Utility of molt data for linking life stages and estimating abundance of Dungeness crab (*Metacarcinus magister*) in Puget Sound

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Abstract

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The Puget Sound Dungeness crab fishery in Washington state is culturally, economically, and recreationally valuable. Despite the importance of the fishery, large data gaps often render abundance estimates of Dungeness crabs highly uncertain; no demographic data are typically available for the several-year period between larval and adult stages. Since crabs molt in regular intervals like all arthropods, shed molts may provide a useful index of population abundance during these intermediate years, at relatively low effort and cost. While these molt data are indirect evidence of a Dungeness crab, they nevertheless provide information that a crab was once present. When paired with other datasets, molt data could increase confidence in abundance estimates and determine size class distribution of Dungeness crab in intermediate life stages across space and time in Puget Sound. My analysis using Bayesian hierarchical models shows spatial, but not temporal, variation in predicted mean molt count. Predicted mean counts of Dungeness crab megalopae are positively correlated with predicted mean counts of Dungeness crab molts. This positive relationship varies across space with Northern Hood Canal as a notable outlier.

TABLE OF CONTENTS

List of Figures

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DEDICATION

Dedicated to my dear cat, Binx, who sits by my side every time I work from home.

INTRODUCTION

The Puget Sound Dungeness crab fishery is culturally, economically, and recreationally valuable. Dungeness crab have been stewarded and managed by Indigenous Peoples since time immemorial (Frid et al., 2016; Ban et al., 2017), and in the present day, the fishery is co-managed between the Northwest Treaty Tribes and Washington State (United States v. State of Washington, 1974; United States v. State of Washington, 1995). Co-managers of the Puget Sound Dungeness crab fishery largely rely on landings data for abundance estimation, which leads to spatial and life history data gaps since landings data are fishery-dependent and only include data on adult male Dungeness crab. Dungeness crab molt data could be used to address these data gaps, but these data must first be investigated to determine if patterns expected based on Dungeness crab biology emerge to provide more direct use for co-managers. As a first step, here I ask: Do Puget Sound Dungeness crab molt data exhibit variation across space and time consistent with expected biological processes? Can these molt data be used to link multiple life stages of Dungeness crab?

The spatial structure of the Puget Sound Dungeness crab fishery leads to a gap in adult Dungeness crab data when management areas are closed. Northwest Treaty Tribe Puget Sound Dungeness crab fisheries include commercial and subsistence Dungeness crab fisheries in their "usual and accustomed areas" (U&As) identified in their treaties (United States v. State of Washington, 1974; Poe et al., 2015). Washington state Puget Sound Dungeness crab fisheries include commercial and recreational fisheries (WDFW, n.d.a.; WDFW, n.d.e.). For Washington state commercial fisheries, there are nine Puget Sound Crab Management Regions (PSCMRs), while the recreational fishery is managed in eleven Marine Areas (WDFW, n.d.d.; WDFW, n.d.e.). There is no stock assessment for Puget Sound Dungeness crab fisheries (Buckner et al., 2020).

Instead, allowable catch is jointly determined by the Northwest Indian Fisheries Commission and the Washington Department of Fish and Wildlife and is calculated based on two types of data: landings data and test fishery data (WDFW, n.d.a.; WDFW, 2020). Test fisheries provide fishery independent data, while commercial and recreational catch numbers provide fishery dependent data throughout open seasons (WDFW, 2020). PSCMRs without commercial fisheries do not generate commercial landings data and therefore produce less information about the adult Dungeness crab life stage compared to areas with commercial fisheries. Molt data, however, are independent of the Puget Sound Dungeness crab fishery and can be gathered in areas where recreational and/or commercial take are prohibited. Molt data could also be used to capture distribution and size-class information for juveniles, adult crab under the legal limit, and female crab, which are not available in landings data (Washington Department of Fish & Wildlife, n.d.a.).

Catch allowance in the Puget Sound Dungeness crab fishery is determined through the "3 S" management method: size, sex, and season. The same restrictions for size and sex exist across all management areas in Puget Sound; crab retained must be male and must be at least 6.25 inches wide across their carapace, measured in the notch in front of the widest marginal tooth (WAC 220-340-420). The opening and closing of fishing seasons are timed to decrease handling mortality for soft-shell (recently molted) crab and increase the amount of meat present per crab (Kruse et al., 1994; Buckner et al., 2020; WDFW, n.d.b.). In the Washington state recreational fishery, only five males are allowed to be taken per person per day, during open seasons (WDFW, n.d.g.). The catch allowance per management region is determined by the methods described above. Filling in the existing spatial and life history data gaps through larval and molt datasets could help co-managers with season opening and catch allowance determinations.

Larval and adult Dungeness crab life stages are monitored in Puget Sound, but the juvenile life stage remains difficult to study, leading to another management data gap (Buckner et al., 2020). A more robust understanding of the juvenile life stage could lead to more targeted management across space and time by informing co-managers of abundance of different age classes of crab in each management region. Dungeness crab are juveniles from the time they settle to the substrate following their larval life stage until they are around 100 mm wide, a period of about two years (Rasmuson & Lesser, 2013). Juvenile crab between 5 and 100 mm cannot be gathered using light trapping methods, and juveniles under 1.25 inches are too small to be retained in traditional Dungeness crab traps (Rasmuson & Lesser, 2013; Cook et al., 2018; WDFW, n.d.f.). The juvenile life history stage is a critical one for Dungeness crab since they must use this time to settle in an area and grow to a size where they are less vulnerable to predators (Rasmuson & Lesser, 2013). This life stage is also important because it links the larval and adult life stages, a key area of interest identified by co-managers (Buckner et al., 2020).

