Variability and mixing of the Kuroshio and impact on ecosystem and fisheries

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The Kuroshio is spawning and nursery grounds of many kinds of fish and sustains world-largest fishing grounds around Japan, although nutrient (especially nitrate) is depleted in the subtropical North Pacific. Nutrient supply process peculiar to the Kuroshio could sustain the Kuroshio ecosystem. Decadal to inter-decadal variability of the Kuroshio also has a tremendous impact on ecosystem and fisheries, especially for the Japanese sardine (*Sardinops melanostictus*). In the period from large sardine population to declining phase during 1980s and 1990s, sardine recruitment is related to the variability from winter to spring in the frontal zone just north of the Kuroshio axis, where vertical mixing and nitrate upward flux are enhanced. We review research on the sardine variability including recent phase of the growing population and nutrient supply by enhanced vertical mixing on the basis of recent observations performed along the Kuroshio under the Japanese 5-year project “Ocean Mixing Processes: Impact on Biogeochemistry, Climate and Ecosystem (OMIX)”.

Keywords: Kuroshio, sardine, mixing, nutrient

Reproducing migration history of Japanese sardine using otolith d18O and a data assimilation model

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A new method to reproduce migration histories of Japanese sardine (*Sardinops melanostictus*) was developed by using the combination of otolith oxygen stable isotope ratio ($\delta^{18}O$) and a data assimilation model. Firstly, rearing experiments for three different temperatures were conducted for a month and otolith $\delta^{18}O$ were analyzed. A linear relationship between otolith $\delta^{18}O$ and temperature was determined for the first time for Japanese sardine as follows: $\delta_{otolith} = \delta_{water}$-0.181*Temperature+2.690, r^2=0.91 (1). Secondly, seawater $\delta^{18}O$ and salinity in the western North Pacific were revealed to be strongly correlated from *in situ* samplings: δ_{water}=0.5951*Salinity-20.347, r^2=0.89 (2). Micro-volume $\delta^{18}O$ analysis and our original micro-sampling technique enabled us to extract otolith $\delta^{18}O$ profile in a temporal resolution of 10-15 days through whole life of juveniles approximately 200 days post hatch. For the dates corresponding to each value of the profile, surface temperature and salinity in the range of 30-55N, 130-180E were extracted from a data assimilation ocean model FRA-ROMS which reproduces ocean environment realistically. Temperature and salinity in each grid were converted into otolith $\delta^{18}O$ value using Eq. (1) and (2). Grid points in which the calculated otolith $\delta^{18}O$ value was equivalent to actually analyzed one were considered to be the location of the individual on the date. Movements of the juveniles reproduced by this method clearly showed the northward migration from the Kuroshio-Oyashio transition zone to the Oyashio region and the estimated location on the sampling week approached to the actual sampling point, which indicated the high accuracy of the method.

Keywords: Sardine, Otolith, Oxygen isotope

Long-term variability of larvae feeding grounds of Japanese sardine and its environment

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Since 1980s, many previous studies have suggested that Japanese sardine (*Sardinops melanostictus*) is influenced by climate change. Recently, two studies focused on where and what is significant for controlling the stock. One study suggested that the environment of winter Kuroshio front area controlled the stock variation because that area was main distribution area of sardine larvae in 1980s. Another study revealed the dependency of larval growth on temperature, so-called “Optimal temperature hypothesis”. According to this hypothesis, the stock variation depends on the ambient temperature of larvae.
Japanese sardine has a notable habit that their spawning grounds move drastically in decadal scale. It implies that distribution area of larvae also changed. Considering this spawning habitat, the current distribution area of larvae has already not been in the winter Kuroshio front area. On the other hand, if the optimal temperature hypothesis can totally explain the stock variation, long-term stock variation depends on ambient temperature of larvae wherever they are distributed.
Whether the significant area for the stock variation has changed and whether ambient temperature controls the stock variation in decadal scale are important points to understand how the climate change affects the sardine stock. However, there is few knowledge about long-term variability of larvae feeding grounds.
In this study, we estimated the larval distribution area and environment from 1980s to 2000s by using the most advances reanalysis dataset. Through the comparison between past environment and the stock variation, we examined above two hypotheses.

