Variations and Perspective for Forecast of North Pacific Marine Ecosystem

Shoshiro Minobe (Hokkaido Univ)

This talk consists of two our recent studies, which are related PICES WGs.

Marine Ecosystem Variations over the North Pacific and Their Linkage to Large-Scale Climate Variability and Change

Emi Yati, Shoshiro Minobe, Nathan Mantua, Shin-ichi Ito, Emanuel Di Lorenzo (2020, Frontiers in Marine Science, referred in IPCC-AR6 WG2) https://doi.org/10.3389/fmars.2020.578165

(PICES WG 27, North Pacific Climate Variability and Change)

Toward regional marine ecological forecast using global climate model predictions from subseasonal to decadal timescales: bottlenecks and recommendations.

Shoshiro Minobe, Antonietta Capotondi, Michael G. Jacox, Masami Nonaka, Ryan R. Rykaczewski (under revision for Frontiers in Marine Science)

(PICES WG 40, Climate and Ecosystem Predictability)

Marine Ecosystem Variations over the North Pacific and Their Linkage to Large-Scale Climate Variability and Change

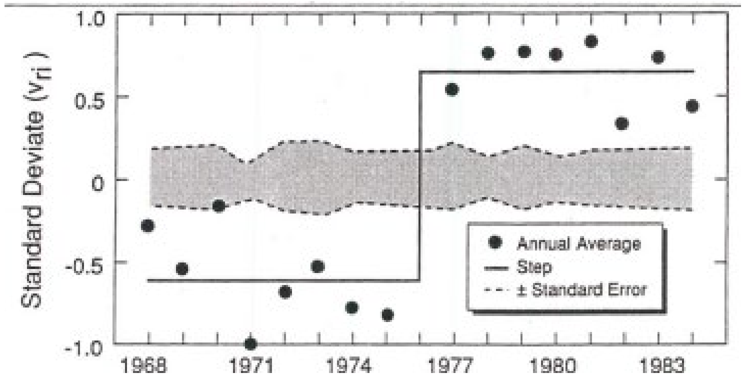
Emi Yati, Shoshiro Minobe, Nathan Mantua, Shin-ichi Ito, Emanuel Di Lorenzo
(PICES WG 27, North Pacific Climate Variability and Change)

Published in November 2020 in Frontiers in Marine Science
https://doi.org/10.3389/fmars.2020.578165

Introduction

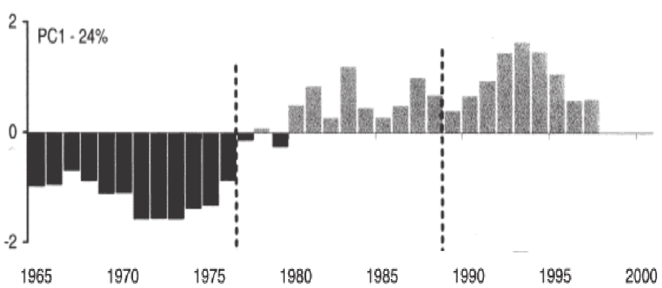
- The impact of climate variability on marine ecosystems has attracted much attention since the 1980s.
- The first step was to analyze specific species such as sardines and salmons.
- The second step was to analyze a number of species with averages (Ebbesmeyer et al. 1991)
- The third step was to analyze a large number of species using multivariate analysis method (Large Multivariate Analysis, LMA) (Hare & Mantua 2000).

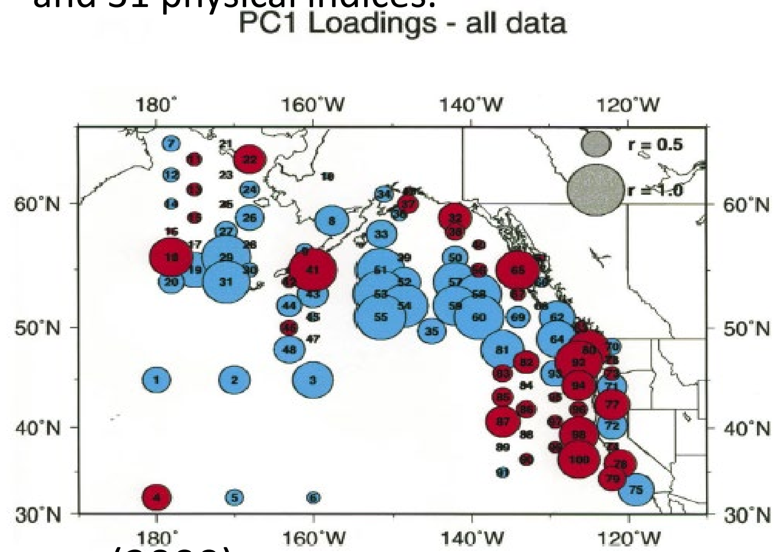
Averages of normalized 7 biological indices and 33 physical indices



(Ebbesmeyer et al. 1991)

Principal component analysis of 69 biological and 31 physical indices.