Molt data are additionally advantageous in terms of cost and effort. The Sea Grant Molt Search program trains participatory scientists to collect molt data (Washington Sea Grant, n.d.). These surveys are then completed by volunteers in their own time. The only cost associated with this work is the cost of training the volunteers and maintaining the dataset. Molt data are gathered via intertidal surveys and can be performed at any beach and at any time by trained volunteers. Juvenile crabs molt multiple times per year, at a rate determined by temperature and food availability (Terwilliger & Dumler, 2001). It is therefore possible to collect molt data on Dungeness crab at any time of year on any publicly available beach, not just during the adult molting season. While this survey method is a powerful tool to gather Dungeness crab information across large spatial and temporal scales, it remains an open question whether those data are reflecting molting patterns expected based on Dungeness crab biology, and if these data can be successfully linked to other life stages. The objectives of this thesis were to: (1) assess the spatial and temporal variation in occurrence of Dungeness crab molts, (2) quantify the size frequency distributions of molts across space, and (3) assess the relationship between larval and molt abundance. By better characterizing the spatial and temporal dimensions of the molt data, as well as the life history stages represented, this work helps to clarify the potential applications and limitations of these data for Dungeness crab assessment.

METHODS

Washington Sea Grant and Washington State University Extension host the Molt Search Program which trains participatory scientists to gather crustacean molt data during 20-minute beach surveys (Washington Sea Grant, n.d.). Data collection began in April of 2023 as an early detection effort for detection of the invasive European green crab (*Carcinus maenas*) (Washington Sea Grant, n.d.). Researchers realized this effort could also be a method to gather valuable information on Dungeness crab. The location and timing of the survey are determined by the individual conducting the survey and are standardized to 20 person-minutes of active searching. During that period, participants walk continuously along a wrack line or water line where molts are most likely to be deposited and pick up crustacean molts one at a time. After the transect is completed, molts are photographed, identified, counted, and measured. Participants record survey data in the MyCoast App or website (https://mycoast.org/wa/crab/report). Data include a photo of molts found alongside an item for scale, time, tide, location, participant information, presence/absence of all molts, presence/absence of European green crab molts, presence/absence of Dungeness crab molts, optional Dungeness crab measurement information, and any additional notes. The molt count represents a full census of intact molts along the transect, excluding any molt with less than 50% of its carapace remaining to prevent double counting. All molts are crushed at the end of each survey to prevent another Molt Search participant double-counting those same molts in a later survey. If ten or fewer Dungeness crab molts are found during a survey, their carapace widths, widest point to widest point, are all measured. If more than ten Dungeness crab molts are found, ten molts are haphazardly selected to be measured and recorded, meaning no more than ten measurements are included per survey. Washington Sea Grant staff contact survey participants through MyCoast if edits or clarifications on survey data are needed. Once reviewed, staff mark surveys as “public” and publish them on the MyCoast website.

I downloaded all Molt Search survey data (.csv) from the MyCoast website and prepared the data for analysis in R (R Core Team, 2025) using dplyr (Wickham et al., 2023), tidyverse (Wickham et al., 2019), and sf packages (Pebesma, 2018; Pebesma & Bivand, 2023). Surveys before April 2025 did not always include Dungeness crab molt information because it was optional before that time. I analyzed all surveys which were submitted before the mandatory inclusion of Dungeness crab information to determine the number of Dungeness molts found per survey. I removed any incomplete and/or compromised surveys from analysis. Surveys with zero molts observed were recorded as such.

I chose to start the process of linking Dungeness crab life stages by incorporating a fishery independent dataset which includes counts of the megalopae stage of larval Dungeness crab. Since molt data include both juvenile and adult life stages, it would be most informative to connect these data with larval information. The Pacific Northwest Crab Research Group (PCRG) monitors larval Dungeness crab annually from April through September using standardized light traps across Washington (Cook et al., 2018; Pacific Northwest Crab Research Group, n.d.). The PCRG Larval

Crab Technical Team shared data from 22 light trap locations from April 2019 through September 2025 with me. I filtered out data from sites that are not situated within my study region and removed data from before April 2022 to better align with the Molt Search dataset which began in April of 2023. I removed any incomplete and/or compromised surveys from analysis.

I downloaded shapefiles for my Puget Sound Crab Management Regions (PSCMRs) from ArcGIS Online for spatial analysis (Washington Department of Fish & Wildlife, 2023). I used ArcGIS Pro to cut PSCMR 5 (Hood Canal) into two polygons with the boundary at Ayock Point, and PSCMR 6 into two polygons with the Tacoma Narrows Bridge as their boundary (Esri Inc., 2024). PSCMR 3-1 only has 3 datapoints, so I combined it with PSCMR 3-2 (n = 45) to be comparable to area 3-3 (n = 52). This splits the Strait of Juan de Fuca into east (3-1 and 3-2) and west (3-3) regions. I grouped molt and larval survey locations into PSCMRs in R (R Core Team, 2025) using the sf package (Pebesma, 2018; Pebesma & Bivand, 2023) (Figure 1).

