# Summary of Changes and Edits

We would like to thank both Reviewers for the detailed and constructive comments on our manuscript. We made a number of changes in response that we believe make the message of the study more clear and robust. We added a number of new equations, edited all main text Figures and Tables, and have added many new Appendix figures to provide depth to some of the methodological choices in our analysis. In the next paragraphs, we describe the overall major updates we have implemented, many of which are related to comments that were common to both Reviewers. Below, responses to individual Reviewer comments are provided.

On the technical side, both reviewers requested more clarity around the methods used to produce cost and profit estimates for the Dungeness crab fishery, and provided helpful references and suggestions to improve this part of the analysis. We have implemented many of these suggestions. Most importantly, we have adjusted all recorded revenues and costs for inflation, normalizing to 2010 dollars using the consumer price index suggested by Reviewer 1. Additionally, we have altered our estimation of costs to account for fuel price differences between California and the other states across the study period, again using data provided by Reviewer 1. While the effects of these changes on our results are non-trivial (i.e., the changes affect the clustering of certain vessel-seasons, as well as the significance of changes in revenues and profits during the MHW period for certain behavioral groups), overall the updates to revenue and cost estimates do not alter the main qualitative conclusions of the paper. Throughout the revised manuscript, we have edited the text to better describe how revenue and costs were calculated, including a new description and equations for the fishing cost estimation.

Reviewer 2 suggested the inclusion of vessel size (length) as a clustering variable, and we have implemented this into the analysis and added language describing its effect. As a result of the changes to revenue, costs, and variables used for clustering, all tables and figures have been updated from the originally-submitted manuscript. While we do not think these changes substantially alter the lessons and conclusions of the study, we appreciate these suggestions of the reviewer that have made our analysis more robust.

Both reviewers also asked, in general and in specific places or paragraphs, for more information regarding the context of the Dungeness crab fishery during the marine heatwave years, and how it relates to the broader context of other west coast fisheries during the study period. In multiple places in the Introduction and Discussion, we have edited and added to the text to this effect to provide more clarity and context to the reader. We have especially highlighted that many factors, some unrelated to the marine heatwave, affected fisher behavior over the study period. Reviewer 2 in particular also asked about decisions of fishers to participate in other (non-Dungeness crab) fisheries and what entry-exit dynamics were like during this time period. While a full dynamic fisheries participation network analysis is outside the scope of this paper, we are also interested in these dynamics and have added Appendix figures and some discussion to better describe some of these entry-exit patterns, including an emphasis that this could be a focus of future research.

# Reviewer comments:

## Reviewer #1:

The authors of "Mobility and flexibility enable resilience of human harvesters to environmental

Perturbation" have provided an interesting approach to a very important question. Quantifying fishing fleet responses to environmental perturbations is and will continue to be critical to climate change adaptation. I think this study is important and should be considered for publication but I think there are a few components that regrettably may require some additional / redone analyses (I hate when reviewers ask for this).

Because the hypothesis of this paper is fundamentally tied to fisher behaviors around space use and cost/revenue during certain time periods, I have a couple of primary concerns with how cost/revenue were treated. Particularly, (1) were revenue values (crab and non-crab) inflation-adjusted; (2) were costs of non-crab revenues accounted for; (3) were differential operating costs examined for Washington, Oregon, and California? Most notably, it seems that non-crab revenues were key for clustering vessels into the groups that were then used for MHW hypothesis testing. Intuitively, it seems like the effects of higher fuel costs in California, for example, could affect non-dungeness revenues or lead to shorter trips in California than, say, Washington or Oregon? I don't know this to be the case, but my more detailed comments below about inflation and state-specific costs hopefully provide the authors with more specific guidance. If the authors have not accounted for such components already, low inflation through much of the 2010's and particularly low fuel prices in 2015-2018 may even amplify their findings? Hopefully, the authors have already considered these aspects and it is simply a matter of clarifying the text, and not new analyses. However, I think some of these issues are rather important to address, and I recognize that they are rather major revisions if necessary.

We thank the reviewer for these comments, and we have significantly edited much of the analysis and manuscript to address the issues raised here. Much of our approach is described in the Summary section of this response (above), but to summarize:

1. We have inflation-adjusted all revenue and cost values according to the inflation index suggested by the reviewer. This means that throughout the manuscript, all reported revenues, costs, and profits are now in 2010-adjusted USD. Although this changed some of the raw numbers in the analysis, the main conclusions of the paper have remained the same to the original submitted manuscript. We have described in multiple places in the Materials and Methods section how revenues and costs were inflation adjusted
2. Costs of non-crab revenues were not accounted for. The fishing costs that go into our profit calculations were only for fishing trips targeting Dungeness crab, so to the extent practicable, there is no incorrect application of a Dungeness fishing cost model to a non-Dungeness fishing trip. Revenues from non-Dungeness fisheries were calculated separately and included as a vessel-season behavioral metric (as described in the methods), without estimating non-Dungeness profit. While we think that a deeper investigation of expected profits across fisheries is an important consideration in thinking about diversification and adaptation, we think that such an endeavor is outside the scope of this manuscript. Moreover, the Dungeness crab fishery occurs in the winter and is often the most valuable/profitable option for fishers at that time— therefore, we hypothesize that the decision to fish is often determined by conditions in the Dungeness crab fishery itself (market conditions, algal blooms, entanglement risk, etc.), and not by profit potential in other fisheries.
3. We have included a relative fuel price index in our Dungeness fishing cost model, as suggested by the reviewer, resulting in newly-designed equations (Eqs. 2-7 in the revised manuscript) and new Appendix figures (particularly Figs. A.16-A.18). Our goal with these updates was to better clarify our approach to fishing cost estimation, and provide more concrete information on the differential cost of fishing by vessel size. Overall, while the fuel price incorporation was important, it does not have an enormous impact on cost estimation because of the additional, other types of costs associated with fishing.

