Modeling ecological responses of Pacific saury (*Cololabis saira*) to future climate change and its uncertainty

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ABSTRACT

An ecosystem based bioenergetics model was used to investigate responses of Pacific saury (*Cololabis saira*) to global warming. The model was forced by the projected sea surface temperature (SST) generated by climate models that formed the bases for the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC-AR4). Twelve climate models, which reproduced the Pacific Decadal Oscillation well in comparison with observations, were selected and B1, A1B, and A2 emissions scenarios were used. In total, thirty-three ensemble simulations were conducted of which, twenty-four (73%) showed a decrease of wet weight of Pacific saury. The migration pattern was modified in eleven (33%) cases. In these cases, higher SST and size reduction under global warming prevented or delayed the southern migration of saury in winter. As a result, egg production was enhanced by the higher availability of prey plankton in the modified spawning region. A case study to separate the direct temperature effects was conducted, in which prey plankton density was assumed to be the same as the control run. The results suggest that a SST increase will directly reduce juvenile growth while a prey plankton density decrease has an influence on the growth of adults and migration pattern, and hence egg production.

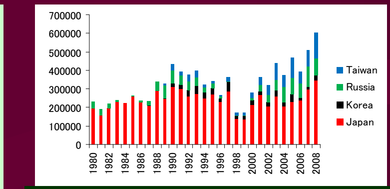


Figure 1. Catch of Pacific saury in Japan, Korea, Russia and Taiwan. Pacific saury is one of the dominant small pelagic fish in the western North Pacific and is widely distributed in the North Pacific. Commercial catch of Pacific saury fluctuated between 0.17 and 0.60 million t during 1980-2008 and the share of the total catch by Japan has decreased from 83.3% in 1980 to 56.9% in 2008.

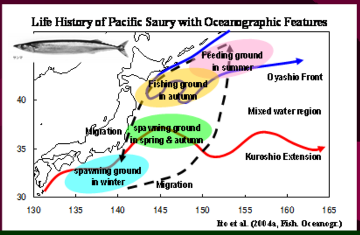
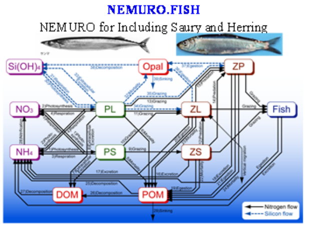


Figure 2. Life history of Pacific saury. Pacific saury spawn from autumn to the next spring. Larvae are advected to offshore and then migrate to the subarctic area for feeding. After sufficient feeding they migrate back to spawn. Their life span is about two years and they make this extensive migration twice within their life.



Megrey et al. (2007a, Ecol. Model.), Ito et al. (2004b Fish. Oceanogr.) etc.

Figure 3. Schematic flow chart of NEMURO. FISH. Solid black arrows indicate nitrogen flows and dashed blue arrows indicate silicon flows. Dotted black arrows represent the exchange or sinking of material between the modeled box and below the mixed layer depth.

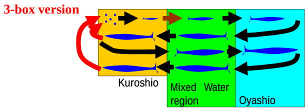


Table 2. Life stages of Pacific saury in the saruy bioenergetics model

Stage	region
larvae	Kuroshio
juvenile & young	mixed region
small	Oyashio
adult	mixed region
adult matured	Kuroshio
adult	mixed region
adult	Oyashio
adult	mixed region
adult matured	Kuroshio

9 life stages

Ito et al. (2004b, Fish. Oceanogr.)
Ito et al . (2007, Ecol. Model.)
Mukai et al. (2007, Ecol. Model.)

Figure 4. Schematic view of 3-box model of Pacific saruy. Solid black arrows indicate nitrogen flows and dashed blue arrows indicate silicon flows. Dotted black arrows represent the exchange or sinking of material between the modeled box and below the mixed layer depth.

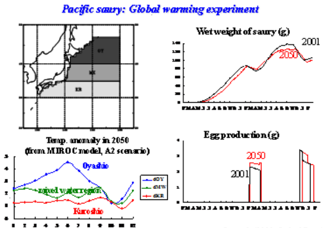


Figure 5. Global warming experiment of Pacifi saury. A simple 3-box version of NEMURO.FISH was forced by MIROC projected SST. The model projected that the weight and KL of saury will decrease by about 10 g and 1 cm respectively under the global warming scenario.

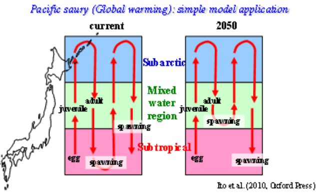
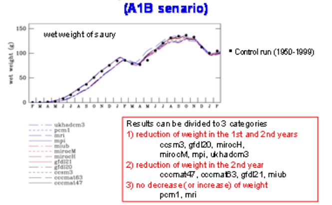


Figure 6. Under global warming situation, fish size is reduced and temperature is enough high in the mixed water region. These factors prevent southward migration of saury in 1st winter and delay 2nd year migration. As a result, saury egg production is enhanced.

