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Persuasive scientific article

Global warming effects on marine ecosystem

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Abstract

The rising temperatures associated with global warming have profound implications for marine biodiversity, species distribution, and ecological interactions. Increased sea surface temperatures have led to shifts in the distribution and abundance of marine species, as they seek more suitable habitats. These changes disrupt established ecological relationships, potentially leading to cascading effects throughout the food web. Marine ecosystem especially fish ecology in the sub-arctic ocean must be changed due to global warming. In this manuscript, the introduction of marine food web will be discussed and it has been explained and concluded what will happen on marine food web due to global warming based on simulation results by a physical ecological coupled model.

Keywords: Global warming; Common Squid; Chum Salmon; Walleye Pollack.

1. Introduction

Measuring the isotopic ratio of oxygen trapped in Antarctic ice, represents that global temperature changes have occurred in various cycles ranging from tens of thousands of years to several decades. Figure l shows changes in the concentrations of carbon dioxide and methane in the atmosphere over the past 300,000 years. Based on this information, it is believed that the atmospheric concentrations of carbon dioxide and methane change over tens of thousands of years, and that the earth's temperature was correspondingly high during periods when these concentrations were high. These, of course, are not caused by human activities. However, in the far right corner of this diagram, in recent years, human activity has caused a rapid increase in carbon dioxide over a 100-year time scale, which is much shorter than this recognition. As it is known, there are concerns that this increase in carbon dioxide will cause global warming (Figure 1).

In addition to the increase in carbon dioxide, it must be also considered the influence of the annual solar activity on these periodic temperature changes. Additionally, the Earth's orbit is an ellipse, and this, combined with the precession of the Earth's rotation, causes the northern hemisphere to be warmer and colder depending on whether it is closest to the sun in winter or closest to the sun in summer. It is also known to repeat. Those who claim that global warming is not caused by an increase in carbon dioxide alone emphasize the effects of these other events. It should be noted here that just because solar activity is quiet does not necessarily mean it will get colder, and the precession of rotation is a millennium-scale phenomenon, so the global warming over the past 100 years cannot be explained.

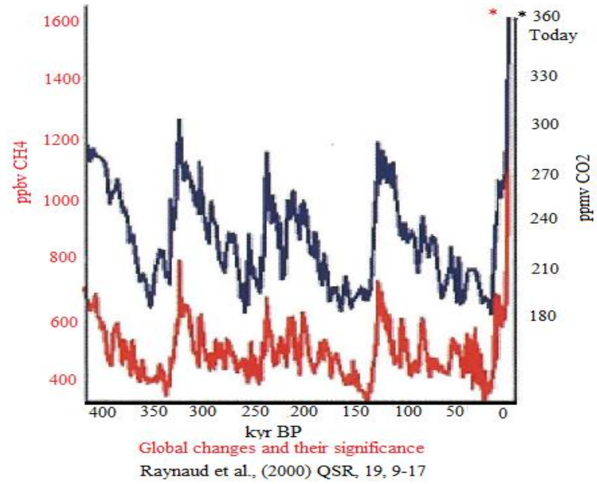

Figure 1. Time dependent features of CO_2 and CH_4 (Raynaud *et al*., 2000)

Human activities not only affect the ocean through global warming by emitting carbon dioxide, but also have an immeasurable direct impact on the ocean. In particular, due to ocean pollution due to pollution and increased fishing activity due to population growth, biodiversity is collapsing and rare species become extinct, or many species such as saury and sardines become extinct. Even if there are some fish species, the decline in resources due to fishing cannot be ignored. Especially after World War II, changes in the marine ecosystem have been dramatic, including a dramatic decline in long-lived higher-order organisms such as cetaceans, marine mammals, and large fish, the explosive rise and fall of sardines and herring, and an increase in short-lived small fish and squid. There are concerns about the decline in ecosystem diversity and simplification, and the shrinkage of cold ecosystems due to global warming.

Figure 2 is a famous diagram by Froese and Pauly (2003) depicting trends in world fisheries over the past 50 years, though it cannot be said that there are problems with the way the statistics were collected. This indicates that the fish species have been fully developed that here, the "development" refers to fish that have been newly harvested for food.