Keywords: Japanese sardine

Variation of environment around the Kuroshio influences the recruitment of chub mackerel (*Scomber japonicus*)

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Chub mackerel (*Scomber japonicus*) in the North Pacific is one of the most important commercially fishes in Japan. It has been thought that its Recruit Per Spawning stock biomass (RPS) can be estimated based on an extended Ricker model including winter-time temperature around spawning ground, spawning stock biomass, and sardine biomass proposed by Yatsu et al. (2005). However, substantial degree of disagreement of RPS between the estimated from virtual population analyses and provided by the model is recognized especially after 2000. Because little study has been done concerning relationship between oceanic environment and annual variation of RPS after 2000, we investigate relationships between RPS and the environment such as winter time surface temperature around the spawning ground affecting spawner, and the Kuroshio pass affecting larvae thorough transports and temperature. In addition, we also attempt to improve the model concerning RPS after 2000. Then, based on particle tracking experiments conducted from mid-March to late April, we reveal importance of experienced temperature of larvae during ~10 days after hatch as well as February temperature of the spawning ground in the Kuroshio inside. Note that the experiments are made under the condition of fixed release positions for particle. It is also indicated that high RPS often occurs when the Kuroshio passes straight through the Izu islands chain during March when the spawner maturate, in contrast to lower RPS when the Kuroshio meanders along the islands. In the case of the Kuroshio meandering, worse RPS is shown when the winter time temperature in the near coast area (in the inside of the Kuroshio) is higher. These results suggest 1) importance of the inside area as a feeding grounds for spawner from late winter to early spring, 2) spatial restriction of spawning grounds tide to the inside area for chub mackerel as feeding and eggs production grounds for spawner, and 3) relationships between the pass of the Kursohio and annual variation of RPS through experienced temperature of larvae during spring related with the distance from the feeding ground for spawner to the Kuroshio axis. In addition to these results, one possibility of the poor reproducibility of the model by Yastu et al. (2005) after ~2000 is proposed as regime change of the Kursohio pass: the flow frequently passes closer to costal region east of the Izu island chain after 2000.

Keywords: Chub Mackerel, Recruitment Per Spawning, Kuroshio

Climate driven shifts in the biogeography of the global ocean

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Examinations of oceanographic samples collected since 1860 combined with the recent use of remote sensing observations has revealed that even if global ocean appears at first sight as a homogenous domain, it is composed by discrete ecological units separated by invisible frontiers. This ecological reality has been widely studied by Longhurst who have partitioned the oceanic realm into 4 biomes and 56 biogeochemical provinces (BGCPs), each division representing regional environmental and oceanographic specificities at a basin scale. Here, we use a recently developed biogeographical approach to identify the environmental envelops of each BGCPs according to a set of parameters (temperature, salinity, oxygen, sea ice, pH,bathymetry and Net primary productuin). Thus, we readapt the static paradigm proposed by Longhurst and allow the examination of the long term variability of the spatial distribution of each BGCP according to environmental conditions derived from 3 Earth system model (IPSL, MPI and GFDL) and for two emission scenarios (RCP 2.6 and 8.5). Spatial variations of the biogeography of the global are thus identified and confronted to observations. Furthermore, projection of the global biogeography reveals a drastic shift of the biogeographical systems of the ocean suggesting a profound reorganisation of present trophic webs. Biogeographical perturbation indices are here computed and could be of interest for guiding the near future management plan of ecosystems conservation.