We appreciate the detailed questions from the reviewer on cost and revenue calculation. We believe that the incorporation of the inflation index and cost variation has significantly improved the robustness of our analysis.

The writing throughout the intro, methods, and results could be improved for clarity and readability. Some sentences currently require several reads in order to grasp the intended flow (e.g., the first sentence of the abstract and introduction, lines 163-164, lines 194-196).

The entire manuscript has been significantly edited for clarity and readability. In addition, language has been added to better frame the context of the study within both the specific case study (i.e., the current management conditions within the west coast Dungeness crab fishery), and within the broader discussion of social-ecological system resilience.

Additionally, in Lines 452-454, the authors hint at issues of crab prices, markets, and competition over time? I think readers would benefit for a more robust acknowledgement of such dynamics. A valuable figure for the paper might show total ex-vessel revenue for the Dungeness crab fishery (all crab vessels) during the time period, and perhaps non-crab ex-vessel revenue for those same vessels. Don't feel like you have to include this figure but consider it or something similar that might help to tell the broader story. Was there a "typical" non-Dungeness target species (or several) and were there any market dynamics during MHW periods that may have provided valuable financial buffers. I'm feeling like you demonstrated a piece of the story but that I just don't have a very good grasp of much of a broader picture with this fishery. The discussion is pretty well-written with respect to big picture concepts around portfolios and buffering but I don't feel sold that you've demonstrated that that is actually what's happening here.

We agree with the reviewer that many factors influence the dynamics of the Dungeness crab fishery, and have added significant text to the Introduction and Discussion to make this point clearer. We specifically highlight high market prices for crab and the potential for changes to productivity and management of other fisheries to affect participation in the crab fishery. We also provide a bit more detail on rationales for interannual variability in the landings and revenue during a crab season (product quantity, which can vary geographically; product quality, which can include domoic acid concerns but also other considerations; and market-driven factors such as price negotiations with buyers). We also in the Discussion specifically describe alternative fisheries in which California crab fishers’ participated.

### Specific comments:

Interesting that VMS coverage for this study only covers up to 26% of the vessels but that that accounts for such a large portion of the landings and revenue. Is that just because Oregon has the best fishing grounds / most effort for crab? Not a critique but an observation that readers might be interested to understand.

Thank you for pointing this out. The 26% refers to all vessels across all three states. Oregon has a much higher relative representation in VMS, on average, and these vessels also tend to land a lot of Dungeness crab. Two new Appendix figures have been added that record the relative VMS representation across the three states in number of vessels (Fig. A.9) and revenue (Fig. A.10). In addition, the manuscript text has been edited in this section to clarify this point.

Lines 146-149. Struggling with this sentence a bit. I think I get it, but perhaps try rewording it a tad for clarity. This is to define the start date, right?

Yes, this was our approach to use the fish tickets themselves to define when the crab season started in each port group. The text here has been edited for clarity.

Lines 151-154: What kinds of impacts did this have on your analyses? How often did this occur?

The majority of crab trips recorded were less than 7 days in length, particularly so at the beginning of the season when the fishery is most active. A new Appendix figure has been added showing this pattern (Fig. A.11), and we added text in the Materials and Methods explaining further why this choice was made.

Line 156: When I got to this first sentence and read "the only other behavioral metric…", I found myself then going back to figure out what the other ones were. I remembered trip duration and season start date. But then I scanned to see if there were others. I wonder if, before presenting each of the metrics as individual paragraphs, you could have a sentence that lists each of them, so that the reader can quickly form a picture of these metrics instead of piecing them together as they read.

Section 2.2 has been reorganized in order to make the introduction of the behavioral metrics more straightforward. Following another suggestion of the Reviewer, we have also included the table of metric definitions in the main text (moving it from the Appendix), which should help to clarify the approach

Line 167: I would remove "apparent" as it seems to diminish your assertion of having identified relevant behavioral characteristics.

Removed

Line 168-170: Unclear why you mention the cluster analysis here unless the results somehow tie into the revenue cutoff you describe in the subsequent few sentences.

Fixed

Line 172: Since you just defined vessel-season above, probably best to consistently use vessel-season instead of then using "each vessel in each season".

Thank you for this comment on clarity. Throughout the Methods, Results, and Discussion, we have made changes to be more consistent in our use of the term “vessel-season” after it is introduced here.

Lines 171-175: Could likely consolidate these lines into a more clear and concise few sentences. This feels like a backwards way to introduce the 95th percentile retention threshold so I had to read these few sentences multiple times to get the flow.

Lines 182-183: If trip distance is a metric, how do you treat trips that had exceeded 7 days and for which you truncated the VMS data. Did you just calculate the distance for all VMS records starting when the data were truncated? And what about their home ranges? Additionally, if you considered non-Dungeness revenue, did you only truncate trip length to seven days for Dungeness trips but considered long trips for non-Dungeness trips? If it does occur, it might be worth noting in a description of the fishery - seems like that could have implications for roving v. local behaviors.

As mentioned above, an Appendix figure has been added describing the mean trip duration for all trips in the data, as well as the proportion of trips that were less than 7 days. The reviewer is correct that for trips that were truncated, distance was calculated for only the truncated portion of all the VMS records associated with the trip. Similarly, as described in the Methods, home range was calculated with all VMS records associated with a vessel-season, after truncation of trips longer than 7 days.