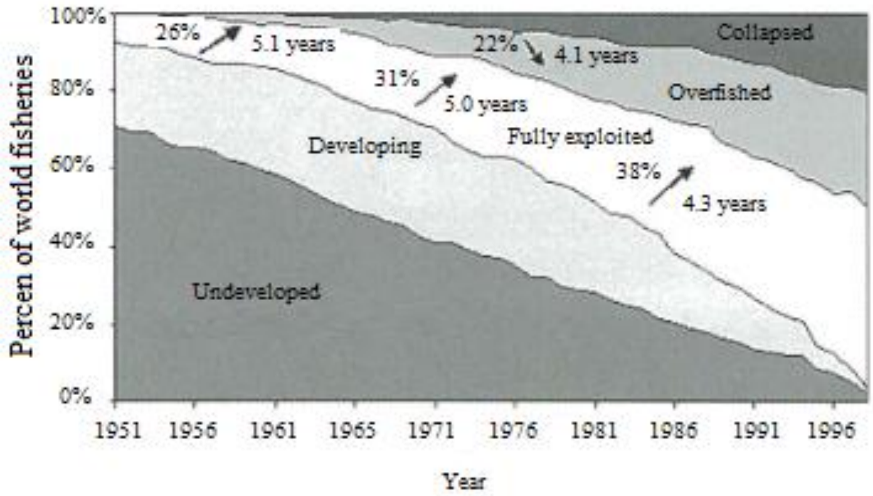

Figure 2. Trend of world fisheries after Froese and Pauly (2003)

1.1.Ocean warming

Specific heat is the amount of heat required to warm the substance 1 g expressed as a ratio to water. The smaller the value, the easier it is to warm up and cool down, and the smaller the amount of heat it can contain. Per weight, the specific heat of water is about four times that of the atmosphere, but per volume, it is approximately 3,000 times the atmospheric pressure on the ground (the molecular weight of air is approximately 29, so dividing by 22.4 liters will give you this value...). The total amount varies depending on how much of the atmosphere is included, but on average it is several hundred times larger. Multiplying the total weight, the amount of heat that can be contained in the ocean is about 1,000 times that of the atmosphere, and that of all the ice on Earth is about 5 times the amount of heat it takes to melt all the ice that is heat of fusion which is calculated as 800 times. Therefore, within the system that governs the Earth's climate, the role of the ocean becomes greater, especially as the climate changes over time. This is because once the ocean warms up, the amount of heat stored there becomes enormous and difficult to return to its original state.

Approximately 84% of the heat generated by global heating over the past 40 years is stored in the oceans (Levitus *et al*., 2005). It is believed that, since not all of the remaining 16% was stored in the atmosphere, this number is about 20 times greater than the amount of heat stored in the atmosphere. The ocean itself has risen on average globally by 0.037 °C, over the past 40 years. It's only 0.037°C. However, if we assume that the amount of heat absorbed by the ocean is released into the atmosphere all at once, as mentioned earlier, in contrast, the atmosphere will warm approximately 1,000 times as much as the ocean, or about 40 °C (Tables 1 and 2).

It can be seen how enormous the amount of heat absorbed by the ocean is. Most of the heat storage in the ocean occurs in the upper 700 m (Figure 3), but in the Pacific Ocean, it is said that, on average, heat storage is limited to the upper 100m. First, let's consider the role of the ocean from various aspects, focusing on the relationship between the ocean and the atmosphere, which has a major influence on weather and climate.

Table1. Comparison between atmosphere and ocean

	Atmosphere	Ocean	
Specific heat (Cp / J / K × g)	1	4	
Specific gravity (g /cm)	0.0012	1	
Ratio of specific heat per 1 cm^3			2000
Big cycle	60 days	200-2,000 years	
Main flow speed (Jet stream vs Kuroshio current)	30 m/s	1 m/s	
Small vortex speed (Tornado VS Whirlpool)	100 m/s	5 m/s	

One day in the atmosphere = 200 to 2,000 days in the ocean

Table 2. Comparison between ocean and atmosphere

The global average ocean temperature is 0.037 °C, and it is rising.
Comparison of ocean and atmosphere • Heat storage amount = (mass) x (specific heat) x temperature • Mass: Ocean l.4 E+2l kg; Atmosphere 5.3 E+l8 kg 140 quintillion tons vs. 5,300 trillion tons: 264 times • Specific heat: Ocean (4000J/C/kg) vs. Atmosphere (1000 J/C/kg): 4 times • The amount of heat stored when the ocean warms by 1°C is 1056 times higher than the amount of heat stored when the atmosphere warms by 1°C. A 0.037 °C rise in the ocean means a temperature rise of 40 °C in the atmosphere.