Hare & Mantua (2000)

LMA Studies for the N-Pacific and Adjacent Seas

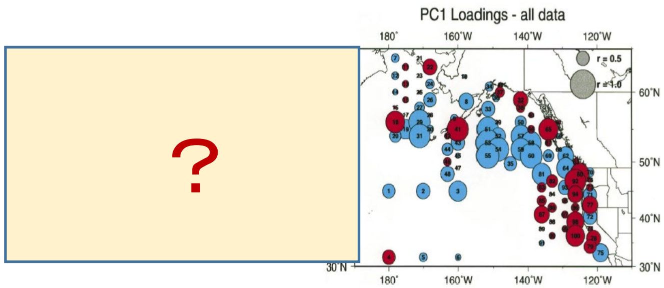
Authors	Analysis Area	Analysis Period	Biological Indices
Hare and Mantua (2000)	Eastern NP	1965-1997	69: salmon catch, groundfish and small pelagic recruitment, invertebrate catch and zooplankton biomass.
Litzow and Mueter (2014)	Eastern NP	1965-2008	64: Same as above
Tian et al. (2006)	Sea of Japan	1958-2003	58: catch data only for large predator, small pelagic, groundfish, invertebrate, seaweed
Ma et al. (2019)	Yellow and East China Seas	1965-2008	147: catch data only for large predator, small pelagic, groundfish and invertebrate.

update

Limitations of previous studies & purpose of this study

However, previous LMA studies have the following problems.

- The western and eastern NP have not been analyzed together, making it difficult to get a complete picture.



- The impact of global warming (climate change) has not been assessed.

Data and Method

Biological Indices

- We combined the data collected by US NOAA and Japan Fishery Agency (2014 report).
- The analysis period was 1965 to 2006, and 120 indices are selected based on 50% criteria of the available data ratio (Hare and Mantua 2000).

Marine biology	Western North Pacific (Japan and Russia)	Eastern North Pacific (Bering Sea, Gulf of Alaska, West Coast of America)	Total
Groundfish recruitment	8	46	**54**
Small Pelagic fish recruitment	8	5	**13**
Invertebrate recruitment	1	7	**8**
Salmon abundance	10	24	**34**
Zooplankton biomass	2	9	**11**
Total	**29**	**91**	**120**