Trip length was a non-factor in calculating non-Dungeness revenue, because only the fish tickets (not the VMS data) were used for this calculation.

Line 183: Don't need to preface units with "in"

Fixed

I've heard that Dungeness fishers sometimes make one trip from port to set pots and a second trip to retrieve pots. Is this the case here? If so, do those cumulative trip distances (setting and retrieving) get accounted for in the way you identified crab trips in the VMS data? Maybe this isn't the case - I'm unfamiliar with crab fishing / data personally.

The reviewer is correct that fishers present a range of behaviors, including multi-day trips at sea for setting and retrieving of pots as well as trips that consist of a setting event followed by a retrieval event at some later date. Unfortunately, neither the VMS nor the fish ticket data give a full view into whether a particular spatial foray was dedicated to setting and/or retrieving pots. As described in the Methods, we have tried to account for any potential bias or errors using various filters (speed and depth cutoffs, exclusion of obviously in-port VMS points), but we acknowledge that the particular behavior the Reviewer notes is not readily observable in our data.

For the cluster analysis, we excluded trip distance due to its collinearity with trip duration, so this issue did not affect the identification of fishing behavioral groups. However, our calculation of trip duration was included in the cluster analysis and we did not distinguish between vessel activity associated with setting vs retrieving of pots. Trip duration for trips that lasted for multiple days while the vessel remained at sea was calculated in a manner commensurate with trips that lasted for multiple days but included a return to port between setting and retrieval of pots (though we removed VMS records from vessels sitting idle in port, calculating the duration of the trip during times the vessel was active and out of port only).

Lines 191-194: Again, could be simplified through use of vessel-season.

Simplified the explanation of this metric.

Line 215 Fix reference

Fixed

Line 218 Delete "repeatedly" as it's redundant with "revisited"

Fixed

Line 218-219 Again, sentence could be streamlined through use of vessel-season (e.g., The vessel-season metric for spatial exploration is defined as the 90th percentile of maximum location choice entropy.)

Fixed. This part of the Methods has been rewritten in response to a comment from another Reviewer, and we have now included an equation that describes location choice entropy, as well as an example time series in the Appendix.

Line 220-221 I was at first confused why this sentence appeared prior to the clustering section but now I I realize that it is meant to serve as a coming together point for sections 2.1 and 2.2. Admittedly, I found the organization of these two sections a bit difficult to follow as it seems that some of the behavioural metrics are woven into the data section while others are in the characteristics section. Moving Table A.1 into the main manuscript would be very helpful. If a reader needs to refer to the appendix in order to follow the paper, then I generally think that element should be in the main body, and I think that this table drastically improves understanding of sections 2.1 and 2.2. You might also consider taking a look at the organization / writing of these two sections generally to improve readability as I went back and forth between the two sections numerous times to try to track the approach.

Following the reviewer’s suggestion, we moved the Appendix table into the main manuscript. Additionally, we have edited the text in the Methods significantly to improve flow, readability, and specificity (e.g., equations and tables).

Section 2.3: A topic sentence in line 223 would help readers to remember / understand what the objective of the clustering analysis was. I initially assumed this first paragraph was going to be all about collinearity.

Fixed.

Lines 236-242: Variable importance plots can be valuable evaluation metrics but can do a poor job accounting for interactions in some cases. Perhaps your collinearity / correlation threshold of 0.7 took care of this but interactions can be tricky so it seemed worth noting. For an example, Dan Ovando does a nice job illustrating this around slide 36 of this presentation (https://www.youtube.com/watch?v=ZONRIycT35Q ). No problem if you've already considered this and it is not an issue. Did you do any hyperparameter tuning or simply rely on default model specification? With the PCA plot / arrows, I'm not entirely convinced that the random forest piece is necessary (it's fine - just not sure if it adds all that much - could be moved to the appendix if you need to save some space).

We appreciate the comments and suggestions of the reviewer, along with the context in the youtube video. Our situation is quite different from that described by Dan Ovando in the lecture (a categorical clustering versus a regression model), but the point is well taken that variable importance can miss important interactions. Moreover, we are not using the random forest analysis to thin variables or even select them for inclusion in the model. Rather, our goal in including both the PCA and the random forest analysis is that they provide a visualization of the spread in the data across key discriminating behavioral variables (following the example of O’Farrell et al. (2019)), as a way to gain insight from the otherwise somewhat opaque clustering algorithm. We believe that the current version of the analysis accomplishes that goal. Additionally, in response to a suggestion by the other reviewer to officially include vessel size as a behavioral metric, we have decided to retain the random forest figure (now updated with vessel size included as a metric).

Section 2.4. I have some concerns about some of the profit/cost assumptions. I'm trying to wrap my head around how they may affect your results. Perhaps they do not, and I'm happy to be proven wrong, though I think it is worth considering a few things. First, you assume an average inflation rate of 2% per year. Indeed, the average inflation rate from 2004 - 2019 (https://www.minneapolisfed.org/about-us/monetary-policy/inflation-calculator/consumer-price-index-1913- ) is close to 2% per year (2.08%) but it is far from linear and is actually negative or near zero for some of the years of your study (e.g., 0.10% in the 2015 heatwave year). Given your use of a year effect, it seems that you could easily instead use a consumer price index for each year to be more precise with your adjustment.

We thank the reviewer for providing a useful inflation index. As described in the Summary and in previous responses, we have incorporated this consumer price index in all of our analyses to adjust all values to 2010 USD.