1.2.Vertical structure of seawater

In places where there are four seasons, the sun warms seawater from above in summer, but the warm water is light, so the warm water covers the surface area and hides it, so it does not warm deep down. In other words, radiation from above the sun warms the ocean from the sea surface to 100-200m. Then, in winter, the upper layer cools and becomes heavier, causing convection and vertical mixing. Figure 4 is a vertical representation of this annual change in water temperature. This shows how warm water covers the sea surface in the summer, and becomes uniform in temperature vertically in the winter, where it is stirred by convection.

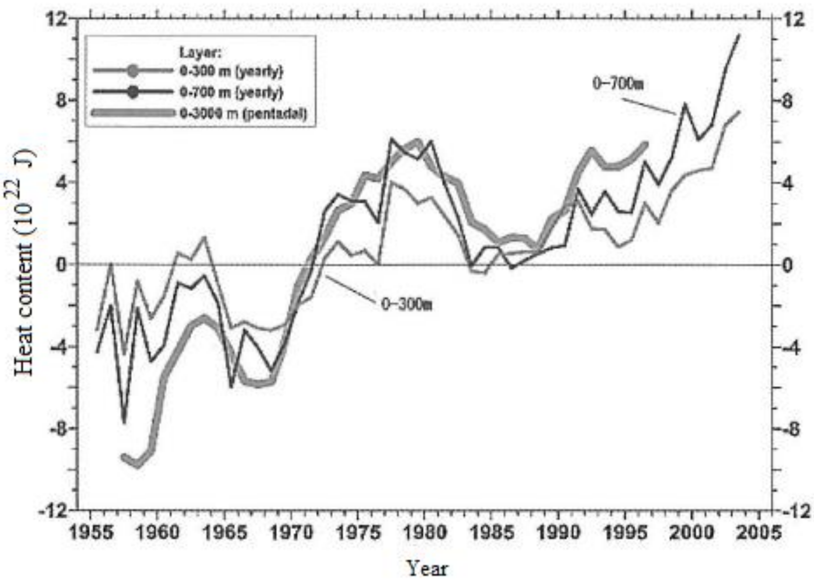

Figure 3. Time dependent features of heat content of ocean (Levitus *et al*., 2005)

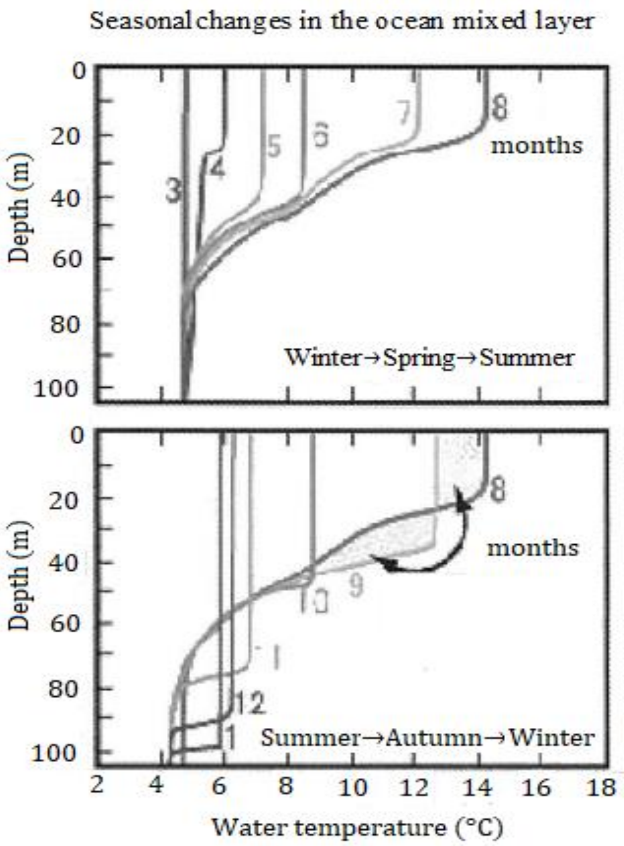

Figure 4. Time dependent features of vertical profile of water temperature in Gulf of Alaska

Figure 5 illustrates how phytoplankton uses nutrients contained in seawater to increase in size due to changes in the vertical structure. In land plants, withered tree leaves and animal droppings fall to the ground and are absorbed by forests, but in the ocean, light only reaches about 100-200 m above the surface, and dead plankton and fish droppings fall to the ground and are absorbed by forests. It is rarely used in the field and sinks as it decomposes. The surface layer of the ocean is not replenished with nutrients through the decomposition of dead animals and plants, making it difficult for plants to grow. Therefore, phytoplankton can only increase when convection occurs and nutrients are replenished from deep within. In temperate regions, in spring, the water temperature rises and the amount of light received from the sun increases, creating conditions suitable for photosynthesis, allowing phytoplankton to proliferate using nutrients supplied from below through vertical mixing during the winter. In the tropics, there is no vertical mixing in the winter, so even if there is sufficient light and water temperature, there are usually very few phytoplankton on the surface layer all year round.