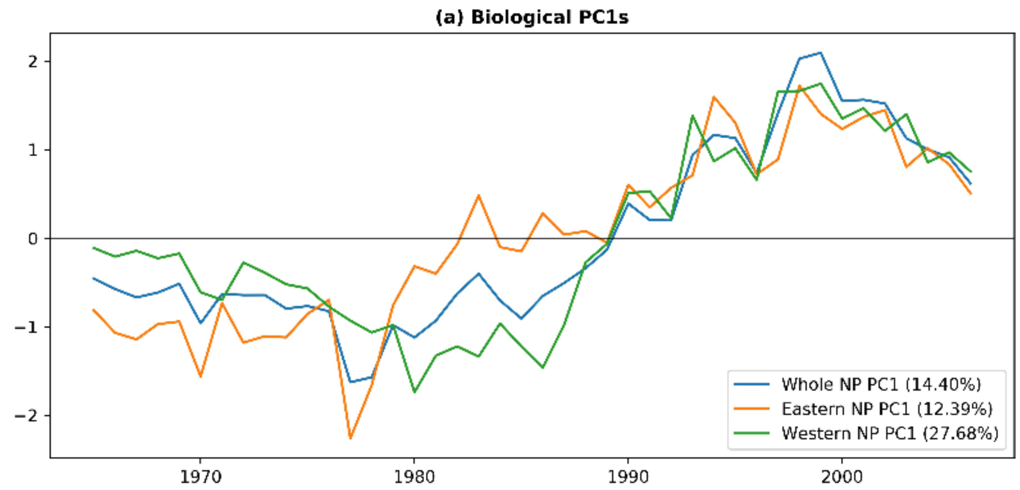
Principal Component Analysis

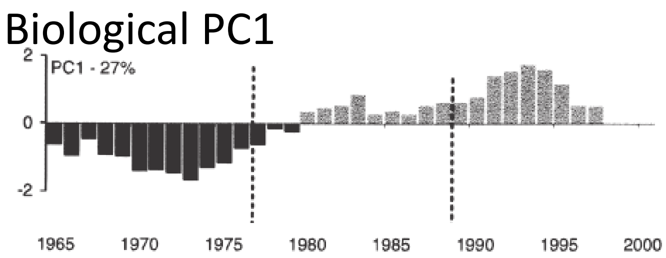
- Principal Component Analysis (biological indices only)
  - Each biological indices are normalized (remove mean, divided by standard deviation)
  - Since biological data has missing values, the covariance needed to compute the principal component analysis only uses the time points where the data is common between the two time series (not replacing missing with zero).
  - The statistical significance of the first principal component is estimated using the Monte Carlo method. Specifically, for each biological indices, 1000 surrogate time series are generated using a first-order autoregressive model, perform principal component analysis, and compare the resulting 1000 explained variance ratios with the observed explained variance ratio.

Results (only for the 1^{st} mode)

The second mode is shown in the paper.

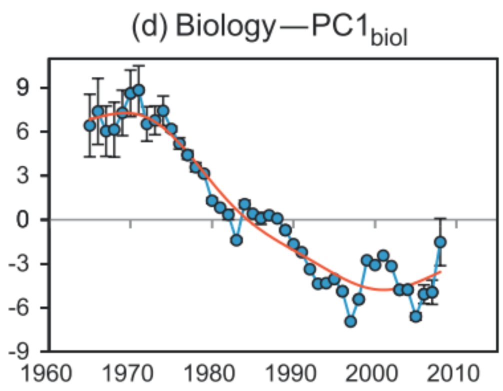
Temporal structure





(Hare & Mantua 2000)

- Overall increasing trends exist.
- Phase reversal is gradual rather than an abrupt shift, especially for the data of the whole NP or eastern NP.
- Similar features were reported by previous studies and gradual nature of the biological phase reversal was emphasized by Litzow and Mueter (2014).
  - The famous abrupt phase reversal in Hare & Mantua (2000) is mainly caused by the effects of physical indices.

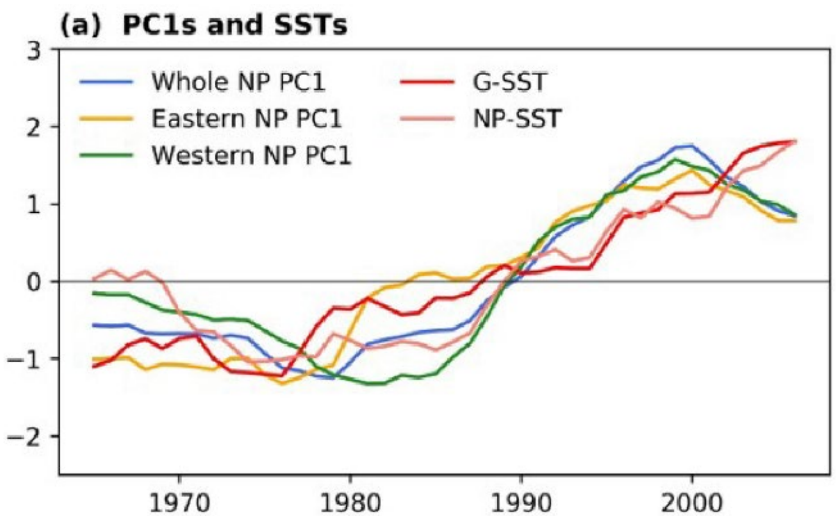


(Litzow & Mueter 2014)

Relationships to physical climate phenomena

Correlation coefficients between the first mode time series and the climate indices smoothed by the 5-year moving average. Red fonts indicate significant correlations at the 5% level.

