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**Joint PICES-NPFC Workshop:**
**The influence of environmental changes on the potential for species distributional shifts and population dynamics of Pacific saury**

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**Summary**
On October 16, 2019 the joint North Pacific Fisheries Commission-North Pacific Marine Science Organization (NPFC-PICES) workshop on the influence of the environment on Pacific Saury was held, in conjunction with the PICES 2019 Annual Meeting in Victoria, British Columbia, Canada. This workshop was the inaugural joint workshop between PICES and NPFC to advance collaboration between the two organizations. Under the proposed PICES-NPFC Framework for Enhanced Scientific Collaboration, the theme area of stock assessment support was identified as a priority area for collaborative work. The objectives of this joint workshop were to:

1. Present an overview of environmental conditions and spatio-temporal changes in Pacific saury distributional areas,
2. Identify periods with significantly different oceanographic conditions that could influence the population dynamics of Pacific saury,
3. Hind-, now- and fore-cast changes in habitat suitability for saury,
4. Propose mechanisms for further research to understand the interaction of ecosystem changes on Pacific saury distribution and population dynamics and associated consequences on stock assessment, and to
5. Discuss and identify approaches to incorporate environmental drivers in modeling the saury population dynamics to improve its stock assessment.

The workshop began with an introductory presentation by Dr. Kazuhiro Oshima (invited) that outlined the consensus stock assessment for Pacific Saury that was constructed by the NPFC

Technical Working Group of Pacific Saury Stock Assessment in 2018-2019. This assessment describes the stock as cyclical in nature, with biomass near carrying capacity in the early 2000's, declining to a low biomass in 2017, with some recovery in 2018. A key uncertainty in the stock assessment and the knowledge of Pacific saury in general is the level to which productivity, growth and survival might be influenced by changes in the ecosystem.

After describing the current condition of the Pacific saury stock as a starting point for further analyses, the workshop moved into presentations and discussions centered around the potential environmental changes that have occurred in the area habited by Pacific saury. Dr. Chuanxiang Hua (invited) presented analyses that examined the habitat suitability for Pacific saury based on fishery effort in relation to changes in sea surface temperature (SST) and spatial variation in sea surface temperature gradient (SSTG). A key finding of this analysis was that SST appears to control the migration and distribution of Pacific saury, whereas SSTG appears to be related to the aggregation of Pacific saury. The year 2016 stood out as anomalous, with a reduced area of suitable habitat and below average SSTG across a large range of latitudes. This year corresponded to variability in the El Nino indices. Dr. Taiki Fuji then presented an analysis of Japan's fishery independent trawl survey data that focused on patterns in the distribution of Pacific saury during summer months (June-July). The presence of competitors for prey species (particularly Japanese Sardine) was shown to have an impact on the distribution of Pacific saury. The distribution of Pacific saury in recent years appears to have shrunk into cooler water in western area of 180 ° with concurrent expansions from the south by Japanese Sardine. The discussion around this first topic of the workshop centered around uncertainties in the relationships between the oceanography and Pacific Saury distribution, the types of variables (both oceanographic and biological) that are important to determining the abundance of Pacific Saury, and in particular the need for more study of the mechanisms underlying the environmental relationships that have been found. Migrations of Pacific Saury as they age, into feeding areas and areas for spawning are extensive and seasonal, adding complexity to the relationship to oceanographic variables.

The second topic for presentations at the workshop was an examination of projections and uncertainties in habitat suitability for Pacific Saury. Dr. Bai Li (invited) presented an analysis of the jointly produced catch-per-unit-of-effort (CPUE) data from NPFC members. Using the geographically weighted regression model, Dr. Li presented evidence for non-stationarity in the relationships between environmental factors and CPUE data, meaning the CPUE was responding differently to environmental covariates in different regions. The important predictors in the model included Chlorophyll A (from satellite data) and there appeared to be a split in the regression model parameters at about 150° and 155° E. The next presentation by Dr. Chih-hao Hsieh conducted species distribution modeling using a variety of methods and an ensemble to determine the distribution of Pacific Saury. This work highlighted the uncertainty around environmental relationships, as the variables and relationships found as important were generally not consistent across model types. Additionally, no single modeling approach was consistently the best, but the

ensemble models tended to outperform the individual models. Dr. Midori Hashimoto next presented an analysis of the Japanese survey data using a vector-autoregressive-spatio-temporal model (VAST). The main findings from this model were that the high density areas for age 0 fish had moved east, while age 1 densities were consistently highest in the north, but had decreased over time. The optimal temperatures predicted from the model were different for age 0 and age 1 fish in the model and the time-series of estimated age 0 abundance index from the VAST was very similar to nominal index. An analysis of the potential link between the environment and recruitment was shown by Dr. Shin-Ichiro Nakayama. Dr. Nakayama found that the abundance of age 0 Pacific Saury was strongly correlated to the abundance of age 1 fish in the following year and hypothesized that the environmental effect (PDO) was linked to the distribution of age 0 fish, but was not strongly influencing the recruitment of age 0 fish. The final presentation during this topic was by Dr. Kirill Kivva (for Andrey Krovnin). Dr. Kivva examined the periodicity in catches for Pacific Saury as a function of the periodicity in the North Pacific Gyre Oscillation (NPGO). There were strong correlations between the index and the catch of Saury at a 0 and especially a 5 year lag. Dr. Kivva presented a number of hypotheses that could potentially explain the lag that were linked to long acting oceanographic conditions, such as long period Rossby waves changing thermal conditions as they moved westward in the North Pacific. Dr. Kivva also pointed out that many fish species in the North Pacific (pollock, cod and pink salmon) show linkages to the NPGO and long term indices of oceanography. There was an active discussion session following these talks that engaged on the types of variables that would be of interest to examine for determining Pacific Saury distribution and abundance, how the modeling might be approached and how the new analyses and information might be used in stock assessment. The broad topics and conclusions are captured in the future directions outlined below.