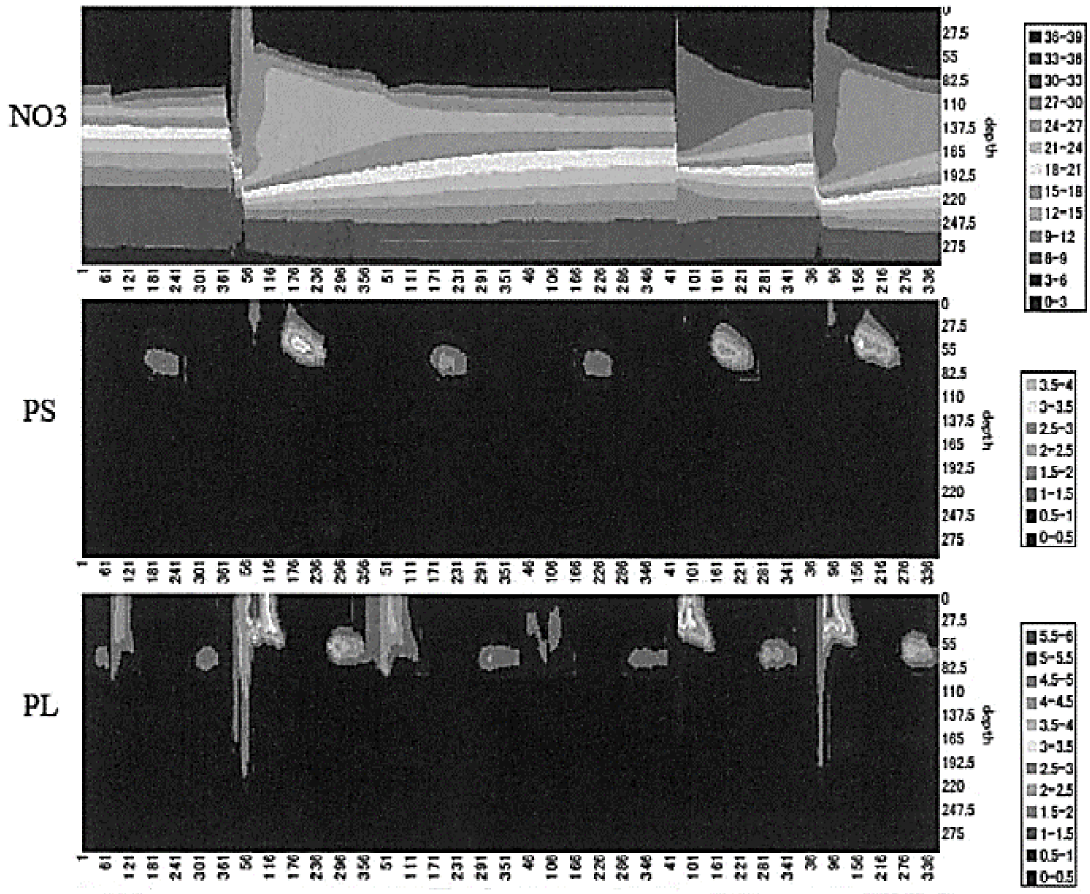

Figure 5. Time dependent features of vertical distribution of nutrient and phytoplankton. PS is small phytoplankton and PL corresponds large phytoplankton, diatom (Kishi *et al*., 2001),