You mention that you assumed inflation into your costs but there is no mention of whether your revenue values (lines 266-267) are nominal or inflation adjusted. Any effort to understand fisher revenue, costs, or profitability should be inflation-adjusted and to ensure reproducibility, clarifying the baseline year to which values are adjusted is important.

See previous response

An additional concern I have related to your cost and profit calculations is the effect of state of origin on trip costs, given different fuel prices in California, Oregon, and Washington. I wasn't sure how much of an effect this would have, but a quick look at fuel price differentials for the different states suggests that costs could vary drastically, with costs especially high for California. The Dewees (2004) reference you cite appears to have surveyed only California fishermen and may not have needed such considerations. Monthly and annual marine fuel prices by state are available from PSMFC (http://www.psmfc.org/efin/data/fuel.html). Not sure if I'll be able to share the plots (through the reviewer platform) that I quickly generated, but they suggest that your Cf term should be a function of L,d,y, and state. In 2017, marine fuel prices in Washington were as little as 75% of those of California and the highest fuel prices were seen early in the time series while lowest prices were late in the time series, in contrast to a simple linear inflation-based cost trend (admittedly, it's pretty linear from 1999 - 2008).

As described in the Summary, we have incorporated these differences in fuel prices by state into the analysis of fishing costs. In addition, we have changed the way that the fishing cost simulation is described in the manuscript to be more clear about where and how these fuel prices factor in to our overall cost estimates. We have included two additional Appendix figures showing the results of the fishing cost model by year, vessel size, and state of landing.

Finally, might trip distance provide a more accurate metric for fuel costs than trip days? In 2004, the Dewes study would not have had access to VMS data (and thus trip distances, ostensibly). Have you compared trip duration and trip distance to determine that they are highly correlated? I imagine they probably are and that this is not a concern but it seems worth examining - especially if vessels made multiple out-and-back to set and retrieve pots.

Yes trip duration and trip distance were highly correlated (⍴=0.61), enough so that trip distance was thinned from the cluster analysis.

Line 284 Why did you not calculate at least a coarse estimate of costs from non-Dungeness revenue. Given that the basis of the hypothesis is about space utilization, it seems important to think about costs associated with roving v. local behaviors for non-crab trips. Assuming a vessel's fuel consumption and crew costs are similar whether they are fishing for crab or not, it seems reasonable to explore. Or even exclude crew and at least include potentially high fuel costs? This seems like an important point to me as it appears to be foundational to your clustering analysis. Perhaps fuel costs were associated with non-crab trips already - if so, I think this is important to clarify.

See response to the first Reviewer comment above (point #2).

For your cost simulations, I assume that you resampled each of your parameter estimates used to estimate C but it would be good to clarify how your resampled. This would aid reproducibility for error propagation.

The Reviewer is correct. We draw 10,000 samples from the inflation-adjusted estimates of costs reported in Dewees et al. for each combination of state and year (to account for inflation and fuel prices differences). The end result is a state-, year-, and vessel size- specific estimate of both daily costs and crew share of trip revenues, each of which represents a mean of 10,000 simulated samples. As described above, this approach has been more thoroughly described in the revised manuscript, with new equations and Appendix figures displaying the results of the costs simulation.

Line 261: More information about your cost simulations would be helpful. Did you iterate over the distributions for each of our cost parameters or only

See previous response

Section 2.5 - do you think it is important that the fleet did not show any apparent response to the 2014 onset of marine heatwaves? Just wondering what aspect it might have been of the later heatwaves that led to the need for a response. This seems like it might be a really useful part of understanding in order to inform future adaptation / resiliency.

The recent MHW on the US West Coast began to show biophysical impacts in 2013, but those and social impacts lasted much longer (Suryan et al. 2021, Samhouri et al. 2021). In 2015, the US West Coast experienced a harmful algal bloom of unprecedented scale when the anomalously warm waters were supplied nutrients from the spring upwelling (McCabe et al., 2016). Toxin levels in Dungeness crabs became dangerous for human consumption, persisting even after the bloom subsided and resulting in lengthy delays of the 2015-16 and 2016-17 Dungeness fishing seasons. Degraded meat quality of crabs in 2017-18, which may have been a result of lingering influences of the MHW, also caused delays to the season opening.

Our text in the Introduction and Discussion has been edited to provide significantly more information on the context and potential other drivers of fishing dynamics during the MHW time period.

Line 289 - since you already described using R packages in the clustering analyses previously, perhaps this sentence would be more appropriate earlier in the text?

This sentence has been moved up in the document

Line 294: Don't need to define VMS again.

Fixed

What proportion of vessels switch behaviors over time? How many more switched strategies during the MHW? Did any vessels switch strategies only during MHWs?

Although we did not do an extensive analysis of individual vessels’ group membership over time, we have added additional figures to the Appendix (A.12,A.13) that help to elucidate some of these patterns in group membership and group switching. There were no clear, directional effects of the MHW period on group switching, and staying within the same behavioral group was much more common than switching groups (Fig. A.13). The dynamics of group switching, combined with individual vessels’ decisions to enter or exit the crab fishery in each season, are interesting and deserve further attention in future research (following Fisher et al. (2021)).

Figure 2. Might make the Newport dot larger. In panel B, you describe the revenue "relative to all other fisheries". I assume that means crab revenue relative to non-crab revenue for those same vessels? Or relative to non-crab fishers?

That is correct, the value is mean weekly crab revenue relative to non-crab revenue for the same vessels. In other words, in a given week, how much did the vessel earn from crabbing vs. other fisheries?

