

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)” .

キーワード：黒潮、マイワシ、混合、栄養塩

Keywords: Kuroshio, sardine, mixing, nutrient

耳石の酸素安定同位体比と海洋同化モデルを用いたマイワシの回遊履歴推定

Reproducing migration history of Japanese sardine using otolith $\delta^{18}\text{O}$ 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 ($\delta^{18}\text{O}$) and a data assimilation model. Firstly, rearing experiments for three different temperatures were conducted for a month and otolith $\delta^{18}\text{O}$ were analyzed. A linear relationship between otolith $\delta^{18}\text{O}$ and temperature was determined for the first time for Japanese sardine as follows: $\delta_{\text{otolith}} = \delta_{\text{water}} - 0.181 \cdot \text{Temperature} + 2.690$, $r^2 = 0.91$ (1). Secondly, seawater $\delta^{18}\text{O}$ and salinity in the western North Pacific were revealed to be strongly correlated from *in situ* samplings: $\delta_{\text{water}} = 0.5951 \cdot \text{Salinity} - 20.347$, $r^2 = 0.89$ (2). Micro-volume $\delta^{18}\text{O}$ analysis and our original micro-sampling technique enabled us to extract otolith $\delta^{18}\text{O}$ 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 $\delta^{18}\text{O}$ value using Eq. (1) and (2). Grid points in which the calculated otolith $\delta^{18}\text{O}$ 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.

キーワード：マイワシ、耳石、酸素安定同位体比

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.

キーワード：マイワシ

Keywords: Japanese sardine

2000年以降のマサバ資源量に関わる黒潮の海洋環境変動

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

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マサバ (*Scomber japonicus*) 太平洋系群の加入量変動の指標である再生産成功率 (Recruit Per Spawning stock biomass; RPS) は、産卵場水温、産卵親魚量、マイワシ資源量を説明変数とする拡張リッカー型再生産モデルで高精度に推定できると考えられてきたが、2000年ごろを境に、近年推定精度が著しく低下している。しかし、このレジーム変化をもたらした海洋環境変化および近年の加入量年々変動に影響を与えている海洋環境変動に関する知見は乏しい。そこで本研究では、マサバ親魚に影響する産卵場環境や、卵仔魚輸送に影響する黒潮の動態と加入量変動の関係解明を目的として研究を行い、さらに2000年以降の加入量変動について既往モデルの改良を試みた。本研究により、黒潮域内側に分布する産卵場水温の冬季表面水温の重要性に加えて、粒子追跡によるマサバの生活史の最初期ステージの経験水温の推定が、加入量変動の高精度化に寄与することが明らかとなった (なおこの粒子追跡実験は放出場を固定したものである)。さらに、親魚が成熟して産卵期を迎える3月に黒潮が非大蛇行接岸流路をとる場合は加入成功率が高く、伊豆諸島を迂回する流路の場合は加入成功率が低～中程度であったことが示された。迂回流路の際にも、黒潮内側域沿岸付近の冬季表面水温が相対的に高い年はとりわけ加入が悪い傾向があった。これらの結果から、晩冬期～春季の産卵親魚の摂餌場としての黒潮内側域の重要性と、卵の量・質に親魚の摂餌状態が影響するマサバの、摂餌場-産卵場の空間的制約の可能性、そして黒潮流路分布に伴う春季仔魚の経験水温の年々変動が加入に与える影響が示唆された。既往モデルの推定精度が2000年以降悪くなる原因の一つとして、黒潮の流路が2000年ごろを境に変化し、伊豆諸島の東側でより沿岸側を通過するようになったことが挙げられた。

キーワード：マサバ太平洋系群、加入量変動、黒潮

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 envelopes 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.

キーワード : climate change、 biogeography、 Earth system model、 Biogeochemical provinces、 Longhurst、 Non analogue Biogeographic state

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

物理・化学・生物学的な観点からの日本海暖水域と冷水域の違い 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 ($>0.7 \mu\text{m}$) for stable isotope analysis, and environmental DNA ($>0.8 \mu\text{m}$) 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 $>40^\circ\text{N}$ 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.

Nutrient concentrations were depleted ($<1 \mu\text{M}$) except silicate at the surface in both waters; however, relationships between nitrate and density (temperature) was different: the nitrate concentration was depleted $<1 \mu\text{M}$ in the water $26 \sigma_t$ in the cold water while $>5 \mu\text{M}$ 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 ($>300 \mu\text{M}$) and apparent oxygen utilization (AOU) was $>-40 \mu\text{M}$ 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.

キーワード：日本海、漁業、対馬暖流、極前線

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 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

サンマ (*Cololabis saira*) の加入量変動に対して成長と水温が与える影響に関するモデリング

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.

キーワード：サンマ、Individual-based model、加入量変動、成長、水温

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