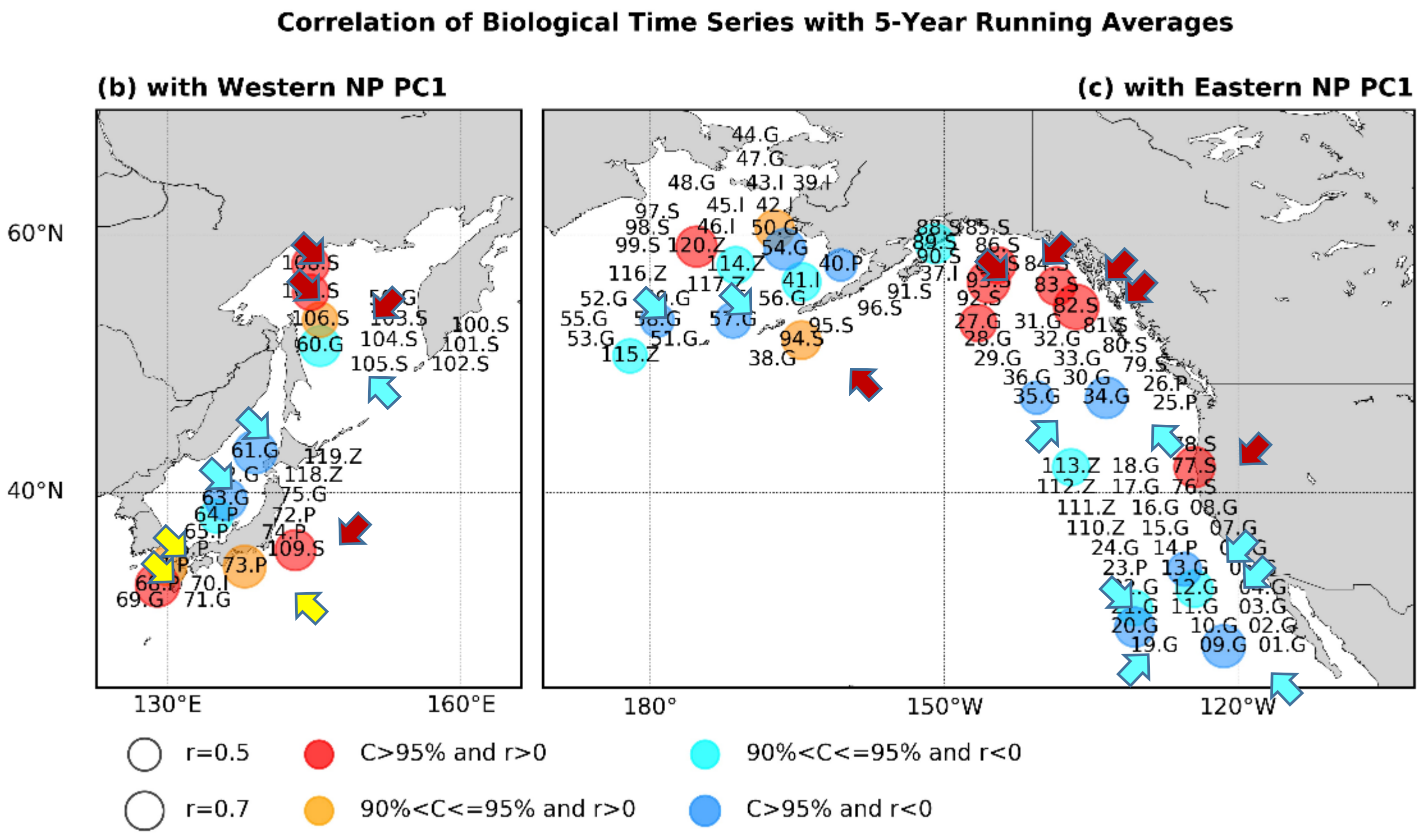
PCs	Global SSTA	NP SSTA	PDO	NPGO	MEI	NPI	AO
Whole NP PC1	**0.87**	**0.88**	**-0.12**	**0.11**	**0.31**	**-0.27**	**0.29**
Eastern NP PC1	**0.89**	**0.76**	**0.21**	**0.07**	**0.57**	**-0.51**	**0.37**
Western NP PC1	**0.77**	**0.90**	**-0.31**	**0.10**	**0.16**	**0.05**	**0.29**



- The first mode is strongly correlated with the NP and global ocean-averaged SSTs.
- Global warming plays a major role in the first mode.
  - The reason why the relationship with global warming has not been reported in previous studies is because it has not been investigated.

Major changes in North Pacific ecosystems have been driven by the overlooked effects of global warming.