The caption of Figure 2 has been edited for clarity.

Lines 335: Should this say "were not significant" instead of "were not as substantial"? Also, according to figure A.3, it seems that the numbers of specialist vessels increased in MHW v. non-MHW periods (though perhaps not statistically?) - how does this rectify with the shift in non-crab revenue? I suppose that the clusters are generalized over all years and not individual years, right?

Yes, the Reviewer is correct that the clusters were generalized over all crab seasons. The text has been edited with more specific significance language.

Line 364: What do you mean by "raw"? Is this nominal?

This language has been changed. We were referring to the difference between increase in total mean profits (USD), versus a percent increase in profits.

Line 440: fix reference

Fixed

Lines 448-452: Would be nice to know how many fishers left during those years. Did they return in subsequent years? Possibly to easily see that without needing to immediately toggle to Fisher et al., 2021?

We have included an Appendix figure (Fig. A.13) that measures some of these entry-exit time series. It is somewhat difficult to measure these dynamics, since there are so many transitions a fisher can decide to make (e.g., stop fishing entirely, fishing in a different fishery, return from not fishing in the previous season, etc.), but we appreciate the interest of the Reviewer and have described in the Discussion section more of the myriad factors that likely play into fishers’ decison-making.

Line 462: Perhaps "response" instead of "solution"?

Fixed

## Reviewer #2:

The authors present a novel and interesting investigation of the way that different groups of US West Coast fishermen participating in the Dungeness crab fishery have fared during a period of environmental change as characterized by several marine heatwaves. I think the research will be of interest to the readers of the journal particularly in light of 1) methodological advances regarding the integration vessel movement and economic data and 2) the introduction and description of new fisheries livelihood categories (adding a movement axis of local vs. roving on top of the specialists vs. generalists diversification axis that others have described previously) that show great potential in advancing the way scholars across systems can conceptualize the way that resource users interact with and adapt to changes in the marine environment. That being said, I would advocate for a substantial revision to address the following points:

Point 1: I think the impacts of the Marine Heatwave events (which are amorphously defined by the authors) should be reframed in terms of their importance in influencing fisher's livelihoods and decision-making during the study period. This was only one of many factors that US West Coast crab fishermen negotiated over the course of the study period. In particular, I would guess that changes in revenue by category was influenced less by the Marine Heatwave as compared to 1) interannual changes in the price per pound paid for crab (which continue to skyrocket as the Chinese export market has developed) and 2) productivity of other regional fisheries (i.e. I believe both landings and revenue associated West Coast groundfish and pink shrimp boomed during the latter half of the study period). Likewise, decisions concerning when and where to fish are not only mediated by whale closures, meat content, and domoic acid levels associated with extreme environmental events but also by a) cyclical changes in the geographic locus of productivity and b) fishing unions agreeing to the price per pound being offered by buyers and processors.

We agree with the reviewer that many factors influence the livelihoods and decisionmaking of Dungeness crab fishers, and have added text to the Introduction and Discussion to make this point clearer. We specifically highlight high market prices for crab and the potential for changes to productivity and management of other fisheries to affect participation in the crab fishery. We also provide a bit more detail on rationales for interannual variability in the landings and revenue during a crab season (product quantity, which can vary geographically; product quality, which can include domoic acid concerns but also other considerations; and market-driven factors such as price negotiations with buyers).

As an aside, we reviewed landings and revenue time series for non-whiting groundfish and shrimp over the study period (Figures 4.1.1 and O.2.1 in the 2022 CCIEA ecosystem status report https://www.pcouncil.org/documents/2022/02/h-2-a-cciea-team-report-1-2021-2022-california-current-ecosystem-status-report-and-appendices.pdf/). We found that neither boomed during the latter half of the study period, suggesting that productivity of these other fisheries was not necessarily a strong determinant of dynamics in the Dungeness crab fishery

Point 2: I believe the paper would be strengthened by incorporating vessel size as clustering metric (as was done in the 2019 PNAS O'Farrell paper that the clustering methods appear to be drawn from). While it is true this is not a behavioral metric in the strictest definition of the word, I believe it has too much explanatory power to ignore. Larger vessels are more capital-intensive operations likely to make longer fishing trips, travel further distances, use more traps, and (increasingly) own more permits in order to facilitate their access to other fisheries. Indeed, vessel size and capital investment increasingly looks to mediate what sort of response options are available to a fisher when faced with external shocks and stressors. When using a variable like windspeed to assess risk, it is important to note that fishing in a 20-30 knot wind on a 60 ft. vessel involves an inherently different decision-making and risk evaluation process than fishing those conditions on a 30 ft vessel. My intuition suggests that large vessels are very rarely limited by weather while smaller vessels must pick and choose fishing windows with calm sea conditions (which creates some interesting equity dynamics in a derby fishery when fishing start dates are delayed until times of year with traditionally poorer weather). At the very least, if the authors are reluctant to re-cluster, some version of Figure A5 should be inserted into the main text and parsed within a discussion paragraph.

As mentioned in the summary paragraphs of this review, we have adopted the reviewer’s suggestion and included vessel size as a clustering metric. While we were wary of including vessel size because of the reasons given in the initial submission (i.e., vessel size per se is not a behavioral metric), we agree with the reviewer that the metric is too important, and potentially too broadly relevant to other applications to ignore. It is therefore now included in Figure 1 (PCA and variable importance figure), and it emerges as a relatively important variable. Although the inclusion of vessel size does not alter the broad conclusions of our study, it likely had an impact along with the above-described changes in revenue normalization on the updated clustering. We have retained the Appendix figures describing the distribution and correlations of vessel size with other metrics, since we still want to make the point that vessel size alone can be a convenient, but potentially incomplete or misleading proxy for certain fisher behaviors.

