SCIENTIFIC AND STATISTICAL COMMITTEE’S

ECOSYSTEM SUBCOMMITTEE REPORT

Pacific Fishery Management Council

Via Webinar

August 31 and September 1, 2021

The Scientific and Statistical Committee’s Ecosystem Subcommittee (SSC-ES) met via webinar August 31 and September 1, 2021 to review new analyses conducted by the NMFS California Current Integrated Ecosystem Assessment (CCIEA) team that may potentially inform future annual Ecosystem Status Reports (hereafter CCIEA report) to the Pacific Council on the state of the California Current Ecosystem.  The SSC-ES reviewed four topics: A) Threshold Relationships Between Environmental Drivers and Performance of Salmon Preseason Abundance Forecasts, B) Krill-based Indicators, C) Year Class Strength and Distribution of Small Groundfish, and D) Port-level Linkages Between Fisheries using Network Analysis. Dr. Kristin Marshall chaired the meeting.  Meeting participants are listed in Appendix A.

1. **Threshold Relationships Between Environmental Drivers and Performance of Salmon Preseason Abundance Forecasts**

Dr. William Satterthwaite (NOAA, Southwest Fisheries Science Center) presented his paper “Ecological thresholds in forecast performance for key United States West Coast Chinook salmon stocks” (Satterthwaite et al. 2020) and an addendum he prepared for the SSC-ES, “Ecological thresholds in forecast performance for key United States West Coast Chinook salmon stocks – Addendum”. This research evaluated whether the performance of Chinook salmon abundance forecasts are related to environmental conditions, focusing on non-linear threshold relationships. Non-linear relationships have potential to disrupt fisheries management and are not incorporated in current forecast models. Satterthwaite et al. (2020) focused on stocks of high priority for US west coast fisheries management and of predicted importance as prey for Southern Resident Killer Whales. The authors tested 2688 stock-driver-time lag combinations and found 65 non-linear relationships. Of these, 60 demonstrated threshold relationships, determined to exist when the 95% confidence interval of the second derivative of the nonlinear function excluded zero. Among indices capable of explaining at least 33% of variance in forecast performance, oceanic environmental indices were much more common than freshwater or local environmental indices. This may be because forecasts already make use of some measure of cohort strength (e.g. jack returns) that takes place after freshwater and ocean-entry conditions have had their immediate effects. There were mechanistic explanations for many of the observed relationships. When many of the relationships were re-examined with updated datasets (see Addendum), in almost all cases where non-linear relationships had been previously selected, they were re-selected. This work could help fisheries managers identify environmental thresholds past which increased precaution may be warranted. For example, as suggested in the Addendum, NPI could be added to the annual CCIEA report as extreme values of it appear to predict poor Sacramento River Fall Chinook forecast performance and it may be relevant for interpreting some Puget Sound abundance forecasts. Dr. Satterthwaite also demonstrated a straw-person method by which fisheries managers could quantify uncertainty in forecasts and increase precaution when a threshold is exceeded, using similar logic to how groundfish are managed.

While this was the first presentation on forecast thresholds to the SSC-ES, Dr. Satterthwaite addressed many comments the SSC and SSC-ES made in previous discussions of threshold approaches. The SSC-ES appreciated that feedback had been incorporated in many instances, and that acknowledgment was made where previous SSC recommendations were applicable but not yet incorporated. For example, a null model randomization procedure approach was used to look at the chance for false positives and Bonferroni corrections were used for p-values, as previously suggested by the SSC and others when large numbers of tests were conducted in screening for relationships. In the Addendum, Dr. Satterthwaite also examined how robust the identified relationships were to new data, as suggested by previous SSC reviews of threshold work. The relationships tended to remain non-linear, and R2 tended to decrease with small increases in new data. When examining thresholds, one expects little change when “average” new data is added but more substantial changes when more extreme observations are added; this pattern was, in most cases, observed. Non-stationarity in the threshold relationships is not addressed in this work, but is worth consideration in further work.