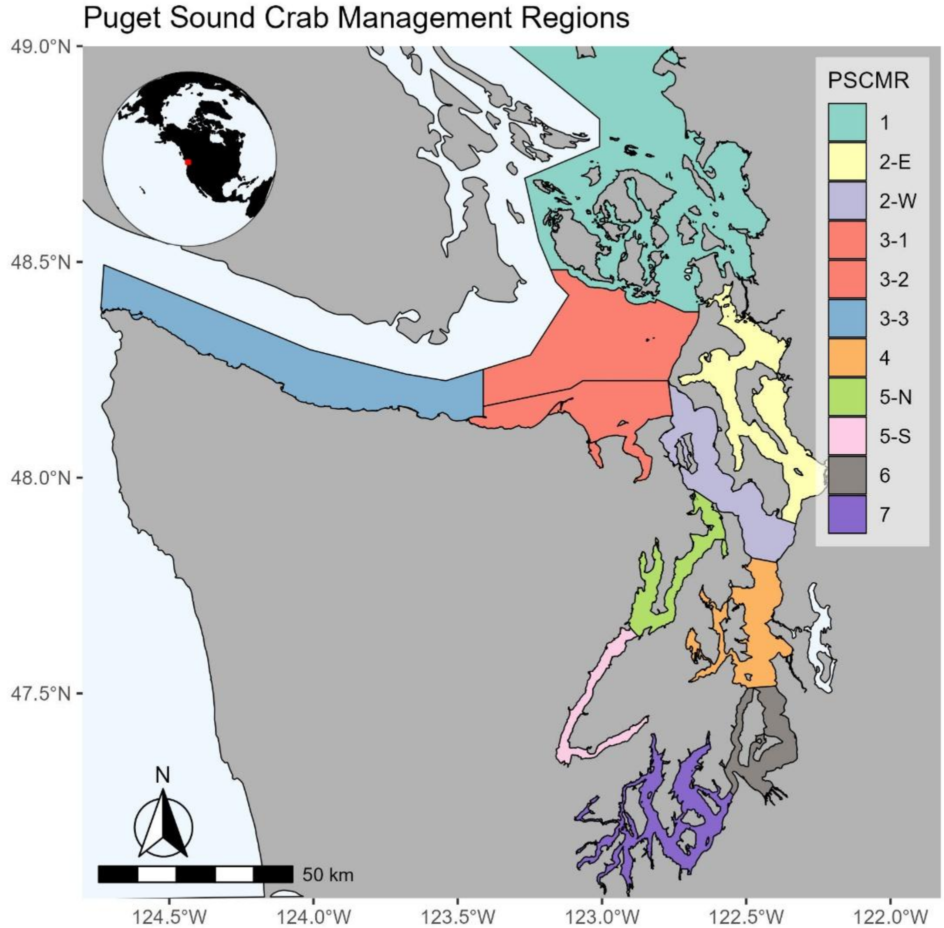

Figure 1. Puget Sound Crab Management Regions (PSCMRs) edited for these analyses. Region 5 (Hood Canal) is split into northern (5-N) and southern (5-S) polygons, Region 6 was split into Regions 6 and 7, and Regions 3-1 and 3-2 were combined.

1.1 MOLT COUNT BY MONTH

I conducted analyses of data in R (R Core Team, 2025) using the STAN package (Stan Development Team, 2025) to assess spatial and temporal variation in mean molt count, as well as the strength of the relationship between larval and juvenile/adult life stages. I used Dungeness crab molt count per survey from the Molt Seach dataset and megalopae count per survey from the PCRG light trap dataset. To extract posterior predictions of mean Dungeness crab molts per PSCMR, I created a Bayesian hierarchical model with two submodels, larval and molt, each with a negative binomial likelihood, random effect of month, random effect of region, hereafter referred to as Model 1. The molt submodel also includes a gamma parameter which creates a linear relationship between larvae and molt counts. Model 1, below, therefore predicted molt abundance as function of month, region, and larval supply. I used the negative binomial distribution as the likelihood for larval and molt datasets because they both have a right skew and are zero-inflated. I analyzed month and region random effects via deviation from overall posterior predicted mean molts. I analyzed MCMC chain convergence via trace plots for each prior and found that all chains converged.

Model 1 Larval Submodel

$$y_{lar} \sim NB(\mu_{lar}, \phi_{lar})$$

$$\mu_{lar} = \exp\,(\alpha_{lar} + \beta_{lar\,region} + \delta_{lar\,month})$$

Model 1 Molt Submodel

$$y_{molt} \sim NB(\mu_{molt}, \phi_{molt})$$

$$\mu_{molt} \sim \exp\,(\,\alpha_{molt} + \beta_{molt\,region} + \delta_{molt\,month} + \gamma * \log(\mu_{lar}))$$

1.2 Molt Count by Region

I created a second Bayesian hierarchical model (Model 2) by removing the month random effect to determine if a better fit could be achieved without it. Model 2, below, predicted molt abundance as a function of region and larval supply; region was included as the only random effect. I used MCMC chain convergence in the same manner as Model 1 and found that all chains converged.

Model 2 Larval Submodel

$$y_{lar} \sim NB(\mu_{lar}, \phi_{lar})$$

$$\mu_{lar} = \exp\,(\alpha_{lar} + \beta_{lar\ region})$$

Model 2 Molt Submodel

$$y_{molt} \sim NB(\mu_{molt}, \phi_{molt})$$

$$\mu_{molt} \sim \exp\,(\alpha_{molt} + \beta_{molt\ region} + \gamma * \log\,(\mu_{lar}))$$

1.3 Bimodal Size Distribution

I investigated size frequency of Dungeness crab molts across regions to determine if Molt Search surveys capture multiple size classes across space. The successful capture of the juvenile life stage is of particular interest because this life stage is not easily observed via other data collection methods. I created histograms of carapace width data in R (R Core Team, 2025) using ggplot2 (Wickham, 2016) for all Dungeness crab molts measured in the Molt Search dataset.

1.4 Larval Link

I analyzed the relationship between larval and molt count across regions through a linear predictor, called gamma (γ). The gamma value returned by the model indicates the strength of linkage between megalopae and molt count.

RESULTS

1.5 MOLT COUNT BY MONTH

Adult Dungeness crab (>100 mm) have a distinct molting season in spring and summer which occurs during their mating season, so I expected to see a difference in the predicted number of molts per survey between fall/winter months and spring/summer months (Rasmuson & Lesser, 2013). Instead, I found that month had no effect on the expected number of molts per survey (Figure 2).