Structure in biological indices

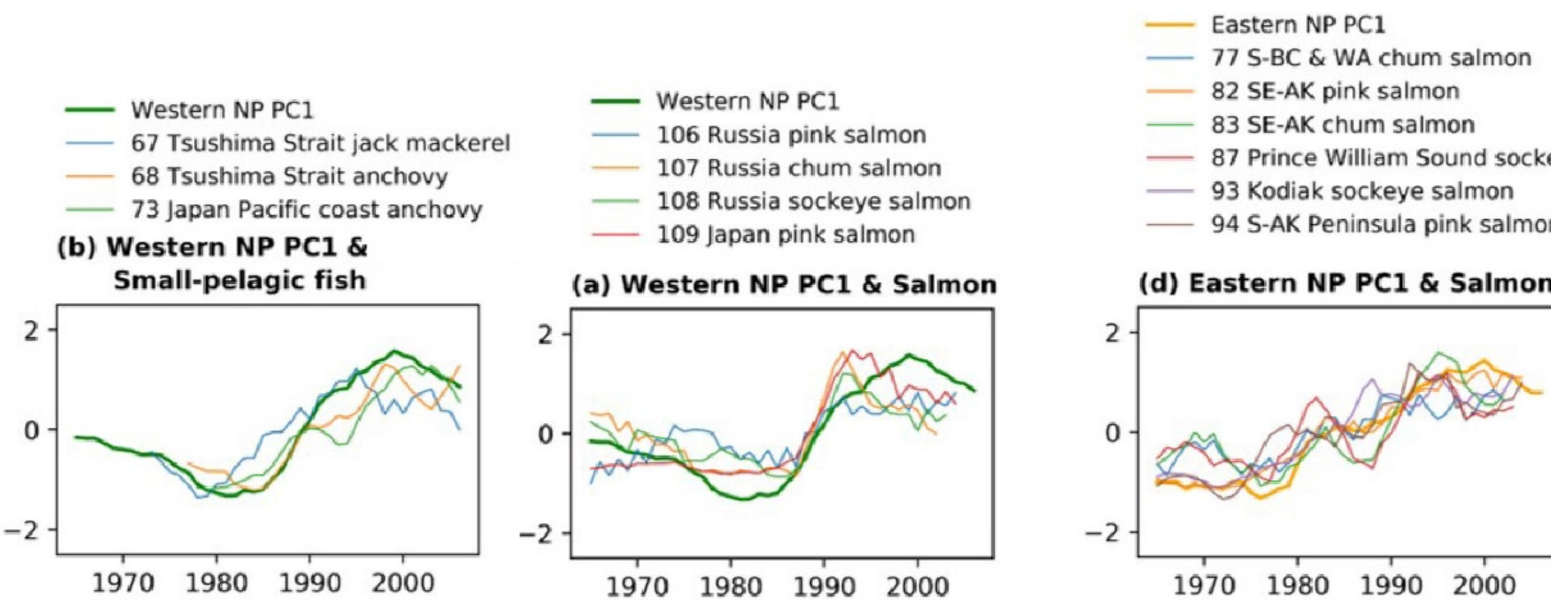


P: small pelagic fish
G: Groundfish
S: Salmon
Z: Zooplankton
I: Invertebrate

- Salmon : Significant positive correlation in 10 indices (30% of all salmon indices).
- Ground fish : Significant Negative correlation in 13 indices (24% of all ground fish indices).
- Pelagic fish recruitment in western NP : Horse mackerel and anchovy are also positively correlated.

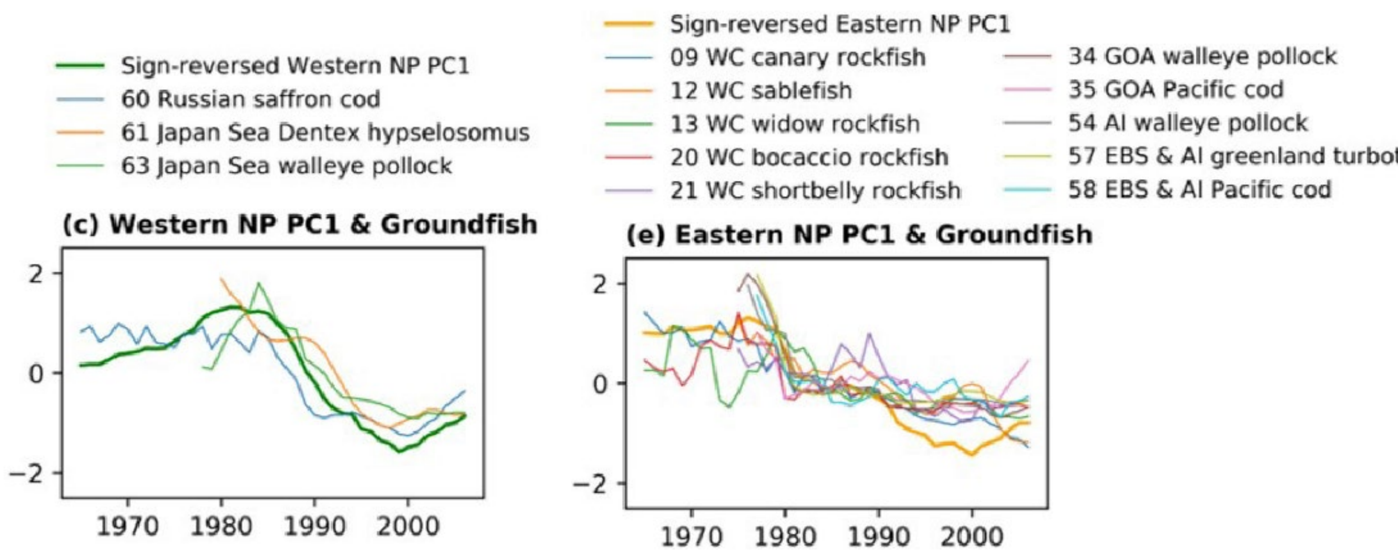
In particular, salmon have been positively affected.