The SSC-ES discussed several other technical aspects of the work and makes the following suggestions:

* The SSC-ES agreed that R2 is a useful metric, but should not be the sole metric to evaluate the utility of models because the performance variable is truncated and thus non-normal, but R2 is from a normal model
* Multi-variable responses or multidimensional indices. Multi-variable responses are certainly possibilities, but difficult. More localized indicators with clear mechanistic hypotheses would be a good place to start such an investigation. Multi-dimensional indices could be useful, but only if the components are related to forecast performance with the same lag
* Another potential approach to explore is using a logit response; if a forecast breaks down with extreme values in either direction (a u-shaped rather than sigmoidal response) then logit might not capture that
* Results showing strong linear relationships should be investigated for inclusion in forecast models
* Consider exploring additional ways to quantify errors in forecasting because this approach is less likely to capture under-forecasts than over-forecasts and multiple metrics may be needed to fully capture the magnitude of error, proportion of error, and the consequences of errors to management.

The SSC-ES appreciated this innovative work and supports using the approach in the CCIEA report to characterize conditions when salmon forecasts may perform poorly. In previous reviews of threshold research, the SSC recommended that the CCIEA report include a small set of pressure variables where a threshold is indicated. The report currently includes recent PDO, and it may be useful to add a “now-cast” or a forecast, as well as include the NPI. These indices could aid in categorizing the risk associated with Sacramento River Fall Chinook and certain Puget Sound Chinook salmon forecasts. If an indicator is in a range that is a threshold for any fish stock, the SSC-ES notes that it is worth mentioning in the CCIEA report. At the same time, the SSC-ES recognizes that nuance is needed in describing errors in forecasting. An indicator being above a threshold does not imply that a forecast will be wrong, but it does mean that more caution might be warranted if the consequences of forecast error are undesirable and forecast error is more likely due to environmental conditions. In general, it would be helpful to see more cross references between the CCIEA report and other Council materials, for example mention of the CCIEA report in salmon statements and vice versa.

1. **Krill-based Indicators**

Dr. Eric Bjorkstedt and Ms. Roxanne Robertson (Humboldt State University) presented an overview of data and methods behind krill-based indicators entitled “Size of adult *Euphausia pacifica* along the Trinidad Head Line: an ecosystem indicator for the California Current.” The review was suggested by the SSC in March of 2021 to better understand how the mean krill size data presented in the CCIEA report could be interpreted in the absence of relative abundance data, given the nuanced nature of interpreting size data alone with respect to population trends and abundance.

Dr. Bjorkstedt described the indicator as representing density-weighted mean body length of adult *Euphausia pacifica* captured in standard bongo net sampling along the Trinidad Head Line (THL), just north of Cape Mendocino, based on biweekly to bimonthly sampling of five standard stations that run along the continental shelf and slope (35 to 780m depth). The region is characterized as having considerable mesoscale variability in ocean conditions and advection patterns, and a key motivation for the location of this survey line was the hope that the resulting data could help inform regional productivity of Klamath river salmon stocks. The survey began in 2007 and is ongoing, details on survey methods and a great many additional survey results are reported in a publication (Robertson and Bjorkstedt 2020) that was also made available to the subcommittee. Data collected in this survey include hydrographic sampling (temperature, salinity), water sampling (nutrients, chlorophyll) and zooplankton sampling (krill, other zooplankton, ichthyoplankton).

Importantly, in this survey adult krill are identified by maturity factors rather than size thresholds, and the results of their analysis indicate that there would be considerable misclassification of adults and juveniles during warm periods if based on size alone. Adult krill are more abundant over the outer shelf and upper slope, although they are often found inshore, though at lower densities, during the upwelling season (and are often larger on such occasions). There are clear indications of shifts in the size distribution over time, for example, in 2008 krill catches were of generally larger individuals, while in 2015 (during the large marine heatwave) adult krill tended to be considerably smaller. While the authors estimate and have reported biomass indices in the literature, they also noted that numerical abundance (the number of individuals) does not change substantially over time, such that a considerable fraction of the change in total biomass is driven by changes in size. This suggests that changes in adult size represent an integrative index of krill in this region, and reflect insights into both available biomass and how it is “packaged and distributed.” The authors also note that they have not yet attempted to develop population models, or relate spawning biomass to recruitment, in order to better evaluate the consequences of smaller females to potential spawning output and productivity.