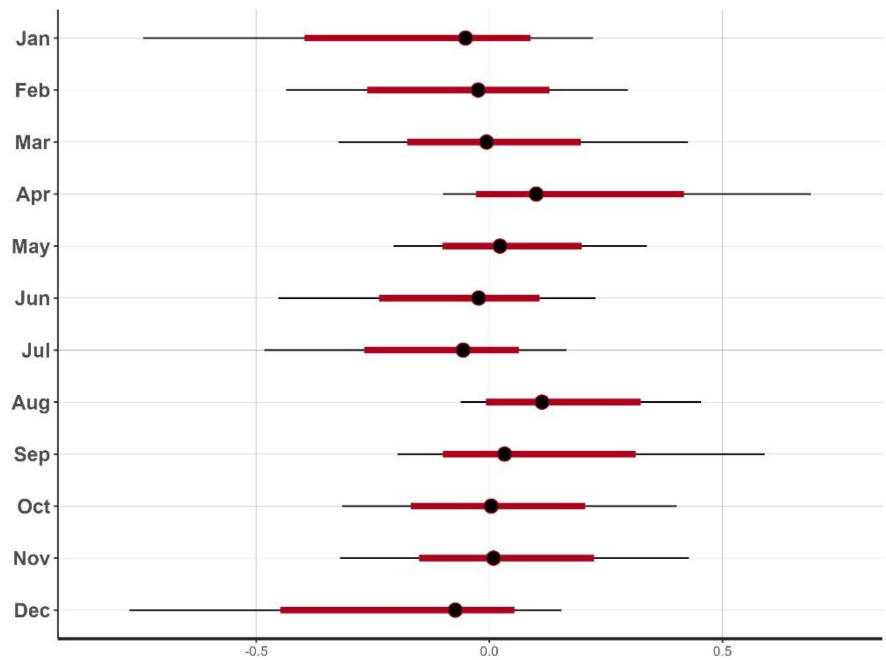

Figure 2. The posterior predicted means of Dungeness crab molts per survey per month. No month deviates from zero, meaning that month is not a useful predictor of molt count per survey.

This lack of month effect could be driven by a few different processes. The survey effort of Molt Search surveys is concentrated in spring and summer months with a large drop in effort during other seasons, especially in winter months (Figure 3). There may not be enough survey data in the winter to detect a difference in number of molts across time. Juvenile Dungeness crab molt detection could be another process obscuring the effect of month. Juvenile Dungeness crab molt 4-6 times during their first year after settling down to the substrate in their post-larval stage, so this process could be increasing the number of molts found across the year and obscuring the expected increase in molt count during adult molting season (Rasmuson & Lesser, 2013; WDFW, n.d.b.).

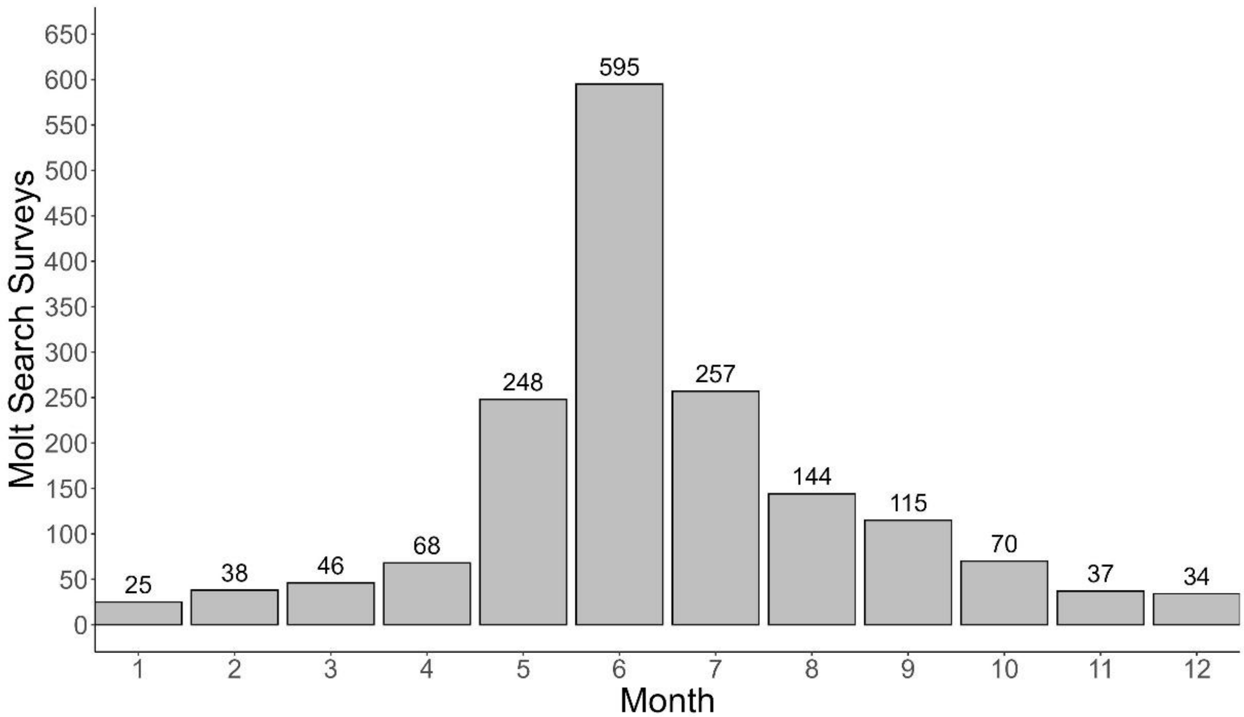

Figure 3. Count of Molt Search surveys per month, showing aggregated effort across all years. Note: this does not illustrate the number of molts per search but rather enumerates the total search effort per month.

1.6 Molt Count by Region

The predicted means of Dungeness crab molt counts per survey show differences across space that reflect expected abundance based on fishery structure (Figure 4), where PSCMRs 5-S and 7 show a low number of predicted molts counts per survey. All Dungeness crab fisheries are currently closed in southern Hood Canal (PSCMR 5-S) and in South Sound (PSCMR 7), meaning that adult Dungeness crab abundance is too low to support fishing in those areas. Low predicted counts of megalopae are also reflected in those same regions. Low predicted means for both larval and Molt Search surveys in these areas indicate that all life stages are at lower levels compared to other areas, not just the adult life stage.