1.3. Seawater dragged by the wind

A westerly wind is blowing around 40° north latitudes. East winds (trade winds) blow around 20° north latitudes. These winds also play an important role in creating ocean currents. It schematically illustrated the large-scale circulation of the world's oceans in Figure 6. The black arrows represent the circulation of the ocean's surface layer. In both the Pacific and Atlantic oceans, there are strong currents only at the western end of the ocean. The current at the western end of the North Pacific Ocean is called the Kuroshio Current, and the flow in the North Atlantic Ocean is called the "Gulf Stream" How can such ocean currents occur? Surface seawater is primarily moved by the wind that blows over it. Trade winds and westerly winds blow around the sea surface of the North Pacific and North Atlantic in a clockwise direction, but due to the Earth's rotation and the roundness of the Earth, strong currents only occur on the western side of these oceans. It is formed only in the Kuroshio Current and the Gulf Stream are particularly strong ocean currents, with speeds of 1 to 2 m/s, which is about as fast as a human can walk quickly. This is very different from winds blowing at speeds of 20m/s or more when a low pressure system develops. This has a lot to do with the fact that water is heavier than air and the ocean is deep. No matter how much air rubs against the sea surface, the current doesn't become that fast. However, the amount of water that flows per second is about 5,000 times that of Niagara Falls, and the Kuroshio Current plays a major role in transporting heat from the tropics to the cold regions. It takes several years for the water in the North Pacific to travel around the North Pacific using this surface circulation. The Kuroshio Current, which flows along the southern coast of Japan, is a warm current because it comes from the southern sea, and in the eastern sea of Tohoku there is a cold current called the Oyashio Current. The current in the ocean is so slow that even when he looks at it, he has a hard time realizing that it's flowing. Moreover, there are probably few people who have ever been to where the Kuroshio Current or Oyashio Current flows. However, the fact that the Kuroshio Current and the Tsushima Current flow from the west can be reminded by the fact that empty cans and industrial waste with Chinese writing on them arrive on the coast of Japan from as far away as China.

1.4. Salty Atlantic Ocean and deep seawater

When the surface of water at high latitudes is cooled by cold winds and becomes denser than the water below, convection occurs and the water sinks. There are two places in the world's oceans where such subduction occurs on a large scale. One is east of Greenland, and the other is in Antarctica that is called the Weddell Sea, both marked with a X circled sign in Figure 6. The reason why surface water sinks off the coast of Greenland but does not sink deep in the Pacific Ocean than in the Atlantic Ocean is because the Pacific Ocean has less salinity due to more precipitation in the Pacific Ocean and there are larger rivers there. Mainly due to this conditions, the saltier Atlantic seawater becomes heavier even when cooled to the same temperature. It is also important to note that while the Pacific Ocean is mostly closed off to the north by the Bering Sea, the Atlantic Ocean is wide and extends all the way to the North Pole. As Atlantic seawater sinks off the coast of Leanland, the warm Gulf Stream can flow northward, dragged along by the sinking. Therefore, Europe is warm even in winter despite its high latitude. Because the Gulf Stream flows north, the salty water from the tropics can reach the coast of Greenland.

The heavy water in east of Greenland sank into a deep layer, and as shown by the white arrow in Figure 6, it also passed around the western edge of the Atlantic Ocean, crossed the equator, and sank out of the Weddell Sea. Along with the water, it flows east around the South Pole. Some of it enters the Indian Ocean, but much of it moves north through the east of New Zealand, crosses the equator, and flows into the North Pacific Ocean. It is now known that the water that reaches the North Pacific Ocean takes about 2,000 years after first sinking off the coast of Greenland. Although surface water moves quickly, water in the deep circulation moves very slowly. Figure 7 is a diagram showing atmospheric flow and ocean general circulation.

