the habitat. For instance, in a typical year, we might see the percent cover of epifauna start to drop in July. But green crab looking for a meal could reduce populations of barnacles and mussels earlier in the year. If we recorded observations on the habitat only once or twice a year, we would likely miss these changes. Monthly surveys give us more time points to identify whether there is a trend or directional change in features over the course of the seasons.

Figure 14 shows the percent cover of each of the four substrate cover categories, averaged over all the sites for each month. You’ll notice that nearly all of the space is either bare or covered with vegetation, and that, on average, **vegetation fills**

in about 16% more of the space in September than it did in April. Some of this increase is the sprouting of new seeds, filling in gaps, or the asexual growth of plants like saltgrass (*Distichlis*) that use rhizomes and runners to spread out and cover new territory. We might expect that, over the winter, storms will remove some of this new growth, but we’ll have to wait until we analyze 2017 data to find out.

Live epifauna (living animals attached or sitting in place) and filamentous green algae are two categories we added in 2016. They are both rare, but present at some sites. A stronger test of our hypotheses about seasonal trends in cover of live epifauna would be to zoom in on sites that actually have some of that category. Percent

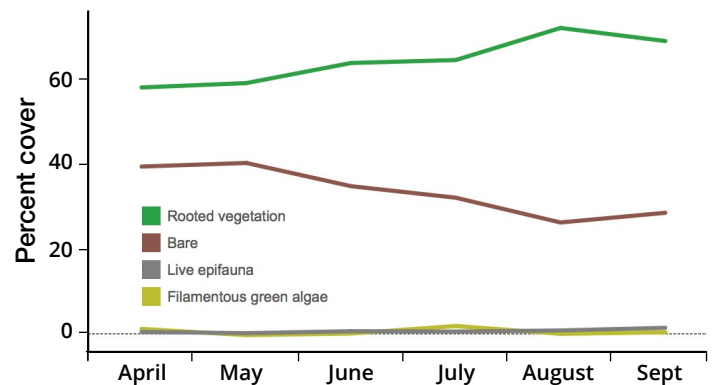


Figure 14. Percent of habitat cover by category and month, averaged across all sites.

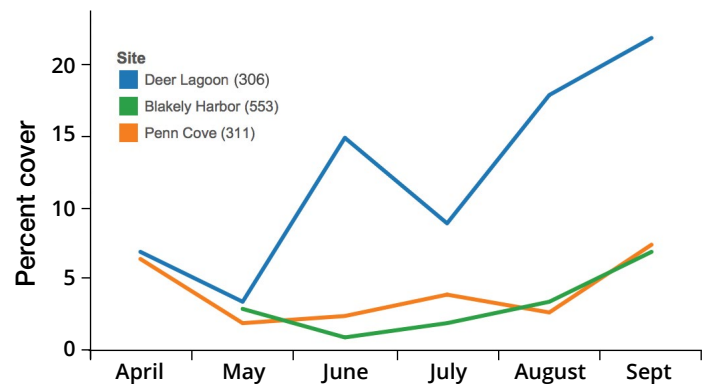


Figure 15. Percent cover of live epifauna by month at the three sites where this category was detected in 2016.

cover of epifauna (averaged across the 10 quadrats) is graphed for the three sites with the most live epifauna (Figure 15). The original hypothesis was that live epifauna would decrease over the season due to stress of daytime low tides. None of the sites show this trend. Blakely Harbor and Penn Cove show a possible, if weak, “U-shaped” trend, and Deer Lagoon shows a marked increase in cover of live epifauna. This increase could be due either to population or individual growth—more mussels and barnacles or bigger mussels and barnacles.