Keywords: climate change, biogeography, Earth system model, Biogeochemical provinces, Longhurst, Non analogue Biogeographic state

The Future Response of Fisheries Production to Integrated Anthropogenic Forcing: Climate Change and Fishing Pressure

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Many empirical relationships between commercial fish recruitment and population biomass with the environment exist, however the mechanisms behind these relationships are rarer. These mechanisms are often region-specific and can dissolve over time. We seek a mechanistic understanding of the variability of commercial fish recruitment and population biomass with respect to anthropogenic forcing, both fishing pressure and future climate change. To do so, we have developed a global stage- and size-based mechanistic model that represents the immature and mature stages of forage fishes, large pelagic fishes, and large demersal fishes. In this talk we will present preliminary results of fish biomass under (1) historical climate without fishing, (2) historical climate with fishing, (3) projected business-as-usual climate without fishing, (4) and projected business-as-usual climate and fishing. The stepwise addition of forcings in simulations 1-3 separate the effects of each, while simulation 4 forecasts the potential fish biomass response to the integrated anthropogenic forcings of climate and fishing.

Keywords: Fish , Climate change

Difference of warm and cold waters in the Sea of Japan in terms of physical, chemical and biological properties

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The Sea of Japan, where is a semi-closed marginal seas of the western Pacific, is divided into warm and cold waters by a thermal front (the subpolar front) and currents (Tsushima Warm Current and the subarctic circulation, respectively). However, shipboard-observations in the cold water were very limited, and the physical, chemical and biological characteristics of the cold water were uncertain. Hence, observations were conducted during two cruises by R/V *Mizuho-maru* (MZ) and *Daigo-Kaiyo-maru* (KY) from the end of August to the middle of September of 2016 across the subpolar front to clear the difference of two waters, in particular, to describe characteristics in the cold water.
Vertical profiles of temperature, salinity, DO and chlorophyll fluorescence were investigated by using CTD and optional sensors at 37 stations. Discrete water samplings for nutrient and chlorophyll *a* concentrations were conducted at selected 25 stations. During the KY cruise, samples for alkalinity, particulate organic matters (>0.7 μm) for stable isotope analysis, and environmental DNA (>0.8 μm) for metagenetic analysis of 18S V9 rDNA were selectively collected at a 10 m depth. Zooplankton and nekton were collected by using a twin NORPAC net (0–200 m) and a mid-water trawl (20×20 m wide, trawled <40 m depth), respectively, at every station of the KY cruise.
On the basis of the clustering analysis of temperature and salinity from 5–200 m, our investigated area was mainly divided into cold and warm waters: 5 stations in approximately >40˚N were grouped into the cold water, and the others were into the warm water. In the cold water, vertical distributions of salinity had no maximum.
Niutrient concentrations were depleted (<1 μM) except silicate at the surface in both waters; however, relationships between nitrate and density (temperature) was different: the nitrate concentration was depleted <1 μM in the water 26 σ_t in the cold water while >5 μM of nitrate in the warm water. Slopes of nitrate concentration at the nitracline was steeper in the cold-water than warm-water. DO concentration was high in the cold waters (>300 μM) and apparent oxygen utilization (AOU) was >-40 μM just below the surface mixed layer in the cold water.
The organisms were different between cold and warm waters; dictyochophyceae and *Neocalanus cristatus* was richly distributed in the cold water, while they were low or rare in the warm water. The amounts and diversities of nekton were very poor in the cold water; only a few individuals of common squid (*Todarodes pacificus*) were collected in the cold-water, while some small pelagic fish, anchovy (*Engraulis japonicus*), horse mackerel (*Trachurus japonicus*) and sardine (*Sardinops melanostictus*), were often sampled as well as the common squid in the warm water.
Our results demonstrated that the characteristics between warm and cold waters are quite difference even during summer from physics to biology. It is considered that temperature directly determines biota of waters, but the primary productivity does not. Primary productivity was suggested high in the cold-water based on the AOU, chlorophyll *a* concentration, and slope of the nitracline. Therefore, the biological productivity will be high in the cold water, but both species diversity and abundance of nekton were poor. In particular, zooplanktivorous small pelagic fish were not caught in the cold water. In hence, these are questioned for future oceanographic and marine ecological studies of the Sea of Japan: who dominate the niche of zooplanktivorous species in the cold water which is corresponding to the small

pelagic fish in the warm water and what controls fish productivity. In the Sea of Japan, surface temperature has been increasing and predicting primary production will decrease in the future according to global warming scenarios. The studies for our questions will help us understanding effects of global warming on fisheries.