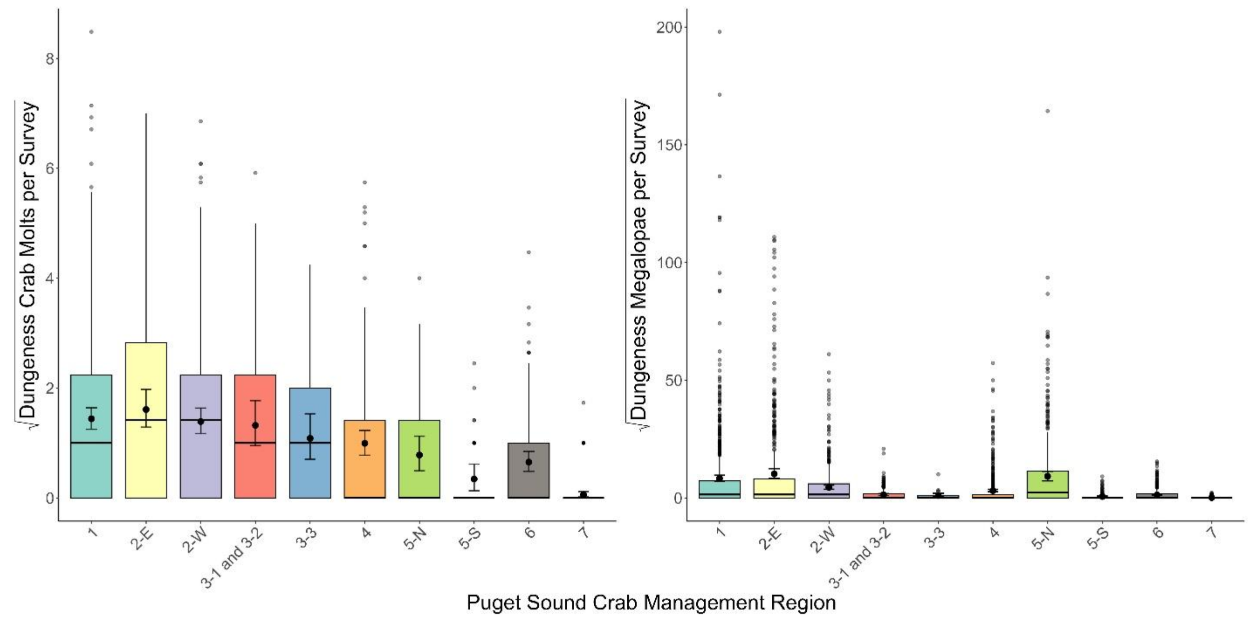

Figure 4. The posterior predicted means of square root-transformed Dungeness crab molt and megalopae counts with a 95% credible interval for Molt Search and light trap surveys within each PSCMR. Boxes indicate the median (middle line), 25^th^ percentile (bottom line), and 75^th^ percentile (top line). Data are square root transformed to better display data spread.

Region, included in Model 2 as a random effect, shows deviation from zero in multiple areas. This means that region does have an effect on the expected number of molts per survey. PSCMRs 3-1/3-2 and 3-3 had substantially greater-than-average molt counts per survey and PSCMRs 5-N and 7 had substantially fewer.

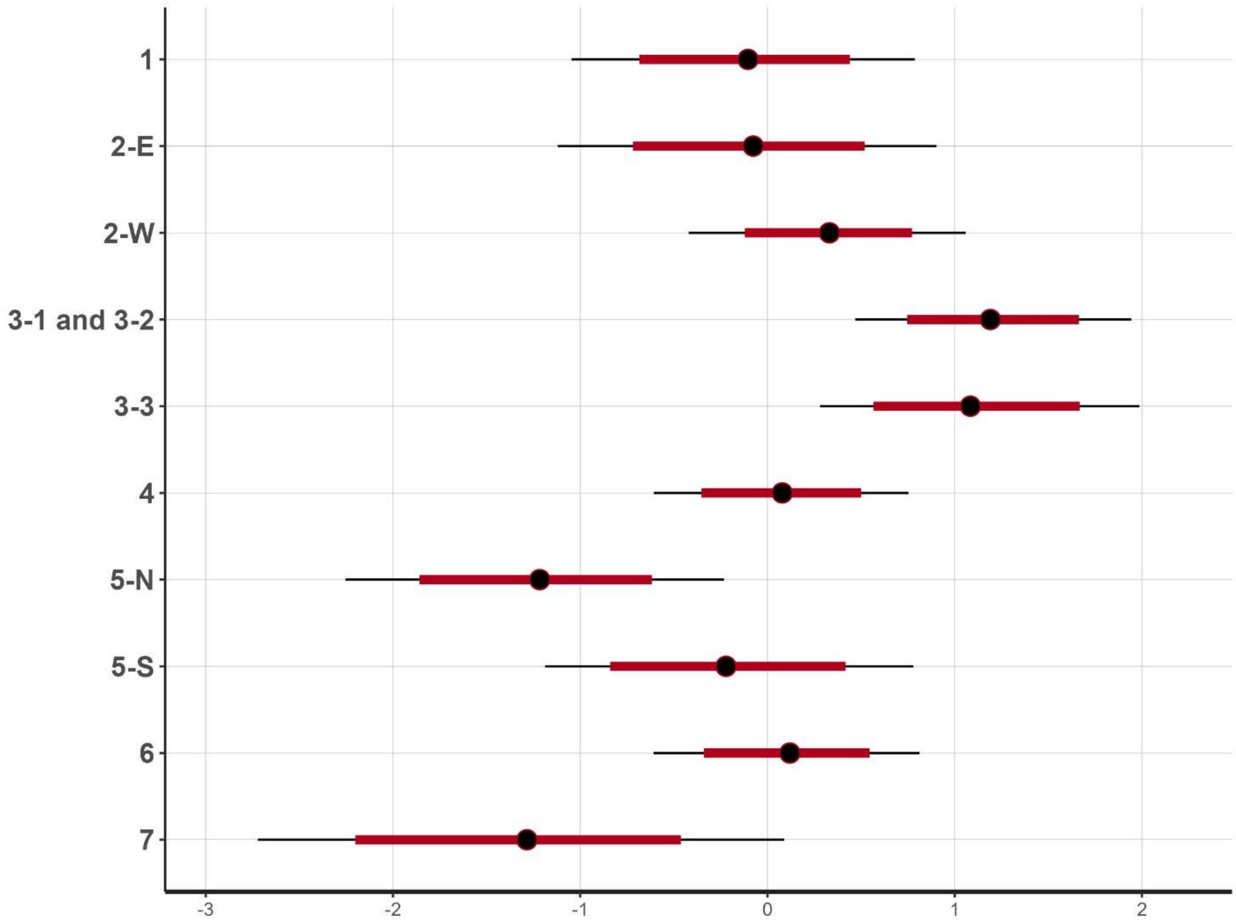

Figure 5. The posterior predicted mean of Dungeness crab per region. Multiple regions deviate from zero, showing that region does influence the predicted mean number of Dungeness crab across space in Puget Sound.