Considerable effort has focused on relating shifts in size distributions from this dataset to environmental conditions. Among the findings are that low frequency shifts in size distributions appear to reflect changes in upper water column ocean conditions, particularly temperature, with convergence towards median adult sizes at warm temperatures. Seasonal increases in average size of mature adults are reduced under warm conditions, and size increases with colder years and with higher chlorophyll levels. Conversely, early furcilia stages are larger during warm years. There is some suggestion that dynamics are preconditioned at some level, with population and size trajectories for spring and summer reflecting observed patterns during the winter. However, there is uncertainty regarding the extent to which shifts in size structure might result from advection rather than local dynamics, as there is evidence for advective drivers of some observations, such as a rapid and steep drop in mean size coincident with the arrival of “warm blob” waters at the coast in late 2014, which happened too fast to reflect localized population dynamics.

For Klamath salmon, it was noted that early ocean survival rates appear to have some general relationship to krill size, such that juvenile salmon rarely have high survivorship when krill are small as adults. The dataset also includes potential assemblage indicators, through the relative abundance of species with warm or cool water affinities.

In discussion, the SSC-ES asked about the spatial representativeness of the index, and the extent to which this indicator is localized or reflects larger scale trends. The proponents suggest that the index is likely to represent the region between Cape Blanco and Cape Mendocino, and thus could be a useful indicator for Klamath River salmon, but differences in oceanography make it uncertain whether the THL index to be a robust indicator of krill demographic or abundance trends reliably beyond this region. However, Dr. Bjorkstedt noted that earlier investigations found that the THL copepod time series (which is behind several years on data processing) correlated well with the Newport Hydrographic Line (NHL), several hundred km to the North, though with important differences in composition and within-season timing. The SSC-ES suggested that more comparisons among krill surveys could be helpful to get a sense of the scale of variability in krill across the California Current Ecosystem, and some surveys that occur less frequently over broader spatial areas could also inform this scale.

The subcommittee also discussed the extent to which mean adult size is the most appropriate indicator, or whether the addition of or shift to a biomass based indicator could be more appropriate or informative. The potential benefits of combining or adding biomass to length, or adding assemblage-based indicators was discussed, recognizing that the precise mix of indicators to report would depend on how the indicators would be used or intended to represent. The SSC-ES suggested greater development of both biomass and size indicators for future CCIEA reports. The potential for “growth products” (e.g., indicators of individual growth rates) was discussed, as were indicators related to shifts in the distribution of mass.

The subcommittee recognized all of these products as helpful indicators of key ecosystem processes in this region, but was uncertain regarding just how to integrate the results into informing management in a useful manner. The potential for helping to inform early marine survival indicators for Klamath salmon was discussed, although it was noted that the current assessment model for salmon fisheries is based on sibling regressions, which reflect information obtained after fish have gone through the presumably more variable initial marine survival phase. However, it could be that an indicator could provide an extra year or more of lead time, which could be helpful given that Klamath River Fall Chinook are currently under a rebuilding plan. Additionally, forage indicators also reflect the conditions that 2, 3, and 4 year old fish are facing in the ocean, and thus krill (or krill predators) could still be affecting later maturation and mortality rates in Klamath salmon. Moreover, as river returns are observed with error, modeling approaches (such as state-space models) that forecast based on multiple indicators of cohort strength could be more robust than univariate approaches that ignore uncertainty. Finally, the SSC-ES suggested that the size-based indicator or other indicators could be useful in the Klamath River stoplight table.

1. **Year Class Strength and Distribution of Small Groundfish**

Dr. Nick Tolimieri (NOAA, Northwest Fisheries Science Center) presented an analysis of juvenile groundfish habitat and abundance proposed for inclusion in a future CCIEA report. A recent publication was the basis of the presentation (Tolimieri et al., 2021). The motivation for the work is to inform Essential Fish Habitat for juvenile groundfish and identify important nursery areas. This research could also potentially lead to an index of recruitment for some species.