The final topic for the workshop focused on mechanisms for further research on environmental impacts on Pacific Saury abundance. Dr. Yong Chen presented an overview of examples from other parts of the world and other stocks where environmental conditions have been incorporated into stock assessment. In general there are two ways to improve stock assessments, the first is to improve the data going into the models. The example given was standardization of CPUE for highly migratory species such as tuna. This type of standardization has already been explored for Pacific Saury. The second way to improve stock assessment is to improve the models themselves. This can be done using environmental variables that would link ecological mechanisms to population parameters and key life history processes in the model. For example, adding an environmental covariate to a stock-recruit relationship such as SST that can modify the stock-recruit relationship. It can also be done using time or area blocks where different environmental conditions may be occurring. For example, regime shifts may change the productivity of an area, so using different parameters for growth before and after the regime shift would be a way to account for the environmental effect in the model. In the discussion that followed this presentation, Dr. Chen highlighted the need to consider the effects of the stock assessments with environmental covariates

on biological reference points and harvest control rules, as well as the need to be able to project future stock condition, which would require projections of the environment under different climate change scenarios as well.

The workshop concluded with a discussion of future directions for research (see below) and future directions for the PICES-NPFC collaboration. It was concluded that further collaboration would be good for moving forward on improving stock assessments for Pacific Saury as well as other species of interest for NPFC. The workshop participants endorsed continuing the discussions and collaborations between NPFC and PICES, with potential ideas of forming a joint PICES-NPFC Working Group and suggesting a broader topic session in the PICES 2020 annual meeting on the effects of the environment on small pelagic fishes that would have participation and engagement from a larger portion of the PICES community of researchers.

During the PICES-NPFC study group meeting on Saturday October 19, Dr. Vladimir Kulik presented his work on the influence of environmental covariates on Russian stocks of Pacific Saury. Dr. Kulik was unable to attend the initial workshop due to travel delays. Dr. Kulik's study utilized a variety of modeling methods (maximum entropy, generalized additive model, random forest model) to predict the distribution of catches in relation to a set of meteorological information available on a daily time step. One of Dr. Kulik's main findings was that years with extreme large and small areas of habitat suitability corresponded to extreme years of catch.

**Recommendations and Future Directions for Research on Pacific Saury**

A number of recommendations for future research were developed during discussions at the workshop. Here we have placed them under four topics with some specific examples for each. The recommendations contain both short and long-term projects that could be undertaken collaboratively by scientists from the PICES and NPFC communities. The data and analyses identified here would support stock assessment activities for Pacific Saury conducted by the NPFC.

1. There should be further studies and analyses to build on the empirical relationships that have been identified to determine mechanistic processes controlling the distribution and abundance of Pacific Saury. Specific examples of the types of data and analyses that would be useful are:

- Oceanographic data and predictions from regional ocean models of variables important to Pacific Saury distribution and population dynamics
- Stomach content data from Pacific Saury and its competitor species at different ages, locations and seasons
- Spatially explicit data on competitor species at the same resolution as the Pacific Saury data
- Analyses that explore the full range of potential oceanographic and biological variables hypothesized to determine the distribution of Pacific Saury

- Examination of otolith microchemistry or other techniques that might improve knowledge about stock structure and spawning and rearing areas (e.g., whether the entire stock is intermixed or whether spawning occurs in distinct areas)

2. Environmental relationships (identified through mechanistic and empirical studies) should be explored in future stock assessments for Pacific Saury. Examples of relatively attainable goals suggested in the workshop were:

- Incorporating the area of habitat occupied by Pacific Saury (through Habitat Suitability Indices or other species distribution models) into stock assessment as measure of carrying capacity
- Linking environmental covariates (such as the PDO or NPGO) to stock-recruit relationships
- Exploring the types of analyses conducted on CPUE data with the fisheries independent survey data to standardize the data and look for patterns that are similar (or different) to the CPUE
- Evaluating the use of seasonal time steps instead of annual time steps in the stock assessment

3. Research to link projections (under different climate change scenarios) and hindcasts of regional ocean models to projections of Pacific Saury abundance should be undertaken:

- Collaboration with the PICES community of researchers should be encouraged (though topic sessions and work groups) to assist with these research areas to ensure that oceanographic data (hind-, now-, and fore-casted) have the spatio-temporal scales consistent with the scales of relevant biological/ecological processes for the saury
- Data from projection models is particularly important, as it allows projection of stock status under environmental changes and can make stock assessment models robust to climate change

4. Analyses should consider the impacts of the environment on biological reference points for Pacific Saury:

- Climate change and longer-term variability (such as regime shifts) will likely have an impact on the productivity of the system, necessitating exploration around time-varying stock reference points