1.7 Bimodal Size Distribution

A bimodal pattern emerges from measured Dungeness crab molts with a larger peak around 40 mm and a smaller peak around 150 mm (Figure 6). This is likely due to the number of times Dungeness crab undergo molting during their first year of life (4-6), before starting to molt once every year when they reach about 100 mm (Rasmuson & Lesser, 2013; WDFW, n.d.b.). These data are therefore showing a pattern that is expected based on Dungeness crab biology, and future analyses may parse juvenile molt size-classes into year 1 and year 2 molts, providing more information for abundance estimates.

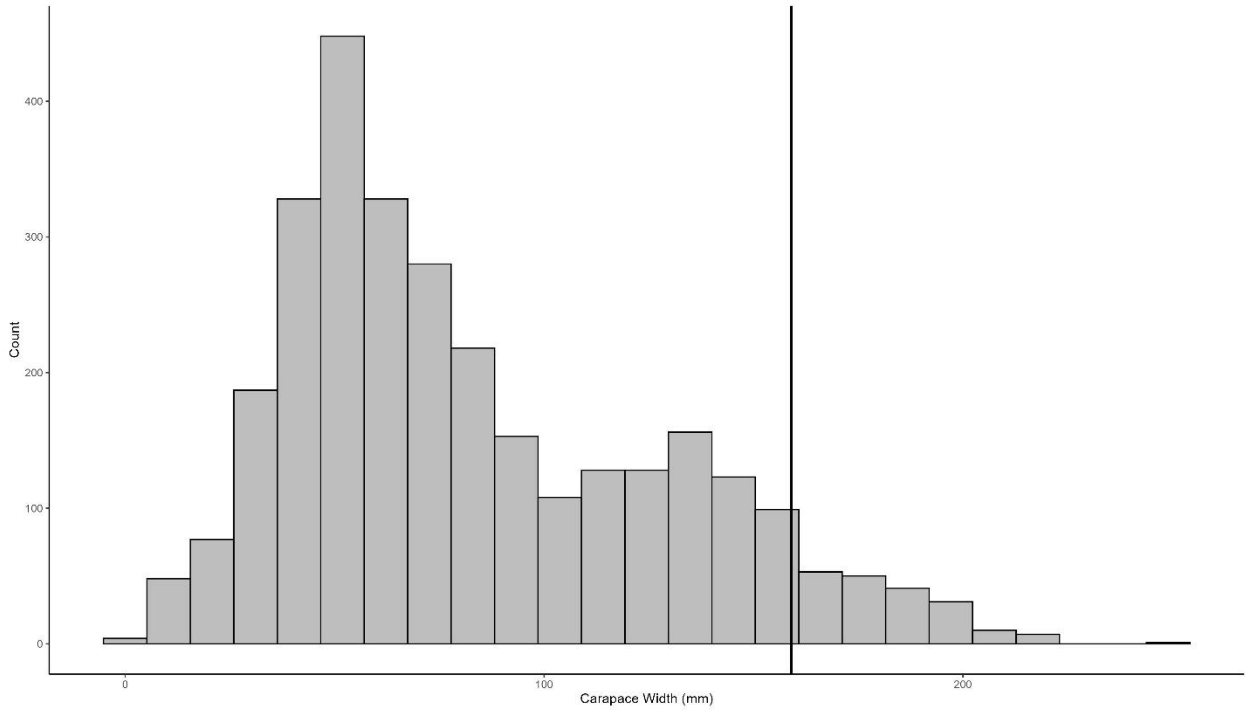

Figure 6. Histogram of carapace width for Dungeness crab molts measured during Molt Search Surveys. The vertical line represents the legal size (159 mm), which is the size at which males are allowed to be retained in Puget Sound.

This bimodal distribution can also be seen in select PSCMRs which have both higher numbers of surveys and higher numbers of Dungeness crab molts found per survey: San Juan and Admiralty Inlet (Figure 7). Other PSCMRs show patterns that differ from the overall bimodal distribution, but most include two distinct peaks, which are likely different age classes of crab.