Point 3: The methods section needs more detail to ensure scientific reproducibility. I understand the authors are building upon methods previously advanced by other published literature but it several cases, even when consulting the references included, it was unclear to me how certain processes were undertaken. Two examples which stand-out would be greater detail in specifying the clustering procedure and the mechanisms used to obtain the "location choice entropy metric". Ideally the authors would include some source code (the recent Fisher et al. 2021 provides an example of how this is done effectively while managing confidential data limitations), but if they are unable to do that at the very least it would be good to see some descriptive equations included (as they are in Section 2.4).

The Methods section has been significantly edited for clarity and details, including in the two specific instances that the reviewer identified. We have clarified how the clustering was performed (*k*-means clustering on a Euclidean distance matrix), and provided an equation and an example Appendix figure describing in more detail the calculation of the location choice entropy metric. In response to comments from another Reviewer, we also changed the description of the fishing cost simulation model to be clearer and more specific.

Point 4: Inferences about harvester resilience would be stronger by considering interannual variability in the selection of livelihood strategies and the generation of revenue. By choosing "vessel-season" as the unit of clustering, the groups which form the basis for the statistical comparisons are dynamic (i.e. as shown in Figure A.3) with many individuals likely changing membership between years. Is a vessel that fishes a single species offshore San Francisco, CA one year and a single species offshore Newport, OR the best considered as a Local Specialist or would this be a Roving Specialist? Likewise, knowing which categories are most connected (i.e. exchange members between years) and how this strength of this connections vary over time (in response to MHW or other events) would be very informative.

We thank the Reviewer for this comment, which is similar to a comment made by another reviewer. We agree that choosing “vessel-season” engenders some tradeoffs in the type of comparisons we can make about individual vessel choices. We have included two new Appendix figures illuminating some aspects of changing group membership, including tracking how many vessels switched from one group to another between seasons. There were no clear, directional effects of the MHW period on group switching, and staying within the same behavioral group was much more common than switching groups (Fig. A.13). The dynamics of group switching, combined with individual vessels’ decisions to enter or exit the crab fishery in each season, are interesting and deserve further attention in future research (following Fisher et al. (2021)).

In thinking about fisheries management in the context of a changing climate, interannual revenue variation is critically important (not every year is going to be a home-run production wise, but that might not matter if fisheries remain profitable over the long-haul). More broadly speaking and of less direct relevance, I think a continued focus on season-level performance may undermined the holistic interventions needed to ensure sustainability of diverse livelihood approaches (does it make sense to issue disaster payments for a bad season if landings/revenue during the next are 2x the long-term average?)

We have added a significant amount of Discussion text acknowledging these good points, including the need to manage for resilience to variation like the Reviewer describes, and to balance single-season performance with longer-term stability.

### Minor notes:

Abstract: The abstract states that "participants that specialized in a single fishery and concentrated fishing effort in small spatial areas experienced the greatest losses driven by the heatwave", yet (if my interpretation is correct) the comparison bar plot (Figure 5) show that all vessels increased revenue during MHW years (red) as compared to non-MHW years (blue) though the difference was not significant for this group. Please clarify.

The Reviewer is correct here, and this was poorly worded. We have edited the abstract to remedy this misinterpretation.

Line 35-40: In referencing the difference between exploratory vessels and those who exhibit a high degree of site fidelity I would reference the dichotomy between "stochasts" and "cartestians" as described by some of the earlier human behavior and fleet dynamics literature. See:

-Allen, P.M. and McGlade, J.M. 1986. Dynamics of discovery and exploitation: the case of the Scotian Shelf groundfish fisheries. Can. J. Fish. Aquat. Sci 43(6): 1187-1200

-Shester, G.G. 2010. Explaining catch variation among Baja California lobster fishers through spatial analysis of trap-placement decisions. B. Mar. Sci. 86(2):479-498

We thank the Reviewer for these references and agree that they are quite relevant. We have incorporated them into the Introduction.

Line 46-48: I think it is important to acknowledge where the integration of spatial (i.e. VMS data) and economic data (landings receipts) has already been done successfully within this system. See:

-Watson, J.R., Fuller, E.C., Castruccio, F.S. and Samhouri, J.F. 2018. Fishermen Follow Fine-Scale Physical Ocean 810 Features for Finance. Front. Mar. Sci. 5: 46.

We agree with the Reviewer and have included this reference in the Materials and Methods section, when describing how we joined VMS to fish ticket data.

Line 63-67: Not all fishing delays in the Dungeness Crab fishery can be attributed to ecological and/or environmental changes. Some are market driven (i.e. fishers striking in order to achieve a higher price; a quick Google search indicates that a strike was part of the picture during the 2016-2017 fishing season as well as others). I think this is an important piece of the puzzle that should be integrated into the narrative as it demonstrates 1) these fishers have agency and 2) in practice vulnerability is the product of overlapping and interacting social and environmental.

As mentioned above, we agree with the Reviewer that many factors influence the livelihoods and decisionmaking of Dungeness crab fishers, and have added text to the Introduction and Discussion to make this point clearer. We specifically highlighted the role of market-driven dynamics and a recent paper by Mao and Jardine (2020), and emphasize the interaction between environmental and social forces in shaping the dynamics we observed.