The analysis used lengths and abundance for 13 species from the West Coast Bottom Trawl Survey. The survey ages a subsample of fish. To estimate age for the measured but unaged fish, length was converted to age using a fixed age-length key for each species. For some species, there were not enough individuals in the smallest age-class (age-0 or age-1), age classes were combined (grouped) for the analysis. In discussion, the SSC-ES suggested that for species with sufficient data, a year-specific age-length key would better account for variability in growth.

Abundance was standardized using the Vector Autoregressive Spatio-temporal (VAST) package, assuming a common intercept across years and spatial variation was explained by spatial and spatiotemporal autocorrelation. The SSC-ES suggests further investigation of the variance surfaces (in addition to abundance) to better understand how the assumption of a common intercept might be affecting the results. For example, a comparison could be done by fitting a temporal model without the spatial field. The SSC-ES caution against extrapolating into areas that have particularly high variance. Investigating alternative approaches to VAST (e.g., sdmTMB) may also allow for more flexibility in the fixed spatial field.

The resulting juvenile spatial distributions were qualitatively categorized as: distinct hotspots (dover sole, shortspine thornyhead, splitnose), distinct hotspots that were temporally variable (hake, darkblotched rockfish), large distinct areas of high juvenile abundance (arrowtooth flounder, English sole, sablefish), and limited latitudinal distributions but no obvious hotspots (Pacific grenadier, lingcod, longspine thornyhead, petrale sole). The SSC-ES agreed that these spatial distributions are a useful starting point for defining juvenile habitat groundfish habitat. Due to multiple distinct patterns, the SSC-ES recommends continuing to focus on species-specific distributions and cautions against combining species into a single juvenile groundfish distribution map.

Validation of the juvenile abundance indices was explored by comparing against the recruitment deviations from the stock assessment model for sablefish, arrowtooth flounder, lingcod, and hake. Only sablefish appeared to have strong agreement. However, the SSC-ES noted in discussion that there are many reasons the two indices may not align, including the structure and assumptions of the assessment model. Therefore, it should not be assumed that the assessment recruitment deviations represent a “true” recruitment index.

The SSC-ES was asked to provide guidance on additional species that could be investigated with this approach and offers the following suggestions:

* Choose species that are well-sampled by the survey. Flatfish are likely good candidates
* Consider using survey selectivity estimated in the assessment models to guide size cut-offs. Assessments typically do not use length at age at very small sizes because they are not well sampled by the trawl
* Avoid applying this method to species that are rock-associated, particularly with the VAST approach. These likely include: widow rockfish, darkblotched rockfish, shortbelly rockfish, and possibly chilipepper rockfish.
* Prioritize species that are important to fisheries

The SSC-ES discussed with the CCIEA team how to include this analysis into future CCIEA reports. The SSC-ES suggests the analysts consider developing indices representing temporal and/or spatial stability. This would condense the distribution maps into annual anomalies in hotpots or area and distribution of juvenile habitat, for example. The SSC-ES suggests that a future application of this work could be to use robust juvenile abundance indices to inform management between assessments, such as through assessment prioritization scoring, scientific uncertainty buffers, or other approaches.

1. **Port-level Linkages Between Fisheries using Network Analysis**

Dr. Jameal Samhouri (NOAA, Northwest Fisheries Science Center) provided an overview of the network analysis approach that has been developed to describe West Coast port groups. An initial set of network diagrams was included in the 2021 CCIEA report. The methods have since been revised and additional work was done in response to feedback following a presentation to the SSC-ES in January 2021 and the SSC in March. In addition to a Powerpoint provided at the SSC-ES meeting, Dr. Samhouri provided the SSC-ES with two publications (Fuller et al. 2017; Fisher et al. 2021) that use similar methods.

Dr. Samhouri presented a number of different networks that were responsive to suggestions made by the SSC-ES in January including:

(1) vessel-level networks with scaling of nodes based on the median proportion of revenue a fishery contributes to vessels in that fishery, alternative minimum revenue thresholds for determining which vessels to include, and different methods of determining edge weights based on the amount and evenness of revenue, or the number of vessels, associated with each fishery pair;

(2) aggregate port-level and state-level networks with fisheries node inclusion determined by a minimum proportion of port or state revenue and node scaling based on relative total revenue; and

(3) time series of vessel-level network diagrams for two ports showing how networks have changed between 2004 and 2019.