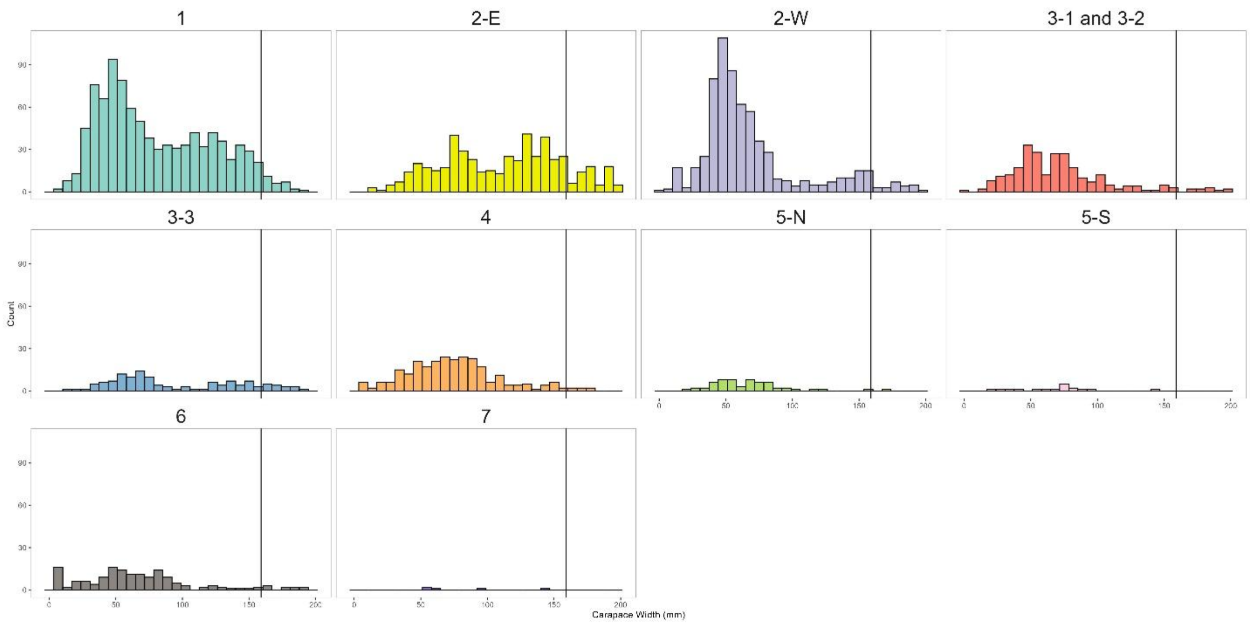

Figure 7. Count of Dungeness crab carapace width measurements across the dataset broken down by PSCMR. The vertical black line sits at 159 mm, denoting the legal size of male Dungeness crab which can be retained in Puget Sound.

1.8 LARVAL LINK

Mean Dungeness crab megalopae per light trap survey and mean Dungeness molts per Molt Search survey show a positive relationship (gamma = 0.42 (0.16, 0.67)) and a saturating curve, such that a marginal increase at very high numbers of larvae is unlikely to yield a correspondingly large increase in molts. In addition, effective sample size and Rhat values were more favorable for Model 2, so I used Model 2 for all subsequent analysis (see Table 3 in the Appendix for model outputs). The best-fit line for the larval-molt relationship is within the molt submodel: $\mu_{molt} \sim \exp\left(\alpha_{molt} + \beta_{molt\ region} + \gamma * \log\left(\mu_{lar}\right)\right)$. Points closer to the gamma predictor line (Figure 8) indicate a relationship between megalopae and molts. 5-N (Northern Hood Canal) is situated the furthest away from the line, an outlier (Figure 8). The predicted mean count of Dungeness crab molts in 5-N is lower than would be expected based on the average larval-molt relationship. There is a general pattern of increasing molts with increasing megalopae counts, but this pattern is reversed in PSCMR 5-N. This could be driven by a higher level of megalopae in recent years, which may not be translating to molts yet (see Table 1 in the Appendix for all posterior predicted means of larvae and molt count). Both larval and molt datasets naturally include a high amount of variation based on biological and oceanographic processes. Larval Dungeness crab do not stay in the water column year-round and are widely dispersed. Megalopae counts have a total range of 0 to 39200, while molt counts range from 0 to 72. Since predicted means of larvae and molts do not show the same patterns across space, this could shed light on challenges faced by different life stages across Puget Sound.

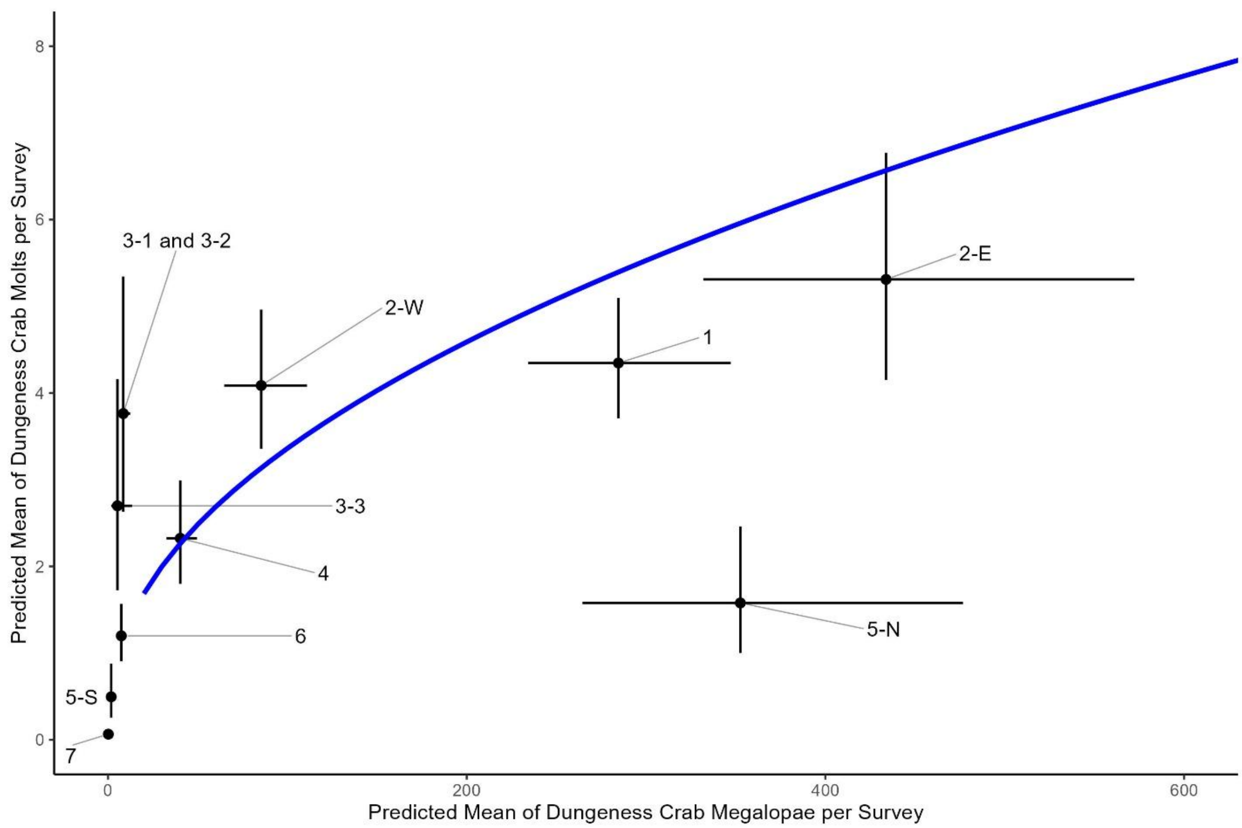

Figure 8. Posterior predicted mean Dungeness crab megalopae per light trap survey plotted against posterior predicted mean Dungeness crab molts per Molt Search survey. Error bars reflect model uncertainty in the larval mean (horizonal line) and molt mean (vertical line). The blue line indicates the best fit line for larval count as a predictor of molt count.