What about the wrack? The amount of wrack observed at the sites was highest in April, and that was mostly due to an abundance of washed up seaweed during that month (Figure 16). This does support our prediction of a spring “bloom” of photosynthetic growth. We don’t see the same trend in eelgrass in the wrack, however, and that is probably because eelgrass is growing at that time, but staying rooted in the deeper areas. If we were to conduct our surveys

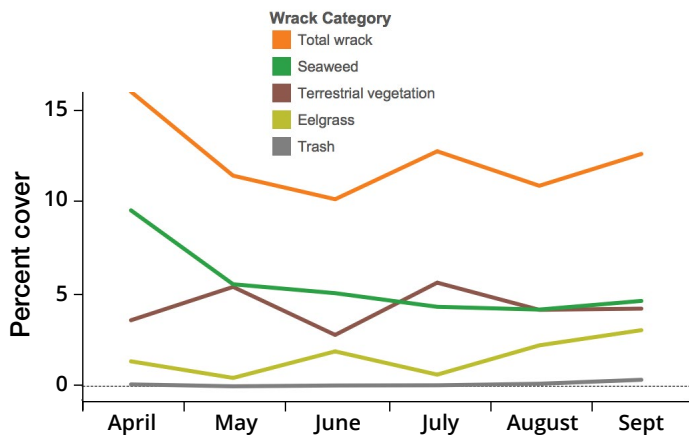


Figure 16. Percent cover of wrack by category and month, averaged across all sites.

during the winter, after the migratory brandt (geese) come through to graze on eelgrass and when storm waves break the long blades, we would probably see much more eelgrass in the wrack. One positive note from these observations is that trash was very rare at all of the sites. Is it possible the very slight uptick in September is the accumulated debris of many summer vacations?

Sometimes, very small changes that happen over the course of several months aren’t apparent to our eyes alone. That is a major advantage of a large data set. When these small changes are aggregated over all of the sites, they become more obvious, and conclusions about them more robust. As Crab Team gathers more data about shoreline habitats, we’ll have a better idea of which aspects show seasonal change and how often we truly need to sample to capture those changes. We can then use that knowledge to assess whether we could simplify the transect protocol and still be confident that we weren’t losing the ability to detect changes.

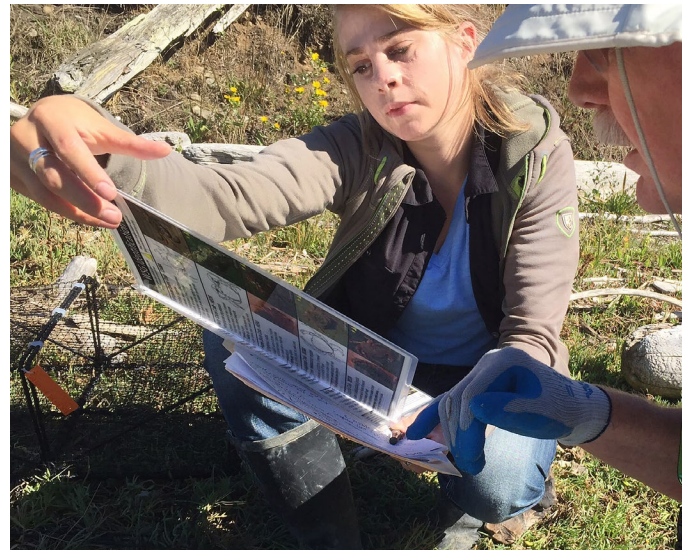


PHOTO CREDIT: SUSAN MADOR

Crab Team Intern, Natalie White, checks identification details with volunteer Charlie Seablom at Penn Cove on Whidbey Island.

CLOSING THOUGHTS

Crab Team staff are immensely grateful for the contributions of volunteers in helping build a monitoring program founded on robust and well-tested methodologies, ultimately advancing the goals and impacts of citizen science. Long-term data sets have been shown to be the most influential in effecting policy and management change. Early detection monitoring by Crab Team volunteers and partners has undoubtedly enabled us to do what has rarely been accomplished in invasion biology—detect and respond to the

leading edge of a potential invasion. Because of volunteer participation, Washington’s Salish Sea has the best chance to avoid ecosystem impacts from this globally damaging invasive. In the role of sentinels, volunteers are also amassing a treasure trove of data on these relatively understudied habitats of the Salish Sea. The value of this data set grows with each year added, and can be applied to other management questions such as the health of restoration sites, and the ecological consequences of human modifications to habitats.



PHOTO CREDIT: ALLEN PLEUS/WDFW

Crab Team Co-PI Sean McDonald and Nicole Burnett of the Padilla Bay NERR check traps set during the rapid assessment at Padilla Bay in 2016.



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THANK YOU FOR BEING PART OF THE CRAB TEAM 2016!



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