Line 98: In looking at changes in profitability over a fisheries time series, I think it is important to discuss changes in input costs (i.e. price per gallon of diesel) and outputs (price per pound paid for crab; though this is likely already reflected in the data, the significant variation across the study period due to changing economic conditions should at least be discussed). Likewise, the authors should reference how the 2% annual inflation parameter was chosen.

We appreciate this suggestion of the Reviewer, and refer them to our responses in the Summary section and to the other Reviewer, who was also concerned with adjusting for differential costs and inflation. To briefly summarize those other responses, we incorporated a consumer price index to account for inflation, and normalized all revenue and cost values to 2010 USD. Additionally, we have included a relative fuel price index to account for state-to-state differences in cost. These changes are detailed in the revised Materials and Methods section.

Line 127: I understand that the PACFIN data and VMS data are confidential, but I would advocate for the sake of scientific reproducibility to include the code through which individual VMS tracks were matched to individual landings receipts. I see this as a major area of research moving forward as marine spatial planning efforts related towards the establishment of offshore wind and aquaculture accelerate. It would be useful for scientists to be working in this area to be building upon common and standardized procedures, which this paper is well positioned to help advance.

We thank the Reviewer for this suggestion, and we have been actively working on packaging and publishing the code and methods used in this paper into a standalone repository.

Line 151: What % of trips and/or data were excluded using this 7-day cut-off?

We have included a new figure (Fig. A.11) displaying mean trip duration across all vessel-seasons, as well as the proportion of trips that were (or were not) truncating using the 7-day cutoff. The number of trips that were truncated in this way was generally low, especially during the busy, early part of the season.

Line 177: Risk-taking behavior is introduced here for the first time. This concept should be defined and introduced in the introduction. In general, I think this is the weakest of the clustering metrics used in this manuscript and by others who have adopted a similar approach. Marine social scientists have described risk within fisheries as a subjective perception based on age, equipment, experience, and psychocultural profiles which has economic (i.e. potential loss of revenue) and human dimensions (i.e. safety concerns). I am skeptical that this complex concept can be reduced to an objective, empirical environmental metric that applies equally to all harvesters. At the very least the authors should mention this as a caveat and discuss related scholarship. See:

Pollnac, R., Poggie, J. and Cabral, S., 1998. Thresholds of danger: perceived risk in a New England fishery. Human organization, 57(1), pp.53-59.

Pollnac, R.B. and Poggie, J.J., 2008. Happiness, well-being and psychocultural adaptation to the stresses associated with marine fishing. Human Ecology Review, pp.194-200.

We fully acknowledge that risk within fisheries is a subjective perception based on fisher age, fishing equipment, fisher and crew experience, and psychocultural profiles which have economic (i.e. potential loss of revenue) and human dimensions (i.e. safety concerns) (Pollnac et al. 1998, Pollnac and Poggie 2008). However, at the scale of the full US west coast over the 12 year study period, we only had access to quantitative data for the safety component of the fishery. We have included this clarification in the Material and Methods section.

Line 199: The authors should describe why they choose to use an inverse Simpson index to measure diversification and how landed species were grouped. Did they use the same metric and groupings that other fisheries diversification studies have used? If so, please add the citations. Groupings may be particularly important within the context of the groundfish fishery (where a single fishery lands a large number of different though ecologically similar species due to the non-selective nature of the gear used). To my knowledge, both earlier (i.e. Kaperski and Holland, 2013) and later (Fuller et al. 2017, Frawley et al. 2020, and Fisher et al. 2021) US West Coast Fisheries studies looking at fisheries diversification have applied indices to aggregated data (i.e. management groups or fishing métiers) rather than individual species. Relatedly, why was a different metric (Shannon's) used for calculating Port Diversity?

We thank the reviewer for this suggestion, and have implemented a slightly altered grouping for the “other” (non-Dungeness) species in the fish tickets that were used to calculate revenue diversity, using management codes directly from the Pacific Fishery Management Council (Figure A.14, https://pacfin.psmfc.org/pacfin\_pub/data\_rpts\_pub/code\_lists/sp.txt). The altered grouping (e.g., grouping all groundfish species together) did not significantly change the results of the study, but we agree that this change brings our methods into closer alignment with other recent work. Secondly, we have added language to this portion of the manuscript describing why we used a Shannon diversity index for port use diversity, and a Simpson index for revenue diversity. The Shannon index tends to be more sensitive to species (or in our case, port) richness, while the Simpson index is relatively more sensitive to dominance/evenness (as described in DeJong 1975 which we have now cited). In this study, we were interested in measuring the impact of the number of different ports used by Dungeness crab fishers, as well as the dominance of Dungeness crab in each fishers’ portfolio, hence the choice of different diversity metrics for the two indicators.

Line 212: More detail should be provided regarding the calculation of location choice entropy.

More details have been provided on the calculation of location choice entropy in the main text, including an equation. In addition, a new Appendix figure (Figure A.15) has been added showing an example time series of location choice entropy across a vessel-season.

Line 224: Likewise, more detail needs to be provided concerning the clustering procedure. I understand the distance metric and the aggregation method, but it is unclear whether the clustering algorithm used was hierarchical, kmeans, pam or some other method entirely. I understand the 'Nbclust' package was used to estimate the number of clusters but am not clear what package and procedure was implemented to do the clustering itself.

We have added additional language to more clearly explain the clustering method and procedure.

Line 278: A time series of SST anomalies across the study area would help justify the determination of which years constituted 'heat-wave' conditions.

We included a new reference (Suryan et al. 2021) that describes the physical and ecosystem responses to this marine heatwave. Overall, though, we have clarified in the Introduction and Discussion that our intent in defining the affected period includes not just the physical anomalies that occurred on the west coast, but also all of the management disruption and uncertainty that came with it. The additional text includes more justification of our choice to define the 2015-16 to 2017-18 seasons as the affected period.