DISCUSSION

The health and longevity of the Puget Sound Dungeness crab fishery is important to tribal, commercial, and recreational fishers, as well as environmentalists who see the inherent value of these crab. Estimating crab abundance in Puget Sound is particularly challenging since they cannot be effectively sampled by trawl or acoustic surveys, common survey methods in other fisheries (Zimmermann et al., 2009). Molt data successfully captures the juvenile stage of life, which connects the larval and adult stages. Linking these life stages of Dungeness crab could help create a broader understanding of the stressors they face in different regions. The management approach of including information throughout the life cycle of the species is demonstrated in salmon management (Johnson et al., 2017; Merz et al., 2013; Sellheim et al., 2020). Challenges for specific life stages can be identified and addressed with the goal of adaptive management and sustainability. While larval data are valuable for understanding Dungeness crab recruitment in different regions, molt data are the largest source of information on the juvenile life stage and therefore the only current metric by which the abundance of this life stage can be estimated across Puget Sound.

The posterior predicted mean number of Dungeness crab molts per Molt Search survey show variation across space when compared to the predicted number of megalopae per light trap survey. Understanding this difference is important for identifying life stage-specific challenges across Puget Sound. PSCMR 5-N (Northern Hood Canal) has a lower predicted mean molt count relative to the predicted mean larval count. There may therefore be some process or stressor that is affecting juvenile and/or adults in that area that is not affecting the larval stage. This could be due to a recent increase in larval supply in this area in the past two years, which may not yet be showing up in the molt data. There could be insufficient habitat for juvenile Dungeness crab, or an overabundance of predators of that life stage. It is worth further investigation to see if this finding could be explained by physical or temporal processes. One example in which life stages appear to be following the same pattern would be in PSCMR 7 (South Sound). All Dungeness crab fisheries are closed in this area and Model 2 returned low predicted counts of both larvae and molts. It appears that Dungeness crab are at low abundance across all life stages in PSCMR 7, which is important information for co-managers as they evaluate fishery closure timelines.

The Sea Grant and Washington State University Extension Molt Search dataset is a promising one. While the dataset is only about three years old, it is already showing patterns expected of molting Dungeness crab based on their biology. For these data to be most useful for management, there are a few improvements and directions that could be implemented. Carapace size data are not currently a required part of the data collection process. While this serves to ensure greater participation and access for the public, efforts could be made to increase the volume of size data. Age structure is of particular interest to co-managers, so more size data would likely be helpful to understand the distribution of sizes (and ages) in the population. It is possible to increase the amount of carapace size data by using ImageJ to analyze images from past Molt Search surveys. A pilot study has already begun to gather this information and could be continued in an undergraduate or graduate project. In addition, a targeted effort could be conducted to increase survey numbers in certain regions and/or certain months of the year. It would be particularly helpful to increase surveys and size measurements in the Eastern Strait, Western Strait, Northern Hood Canal, and Southern Hood Canal, as well as increase the number of surveys in winter months in all regions. Increasing the number of measured crab may not be possible in areas with low Dungeness crab abundance, such as south Hood Canal and South Sound. A summer “Molt Blitz” occurs each year through the Molt Search program (Washington Sea Grant, n.d.). This event could be adapted to create a winter version, or a targeted effort in regions with low effort.

These analyses provide a jumping-off point for Dungeness crab researchers and co-managers to begin exploring the use of molt data in management, especially in areas that are currently data-poor. While molt data have been utilized on a smaller scale, the Molt Search program provides a flexible method of surveying Dungeness crab molts across large areas. Participatory science can serve as a powerful engine of knowledge, especially across large temporal and spatial scales. Once the dataset becomes more robust with time and directed effort, larger-scale questions may be addressed to better inform management. Quantifying age-classes across months and regions would help co-managers to understand how the physical and biological processes are affecting each new cohort of Dungeness crab. The potential for this work is vast, especially in such a well-connected co-management and working group space, and these analyses are hopefully only the beginning of molt data utility in Puget Sound Dungeness crab fishery management.

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Appendix

Table 1. Key of Puget Sound Crab Management Regions (PSCMRs) used for these analyses compared to Washington state commercial management regions and recreational Marine Areas.

PSCMR	Commercial Management Region	Recreational Marine Area
1	1	7
2-E	2-E	8-1, 8-2
2-W	2-W	9
3-1 and 3-2	3-1 and 3-2	6, 7
3-3	3-3	4, 5
4	4	10
5-N	5	12
5-S	5	12
6	6	11
7	6	13

Table 2. Posterior predicted means for Dungeness crab megalopae and molts per PSCMR, rounded to the nearest hundredth with a 95% credibility interval.

PSCMR	Posterior Predicted Molt Mean	Posterior Predicted Megalopae Mean
1	4.35 (3.71, 5.10)	284.57 (234.18, 347.25)
2-E	5.31 (4,15, 6.77)	433.80 (331.94, 572.26)
2-W	4.09 (3.36, 4.96)	85.42 (64.80, 110.97)
3-1 and 3-2	3.76 (2.63, 5.34)	8.50 (5.89, 12.39)
3-3	2.70 (1.72, 4.16)	5.25 (1.78, 13.46)

4	2.32 (1.80, 4.16)	40.30 (32.63, 49.66)
5-N	1.58 (1.0, 2.46)	352.58 (264.56, 476.72)
5-S	0.50 (0.25, 0.88)	1.78 (1.20, 2.59)
6	1.20 (0.90, 1.57)	7.42 (5.75, 9.52)
7	0.06 (0.03, 0.11)	0.18 (0.11, 0.28)

Table 3. Comparison of gamma predictor with 95% credibility interval, effective sample size, and Rhat for Model 1 and Model 2.

	Model 1	**Model 2**
Gamma Predictor and 95% Confidence Interval	0.07136227 (0.0003422658, 0.2069176)	0.4154345 (0.1607326, 0.6677425)
N_eff	370.4472	1750.223
Rhat	1.004377	0.9999286