Time series comparison



Salon in easter NP indicates increasing trend with decadal fluctuations.

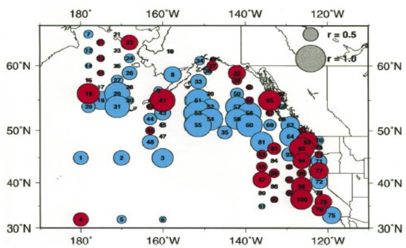
Salmon increase in the western NP occurred until 1990s.



Summary

- A large multivariate analysis (LMA) with principal component analysis was conducted using 120 marine biological indices to investigate the relationship with climate mode. This is the first LMA study using biological indices for the whole North Pacific Ocean.
- The first mode is dominated by a long-term trend component, which strongly suggests a relationship with global warming.
- In relation to the first mode, salmons showed an increasing trend and ground fishes showed a decreasing trend throughout the basin.

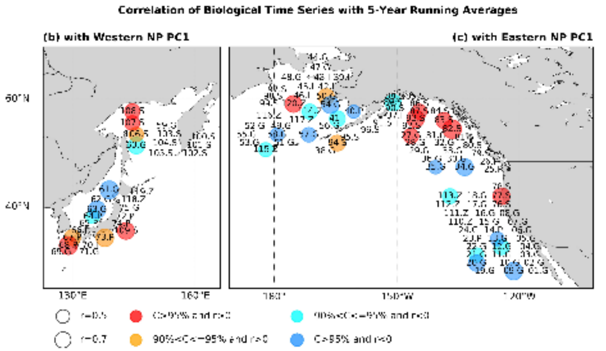
69 bio indices



Hare and Mantua (2000)

29 bio indices

91 bio indices



Present Study

- Did global warming work in favor of the northern limit of the habitat for salmon?
  - Kaeriyama et al. (2014) suggested that warming in the second half of the 20th century promoted the growth of 1st year salmon in the Sea of Okhotsk, leading to an increase of the stock.
  - Carothers et al. (2019) reported an increase in Pacific salmon on the Arctic Ocean side of Alaska after 1990.

→

Future?

The advantage of global warming to salmonids can be a transient response and may not continue to be an advantage in the future.

- Declining trend occurred in the western North Pacific since 1990 .

Toward regional marine ecological forecast using global climate model predictions from subseasonal to decadal timescales: bottlenecks and recommendations.

Shoshiro Minobe, Antonietta Capotondi, Michael G. Jacox, Masami Nonaka, Ryan R. Rykaczewski
(PICES WG 40, Climate and Ecosystem Predictability)

Under revision for Frontiers in Marine Science

- Ocean's physical conditions have been routinely predicted by using global climate models from subseasonal (40-60 days) to multi-annual (up to 10 years) prediction lead time.
  - A prediction lead time is a time difference between the target variable and input data for prediction.
- Such physical predictions can be used for marine biological forecasts.
- However, marine biological predictions based on physical prediction are complex process, for which climate modeling centers, physical and biological oceanographers, and funding agencies need to share a big picture.

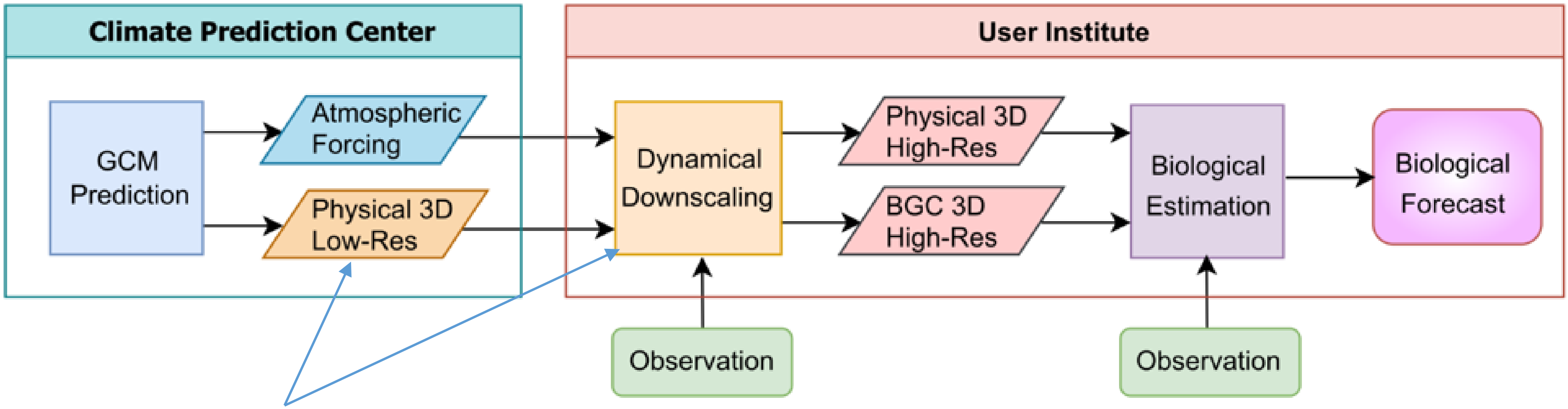
Physical forecasting projects using Global Climate Models (incl. Ocean models)