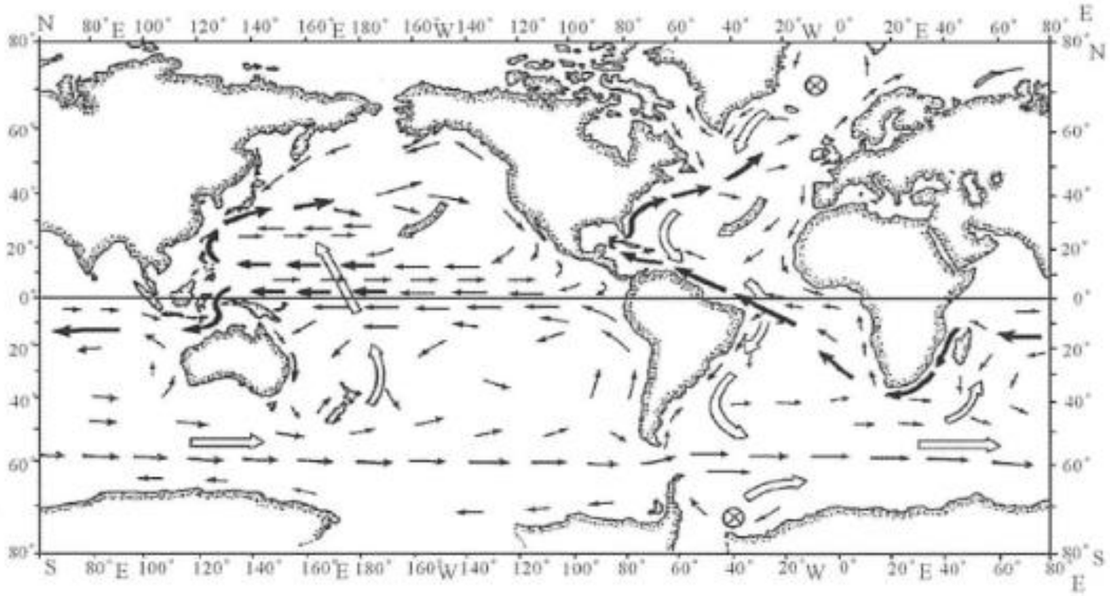

Figure 6. Important sea surface currents of world ocean (Black arrows) and deep circulation (white arrows). ⊗ indicates the area where bottom water is formed.

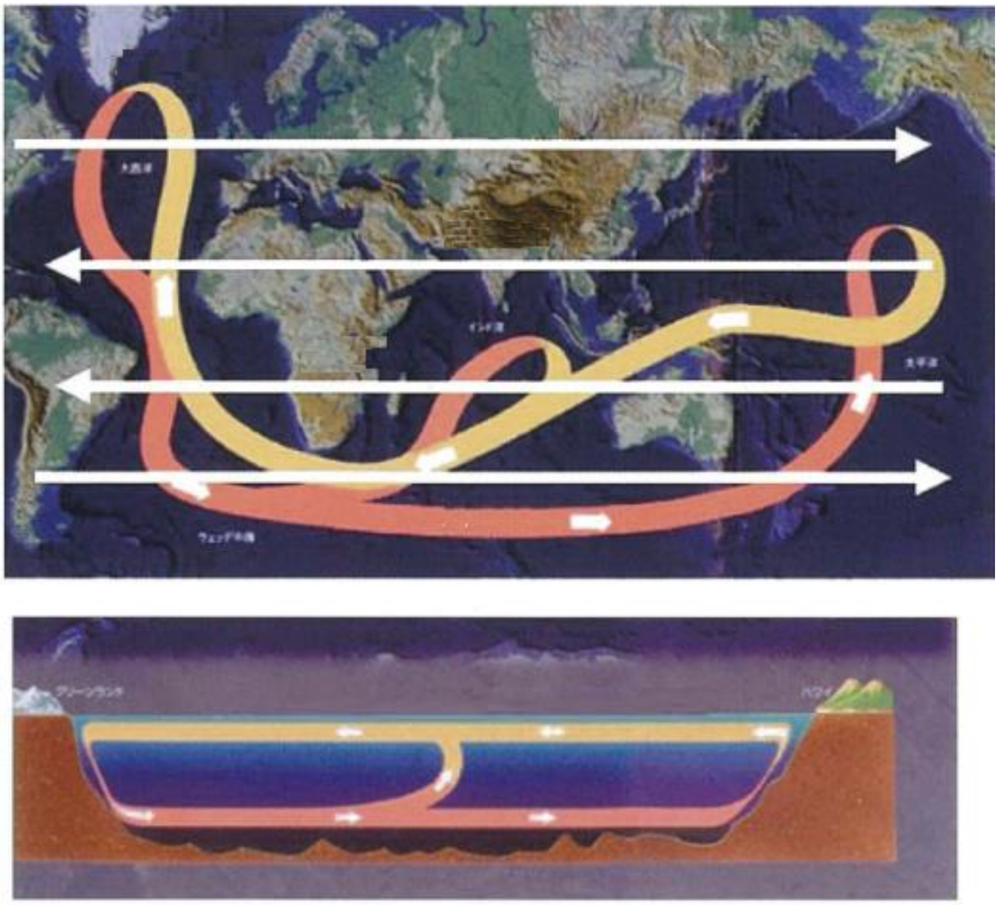

Figure 7. Trade and westerly of atmosphere and general circulation of sea water.