Line 330-Line 331: As discussed above, it is worth referencing external factors that may have contributed to the high non-Dungeness revenue in 2016-2017 and 2017-2018. The way the argument is framed, these high revenues are due to MHW disrupting the crab fishery, but elevated revenues just as easily could be attributed to non-related factors (i.e. profitable and productive fishing years in the groundfish and/or pink shrimp fisheries).

As described in the response to Reviewer’s Point 1 above, we have added more text to acknowledge these alternative explanations for the observed revenue changes.

Line 376: I don't think the "hunter-gather" frame is an appropriate on here, particularly with respect to the Dungeness crab fishery. These biological populations (though contributing to sustainable fisheries) are heavily impacted by human activities (i.e. patterns of harvesting pressure, size limits, introduction of bait). This has been discussed in depth with respect to other pot fisheries targeting crustaceans. See:

Klinger, D.H., Turnipseed, M., Anderson, J.L., Asche, F., Crowder, L.B., Guttormsen, A.G., Halpern, B.S., O'Connor, M.I., Sagarin, R., Selkoe, K.A. and Shester, G.G., 2013. Moving beyond the fished or farmed dichotomy. Marine Policy, 38, pp.369-374.

We have removed this term from the manuscript and rephrased. We agree that “hunter-gatherer” may not be the most appropriate term.

Line 403: The description of specialists doesn't ring quite true, rather than minimizing risk through fishery specific acumen, my sense is that specialists are able to maximize economic returns through their skills and (in the case of larger vessels) their ability to leverage economies of scale. This specialization, though often associated with increases in absolute revenue, has been associated with greater interannual income variability in the face of environmental change. See:

Finkbeiner, E.M. 2015. The role of diversification in dynamic small-scale fisheries: Lessons from Baja California 674 Sur, Mexico. Global Environ. Chang. 32: 139-152.

Thank you for this helpful suggestion and citation. As our focus in this discussion is on responses to variable and uncertain conditions, we feel it is appropriate to consider the coping strategy of specialists as minimizing income risk. However, we agree with the reviewer’s comment that other mechanisms should be considered, so we have added the suggested citation and have revised this statement to now read: “Smith and McKelvey (1986) suggested that specialists and generalists in fisheries use different strategies to cope with variability and uncertainty in income—specialists are efficient and may minimize income risk or maximize returns through fishery-specific acumen or leveraging economies of scale, while generalists hedge against risk by building diverse portfolios (Kasperski and Holland, 2013; Finkbeiner 2015; Oken et al., 2021).”

Line 476: Should fishery managers endeavor to anticipate behavioral change (very tough, if not impossible to do with so much environmental, economic, and political uncertainty) or design and promote mechanisms that encourage resource user flexibility (i.e. enhancing their capacity to respond and adapt to change, no matter what that change is).

We appreciate this suggestion and agree this is an important consideration for managers. We have added the sentence “Likewise, managers should consider policies that enhance the capacity of resource users to adapt to environmental change, such as by reducing the frequency or duration of closures to single-fishery specialists during anomalous conditions.”

Line 490: Not sure that complex systems can be best defined in this way. Yes, there are individual actions, but there are also collective actions mediated by institutions and governance structures. Emergent system attributes are a product of cross-scale interactions and feedbacks between different levels of organization. If this is a line of argument that the authors want to keep, I would recommend moving beyond the Lubchenco citation to consider the work being published by sustainability scholars working in other systems. See:

Mancilla García, M., Hertz, T., Schlüter, M., Preiser, R. and Woermann, M., 2020. Adopting process-relational perspectives to tackle the challenges of social-ecological systems research. Ecology and Society, 25(1).

Scholes, R.J., Reyers, B., Biggs, R., Spierenburg, M.J. and Duriappah, A., 2013. Multi-scale and cross-scale assessments of social-ecological systems and their ecosystem services. Current Opinion in Environmental Sustainability, 5(1), pp.16-25.

We appreciate this point and have added the recommended citations as well as more nuance to this statement as follows: “Because complex systems are in part an emergent product of the individual actions of human actors, which are mediated by local, regional, and global governance structures (Mancilla Garcia et al. 2020, Scholes et al. 2013), informed adaptive management requires an understanding of the drivers of behaviors like those identified in this study along with well-calibrated and nimble responses within governance systems that work across local and regional scales.”

Figure A.3: Intuitively I am having a hard time understanding why there would be fewer generalists during heat wave conditions and more specialists (this is also contrary to what the literature would suggest). This may have something to do with increased groundfish targeting during MHW years or the fact that the defining parameters of what constitutes a generalist vs. specialist may have varied across years. Either way this should be parsed and discussed. Maybe the legend is incorrect (red and blue seem to mean different things here than they do in the main text)?

The colors in this Appendix figure were incorrect, and this has been fixed. We would also point to the new figures in the Appendix (Figs. A.12, A.13) that explore group size and flows a bit further. Our sense is that part of the reason there seem to be more specialists and fewer generalists during the heatwave time period may be as the Reviewer suggests- that the uncertainty associated with this time period resulted in increased groundfish targeting by vessels (generalists) that were readily equipped to do both.

As mentioned in other responses above, we have added significant text to the Introduction and Discussion to parse some of the complexity of the decisions facing Dungeness crab fishers during this time period. In particular, we have added more detail to the Discussion paragraph starting around the new Line 490 providing more details.