Keywords: Sea of Japan, Fisheries, Tsushima Warm Current, Subpolar front

Climate-related shifts in ichthyoplankton phenology of Beaufort Inlet, North Carolina, USA

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Global warming has shifted the timing of seasons in numerous ecosystems worldwide. Many organisms rely on seasonal cues for the timing of events such as reproduction, migration, or metamorphosis, which makes them exceptionally vulnerable to the negative effects of climate change. Furthermore, if the seasonal timings, also known as phenologies, of two or more historically-linked events change at different rates in response to climate change, entire communities could potentially to break down. It is therefore critical for science to develop an understanding of climate change’ s effects on the phenologies of organisms across ecosystems. The purpose of this study is to determine if there have been shifts in the reproductive phenology of winter-spawning estuarine-dependent fish species that spawn offshore of Beaufort Inlet, NC. To do this, we are investigating the phenology of larval fish ingress through the inlet from 1987-present. Data from the Bridgenet long-term ichthyoplankton sampling program conducted by the U.S. National Marine Fisheries Service are being used to assess changes in the beginning, peak, and end of ingress for species in the inlet. To determine if climate changes could be driving potential phenology changes, we are also attempting to correlate any observed phenology changes with environmental variables such as temperature, windspeed, and offshore current activity.

Keywords: Ichthyoplankton, Phenology, Climate change, Reproduction, Estuaries

Projected Changes in the Distribution and Phenology of Nassau Grouper (*Epinephelus striatus*) Spawning Aggregations

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Most projections of how climate change affects species distributions are based on a species' most conspicuous life stage. However, not all life stages are equally sensitive to temperature. Among fishes, spawning adults often have narrower thermal tolerances than other life stages and may constrain population responses to climate change. We tested this hypothesis using data on Nassau grouper (*Epinephelus striatus*), a critically endangered top predator on Caribbean coral reefs. Species distribution models of spawning aggregations and non-spawning adults were used to determine which of seven environmental variables exerted the greatest influence on monthly fish distribution. Based on model output, we calculated thermal niche and ecological niche breadth of each life stage. An earth system model was then applied to project how species distribution and phenology shift under the RCP 8.5 climate change scenario. Sea surface temperature and seasonal temperature gradients affected the distribution of both *E. striatus* spawning aggregations and non-spawning adults, but these life stages differed in their preferred temperatures and reaction to oceanic currents. While the two life stages exhibited similar ecological niche breadth, the thermal niche of spawning aggregations was significantly narrower than non-spawning adults. By 2081-2100, potential spawning habitat was projected to decline by 82% relative to a 1981-2000 baseline, whereas suitable habitat for non-spawning adults decreased by 46%. Poleward shifts in latitude occurred >4 times faster for spawning aggregations than non-spawning adults. These changes were attributed primarily to rising temperatures, whereas changes in hydrography did not have a substantial impact. The narrow thermal tolerance range among spawning *E. striatus* confirms that this life stage is likely to serve as a bottleneck constraining responses to climate change.

Keywords: climate change, Greater Caribbean, Nassau grouper, spawning aggregation, reef fish, species distribution modeling

Modeling effects of growth and temperature on the recruitment variability of Pacific saury (*Cololabis saira*)

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Pacific saury (*Cololabis saira*) is a commercially and ecologically important pelagic fish in the North Pacific. The variability in stock abundance cannot be explained solely by fisheries catch but also related to the reproductive success. In this study, we examine the recruitment variability of Pacific saury using an individual-based model combining a bioenergetics, migration and mortality models. We parameterize the mortality rate with the weight, growth rate and temperature. The annual survival rates (recruitment per spawning biomass: RPS) from the model (mRPS) are calculated from the number of survived fish at age-1, and compared with RPS derived from the stock assessment for 2003–2012. The interannual variability in RPS is well reproduced in the model, especially in cases parameterizing the mortality using the weight and temperature, and weighting the spring-spawned cohort. The importance of the spring–spawned cohort is consistent with the hypothesis derived from observations in 1990–1998.

Keywords: Pacific saury, Individual-based model, recruitment variability, growth, temperature