1.5. Prediction of seawater temperature rise

Global warming projections for Japan, which were included in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Report (AR4), were compiled by the Japan Meteorological and the Environmental Research Institutes, which are parts of the Japan Meteorological Agency (JMA). The Center for Climate System Research, the University of Tokyo (currently the Atmosphere and Ocean Research Institute), and the Japan Agency for Marine-Earth Science and Technology (a research institute of the Ministry of Education, Culture, Sports, Science and Technology) are conducting this research. The details are omitted, but the model includes everything from the interaction between the atmosphere and ocean to the absorption of carbon dioxide by plants in the ocean and land to predict the climate and ocean up to 100 years from now. According to this, sea surface temperatures in the Pacific Ocean has increasing trend (Haghroosta, 2019) and it will be increased by 1 to 2 °C in 2050, and by 2 to 4 °C in 2100. Some people worry about flooding because this will cause the seawater to expand and the water level to rise, but this is only a few centimeters to a dozen centimeters, so the impact on human life is likely to be minor. In Japan, coastal brackish lakes- lakes where seawater flows in and out depending on the tides: Lake Saroma, Lake Akkeshi, Lake Shinji, etc.- are likely to be seriously affected by rising water levels. There are concerns about the impact on the ecosystem as the amount of seawater entering the lake changes and the salinity changes. From now on, it will be explanied how fish change their living spaces as water temperature rises, but just on the premise that fish will continue to migrate and eat food as an extension of the current situation. Fish adapt to changes in water temperature. Recent research shows that some fish species are selected to adapt to changes in water temperature in just four generations, or they change their habitat depth as mentioned above, they live near the sea surface. The water temperature is rising rapidly, but if you dive a little deeper, the water vortex may not change much. Such things cannot be confirmed in a laboratory, and past knowledge such as what things were like during the Ice Age, is not used, because something will happen that you have never experienced before.

1.6. Climate change and changes in fish resources

Amid concerns about the depletion of fisheries resources, the research has recently become focused on "ecosystem-based resource management," which takes into account the feeding environment and the economic status of fishermen. This type of ecosystem-based resource management aims to conserve marine ecosystems that respond to climate changes such as global warming and human activities including fishing from 2006, and other countries surrounding the Pacific Ocean, including Canada, China, Russia, and South Korea, are also planning research projects. Furthermore, GLOBEC (an international research project called Global Ocean Ecosystem Dynamics), the North Atlantic Ocean Science Council (ICES), and the North Pacific Marine Science Organization (PICES), both of which are intergovernmental international ocean research organizations are also providing support for these projects. In Japan, it is being considered for application to fishery resource management within 200 nautical miles. In order to accurately understand the changes and current state of marine ecosystems and predict their future, it is necessary to analyze various models for ecosystem-based fishery resource management (the "model" here does not necessarily mean a mathematical model).

Figure 8 shows temperature changes over the past 400 years according to Klyashtorin (2001) and the periods when sardines were caught in abundance around Japan. This means that changes in the water mix in the ocean's surface layer over a 30- to 50-year period are closely related to the increase and decrease of the sardine population. According to Sakurai *et al*. (2000 and 2003), it was found that during the years when the water temperature in the Sea of Japan was warm, the catch of blue squid was large, and this is known to be caused by differences in the water temperature structure of the spawning grounds (Figure 9). As described above, recent research has rapidly made it clear that climate change, which occurs on a scale of several decades, and biological activity seem to be closely related. This suggests that if ocean temperatures and air temperatures change due to global warming, sea life will change in response. However, eddy warming occurs slowly and unilaterally over 50 to 100 years, and is superimposed on this by fluctuations with a multi-decadal cycle (see Figure 15). If this happens, there is a possibility that the current cold year will have the same water temperature as a future warm year. In this case, there is no guarantee that the phenomena currently occurring in cold years will be extrapolated to the future, and the phenomena occurring in warm years are not predicted at all from current or past experience.

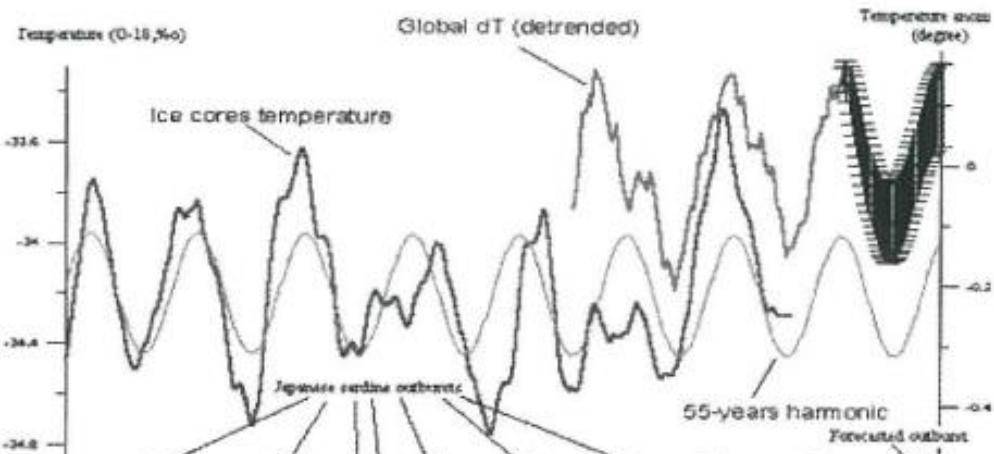

Figure 8. Temperature anomaly based on ice core. Black circles indicate when pacific sardine dominated based on old literature in Japan (Klyashtorin, 2001)