Dr. Samhouri discussed work published in Fisher et al. 2021, illustrating how network characteristics of edge density, centrality and modularity influence the response of participants in a network to a shock. The example focused on HAB-related crab closures in California and suggests that fishers in denser networks are more likely to move to other fisheries while those in less dense networks are more likely to cease fishing. The analysis also shows that for centralized networks impacts vary depending on the centrality of the fishery subject to a shock.

The SSC-ES appreciates the responsiveness of the analysts to its comments and suggestions, and finds the new analyses and network diagrams useful. The networks provide a visual description of the fisheries/species groups of importance to particular port groups and the degree to which they are connected by cross-participation and movement of fishers between them. Fisheries are defined by the same species groupings used in the diversification indices in the annual CCIEA report (rather than by métier as was done in the earlier work by Fuller et al. 2017). The network diagrams complement the diversification indices by providing information about the characteristics of fishery diversification strategies and how they vary across ports.

The network analysis has the potential to contribute to our understanding of how shocks to fisheries may impact particular communities (defined by port group) and potentially reverberate across fisheries. This may be apparent to some degree from simply viewing the network diagram, but quantitative network metrics may provide additional insight into overall stability of networks, and potentially resilience or vulnerability of fishers in a port to shocks to fisheries. These metrics include edge density, centrality, and modularity. Of these, edge density appears to have the clearest relationship to resilience. Networks with high edge density suggest that fishers have greater ability to move effort between fisheries and thus substitute for lost revenue from a fishery that is closed or has a poor year. The effects of centrality and modularity of networks appears to be very context dependent. For example, if the central fishery is closed in a network with high centrality, the impact would be great while it would be small if a non-central fishery was closed. Networks with high modularity would have increased impacts within a module but less outside it. More analysis will be needed to get a better general sense of how and when centrality and modularity mediate impacts of fishery shocks and affect the resilience of fishing communities.

There was some confusion about the scaling of the nodes in the network diagrams that was clarified after the meeting. The scaling of nodes for the vessel level network is based on the median percent of individual vessels’ revenue that the fishery contributed to the fishers that participated in it. The node is large if the fishery provides a large proportion of individuals' revenue to at least half of the fishers involved in that fishery. Even a fishery that contributes a relatively small share of revenue at the port level might be shown as a large node. For example, in the 2019 crab year (Nov 2019-Oct 2020) tuna in Astoria only contributed about 2% of total revenue as compared to 15% for non-DTS groundfish but it had a node similar in size to crab which contributed 33% while non-DTS groundfish had a small node. This approach to node scaling has the advantage of showing relative importance of each fishery to those who fish in it, but it does not necessarily reflect the overall importance of the fishery to the port. If this approach to scaling nodes is used, it needs to be clearly explained, or it may lead to confusion. It would be useful to provide some supplementary information about port level revenue such as a pie chart showing the proportion each fishery contributes to port revenue. In contrast, for the aggregate port or state networks, both fishery inclusion and node scaling are based on the proportion of revenue the fishery contributes to the port or state’s total revenue. This approach highlights fisheries that contribute a large proportion of total revenue yet it may exclude fisheries that are very important to a subset of fishers. Both approaches have strengths and weaknesses and the SSC-ES sees merit in both. Whichever approach is used, the methods used for fishery inclusion, scaling of nodes, and defining edge weights should be clearly explained.