Project Name	SubX	S2S	C3S seasonal forecasting	NMME	CMIP6/DCPP
Maximal prediction lead time	45 days	60 days	5 months	11 months	10 years
Ocean model resolutions	0.08-1 degree	0.25-1 degree	0.25-1 degree	0.25-1 degree	0.5-1.0 degree
2D ocean data availability for forecast data	SST only	temperature, salinity, and current speeds at the sea surface; 0-300 m averaged temperature and salinity; mixed layer thickness; etc.	SST only	SST only	Surface values; vertically integrated values; depth of specific features
3D ocean data availability	No	No	No	No	Yes

We try to clarify that there is a demand for physical variables for biological forecast, and encourage modelling centers make their ocean variables publicly available at least for 2D data, which will not be too much burden for those centers.

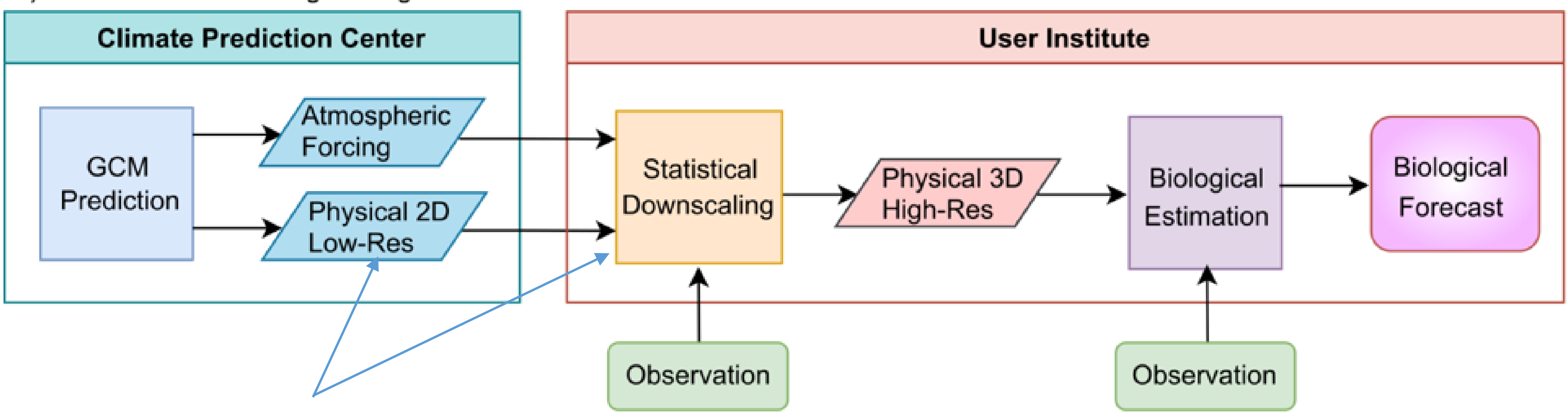
Typical workflows 1/2

a) Dynamical Downscaling of SIngle GCM

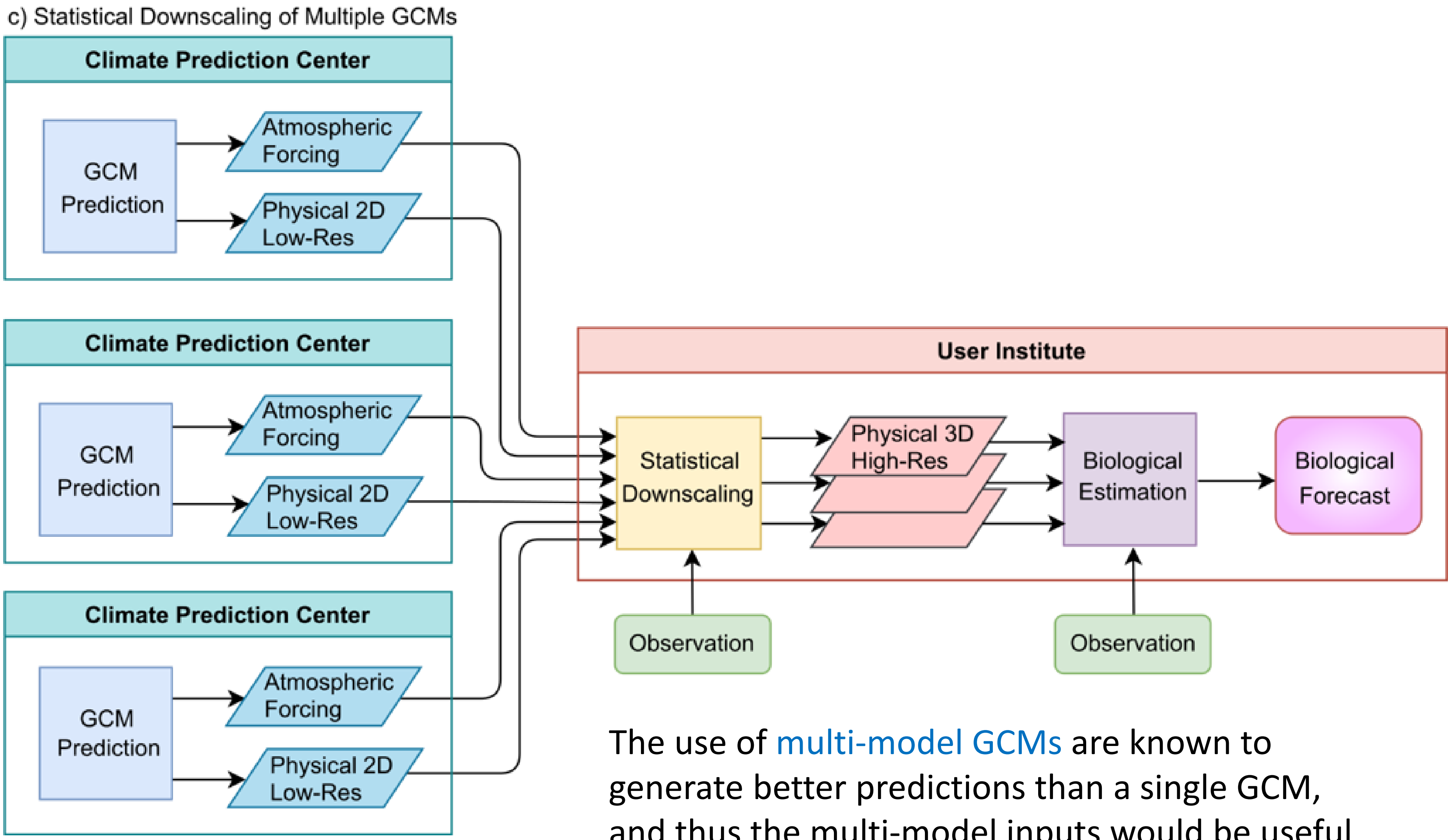


A dynamical downscaling requires physical 3D data, which can be too big in many cases.

b) Statistical Downscaling of Single GCM



Statistical downscaling can build on physical 2D data, which may be more practical.



The use of multi-model GCMs are known to generate better predictions than a single GCM, and thus the multi-model inputs would be useful for biological forecasting.

Based on the first paper…

- What do you know?
  - Salmon abundance generally increased during 1965–2006 but declined near the end of the record in the western NP.
  - Ground fish generally suffered.
  - Global warming already played an important role in marine ecosystem changes.
- What don't you know?
  - We do not know the reason of the salmon changes.
- What is to be done to address these gaps?
  - Updated data including 2007-present should be examined. This is a low hanging fruit.
  - Further studies are needed to know the reason.

Based on the second paper…

- What do you know?
  - Oceanic variables are predicted regularly with prediction lead time from a few ten days to 10 years, but data availability is limited.
- What don't you know?
  - We do not know the prediction skills of marine biological forecast except for very limited number of studies.
- What is to be done to address these gaps?
  - Modelling centers should make a set of oceanic variables (maybe 2D variables as S2S does) publicly available.
  - Downscaling should be conducted for oceanic variables.
  - Prediction skills should be accessed by reforecasting for each target biological variables with cares such as stringent statistical assessment and cross-validations.