Motivation

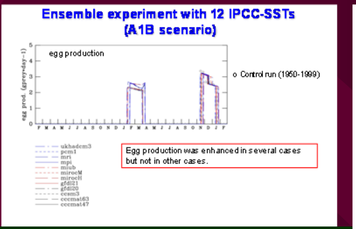
(Ito et al., 2013, ICES-JMS)

The results described above were derived from a very simplified model and always model predictions have uncertainties. The uncertainty could be caused by forcing and deficiency of physical, lower-trophic-level ecosystem, fish growth and fish migration models. As a first step, we evaluated the uncertainty of the saury future projection caused by forcing SST. The objective of this study is 1) to test the robustness of future projections of Pacific saury response and 2) to elucidate the mechanisms that will cause change in wet weight and egg production of Pacific saury under global warming.



Results can be divided to 3 categories
1) reduction of weight in the 1st and 2nd years
ccsm3, gfdl20, mirocH, mirocM, mpi, ukhadcm3
2) reduction of weight in the 2nd year
cccmat47, cccmat63, gfdl21, miub
3) no decrease (or increase) of weight
pcm1, mri

Figure 7. Result of ensemble experiments. Modeled wet weight growth of Pacific saury under observational 1950-1999 climatological SST (black dots) and 2045-2055 SST (A1B scenario) of the twelve climate models (lines)



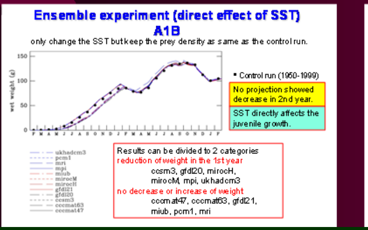
Egg production was enhanced in several cases but not in other cases.

Figure 8. Result of ensemble experiments. Modeled egg production of Pacific saury under observational 1950-1999 climatological SST (open circles) and 2045-2055 SST (A1B scenario) of the twelve climate models (lines).

Table 1. Changes in the wet weight of saury for three carbon emission scenarios (A2, A1B and B1) and SST products. "-----" means the climate model projection was not available for the emission scenario.

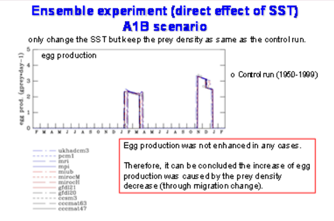
climate model	A2	A1B	B1
HadCM3	decrease in age-0 & 1	decrease in age-0 & 1	decrease in age-0 & 1
MIROC(h)	------	decrease in age-0 & 1	decrease in age-0 & 1
MIROC(m)	decrease in age-0 & 1	decrease in age-0 & 1	decrease in age-1
CCSM3	decrease in age-1	decrease in age-0 & 1	decrease in age-1
ECHAM5	decrease in age-1	decrease in age-0 & 1	no decrease
GFDL2.0	no decrease	decrease in age-0 & 1	-----
ECHO-G	decrease in age-0 & 1	decrease in age-1	decrease in age-1
CGCM-T63	-----	decrease in age-1	no decrease
CGCM-T47	decrease in age-1	decrease in age-1	no decrease
GFDL2.1	no decrease	decrease in age-1	decrease in age-1
MRI	decrease in age-1	no decrease	decrease in age-1
PCM1	no decrease	no decrease	no decrease

Thirty-three ensemble simulations were conducted of which, twenty-four (73%) showed a decrease of wet weight of Pacific saury. The migration pattern was modified in eleven (33%) cases.



Results can be divided to 2 categories
reduction of weight in the 1st year
ccsm3, gfdl20, mirocH, mirocM, mpi, ukhadcm3
no decrease or increase of weight
cccmat47, cccmat63, gfdl21, miub, pcm1, mri

Figure 9. Result of ensemble experiments. Modeled wet weight growth of Pacific saury under observational 1950-1999 climatological SST (black dots) and 2045-2055 SST (A1B scenario) of twelve climate models with keeping the prey density the same as the control run (lines). SST directly influenced wet weight in age-0.



Egg production was not enhanced in any cases.

Therefore, it can be concluded the increase of egg production was caused by the prey density decrease (through migration change).

Figure 10. Result of ensemble experiments. Modeled egg production of Pacific saury under observational 1950-1999 climatological SST (open circles) and 2045-2055 SST (A1B scenario) of the twelve climate models with keeping the prey density the same as the control run (lines). SST did not directly influence total amount of egg production.

Table 2. SST anomaly in each ocean domain (KR, MW, OY) and averaged for the three ocean domains (average) for the A1B scenario and only SST changed case (**highest four, *middle four).

		KR	MW	OY	average
decrease in age-0 & 1	CCSM3	1.36	1.73*	2.80**	1.97*
	GFDL2.0	1.41*	1.86*	1.41	1.56
	MIROC(h)	2.28**	2.73**	2.70*	2.57**
	MIROC(m)	1.71**	2.24**	3.16**	2.37**
	ECHAM5	1.78**	2.07**	3.22**	2.35**
	HadCM3	1.93**	3.30**	2.78**	2.67**
no decrease or increase	CGCM-T47	1.46*	1.48	1.77*	1.57
	CGCM-T63	1.63*	1.55*	1.75	1.65*
	GFDL2.1	1.46*	1.53	1.85*	1.61*
	ECHO-G	1.14	1.41	1.58	1.38
	PCM1	1.10	1.17	1.03	1.10
	MRI	1.32	1.59*	2.04*	1.65*

The tendency, that a higher anomaly of SST causes a greater decrease of weight, was clear. Especially, the response of saury wet weight highly depends on SST in MW. Therefore, it can be concluded that SST directly influenced wet weight in age-0 and SST in MW is most important factor to control age-0 weight.

Reference

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