The SSC-ES is supportive of including port-level network analyses in future CCIEA reports. The following observations and comments arose in discussion and may be helpful to the analysts in preparing future network analyses:

* It should be made clear in any publications and presentations that the analysis reflects revenue by “crab years” (Nov-Oct) as opposed to calendar years for all fisheries.
* Node size and edge weights are comparable within ports but not across ports. While Dr. Samhouri noted that this could be changed to allow comparison across ports, it could be problematic to do so given large differences in absolute revenue and fleet sizes for different fisheries in different ports.
* In contrast to edge weights based only on the number of vessels in fishery pairs, revenue connectivity edges have edge weights that are higher when revenue is higher but also more evenly distributed between the nodes. This may provide more insight into what will happen when a shock happens to one or the other (e.g. more impacts are likely if revenue is more evenly distributed than if one node dominates). While more complex than edges based on the number of vessels, this may be more useful for understanding impacts of shocks. The analysis of network metrics (modularity and centrality) has been based on the revenue connectivity definition and may be less applicable when edges are based on vessel numbers only.
* For the aggregate port level diagrams Dr. Samhouri showed on slide 19, the scaling of nodes was based on the ratio of port revenue for that fishery relative to the revenue from the fishery with the highest revenue for that port. It was discovered after the meeting that there was an error in the diagram for Fort Bragg caused by one tuna fish ticket that had a misplaced decimal point. Tuna should not have had a large node in that diagram and other fisheries should have been included.
* For aggregate level networks, the 10% of total port revenue cut-off results in very few fisheries for some ports. An alternative might be a cut-off based on absolute revenue (e.g. over $100K) or a smaller percent of revenue. Supplementary diagrams at the end of the Powerpoint showed aggregate networks including fisheries that includes at least 5% of revenue which substantially increased the numbers of fisheries included. This lower cut-off might be preferable for aggregate networks.
* For Washington fish tickets reported Port may mean different things for groundfish, salmon and shellfish and this should be checked.
* It was suggested that it would be worth considering the vulnerability of the species themselves and tying that to the vulnerability of the networks (e.g in a network with mostly species impacted by upwelling will be more vulnerable than one that has species that are not impacted by upwelling.
* It was suggested that it might be useful to go back before 2004 for time series analysis and to combine groups of years and look at changes over longer time periods or networks.
* Most of the SSC-ES members that commented found vessel level analysis more useful than the aggregate port-level analysis. The aggregate networks did not provide substantial information that could not be provided with a simple bar chart of share of revenue by fishery for each port. However, the SSC-ES assumed at the time that node scaling for vessel level networks already reflected the relative proportion of port revenue, which it did not.
* It was suggested that a network analysis could provide insight on community impacts when developing a groundfish rebuilding plan that largely affects a portion of the fishery. Doing so might require different exclusion criteria to focus the network on the groundfish fishery similar to the approach used by Fisher et al. (2021) for crab.

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**Appendix A. Meeting Participants**

**SSC Ecosystem Subcommittee Members Present**

Dr. Kristin Marshall (Subcommittee Chair), National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA

Dr. John Field, National Marine Fisheries Service Southwest Fisheries Science Center, Santa Cruz, CA

Dr. Marisol Garcia-Reyes, Farallon Institute, Petaluma, CA

Dr. Michael Harte, Oregon State University, Corvallis, OR

Dr. Dan Holland, National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA

Dr. Galen Johnson, SSC Chair, Northwest Indian Fisheries Commission, Olympia, WA

Dr. André Punt, University of Washington, Seattle, WA

Dr. William Satterthwaite, National Marine Fisheries Service Southwest Fisheries Science Center, Santa Cruz, CA

Dr. Ole Shelton, National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA

Dr. Cameron Speir, National Marine Fisheries Service Southwest Fisheries Science Center, Santa Cruz, CA

**CCIEA Team Members Present**

Dr. Eric Bjorkstedt, National Marine Fisheries Service Southwest Fisheries Science Center, La Jolla, CA

Dr. Toby Garfield, National Marine Fisheries Service Southwest Fisheries Science Center, La Jolla, CA

Dr. Chris Harvey, National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA

Ms. Roxanne Robertson, Humboldt State University, Arcata, CA

Dr. Jameal Samhouri, National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA

Dr. Jarrod Santora, National Marine Fisheries Service Southwest Fisheries Science Center, La Jolla, CA

Dr. Nick Tolimieri, National Marine Fisheries Service Northwest Fisheries Science Center, Seattle, WA

**Others Present**