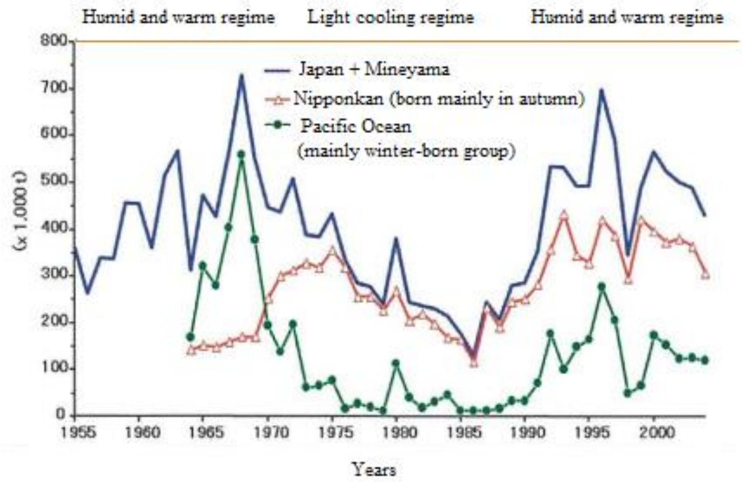

Figure 9. Fisheries of common squid and water temperature of Japan Sea (Sakurai *et al*., 2007)

2. Fish and global warming

2.1. Squid (Japanese common squid)

The time may come when squid will become the dominant species in the waters around Japan. In fact, it is said that common squid make up 80% of the seafood swimming on the surface of the Sea of Japan from summer to fall. With the exception of giant squid such as the giant squid, many of them have short lifespans of less than a year. For example, the rapid increase in stock and expanded distribution of the giant red squid which grows to a weight of over 20 kg per year, and lives on the Pacific side of the United States, has led to a decline in tuna stocks.

Squid species, which transform from low-level food chain predators to high-level predators in a single year, are said to be key species for the marine ecosystem. Until now, Professor Yasunori Sakurai of Hokkaido University has been studying how Japanese common squid responds to cold-humidity regime shifts that is a phenomenon in which seawater temperature increases or decreases from 1 to several degrees Celsius over a period of several decades, independent of global warming. We proposed a scenario of changes in resources, and found that during the cold season, the winter-born herd in particular decreases, and it has been estimated that both autumn and winter-born groups increase during the warm season (Sakurai *et al*., 2007) (Figure 9).

According to Professor Sakurai's hypothesis of Japanese common squid, the areas where reproduction (fish spawning and growing to a size that can be fished) is possible for Japanese common squid, including their spawning grounds, are the continental shelf - shelf slope (100-500 m) area. A sea area where the surface water temperature is 18-23℃, and the mixed layer with a constant water temperature (see Figure 4) does not reach the sea floor (Sakurai *et al*., 2007; Miyanaga and Sakurai, 2006) It is. Although the background of the experiments and demonstrations will be omitted here, this new hypothesis is based on spawning experiments in aquariums, egg development experiments using artificial insemination, and hatching larvae.

It is based on knowledge such as experiments on swimming behavior in each water humidity, the distribution of hatched larvae that appear in actual spawning areas, water humidity, and the depth of the shelf slope where spawning individuals are collected. We have been able to establish ocean conditions suitable for limited reproduction. He believes that if it is possible to monitor how the suitable "reproductive sea area" for the Japanese squid moves seasonally and whether its range expands or contracts, it is possible to predict drastic changes in the stock level for at least the following year. It will be possible. Based on this hypothesis, the ocean area with a sea surface temperature (SST) of 18-23°C (especially 19.5-23°C) was estimated using satellite images on the shelf slope area (water depth l00 -500 m). Once extracted, it can be used as a ``reproduction area," in other words, an area where the hatched Japanese common squid larvae can best survive. By taking into account the environmental conditions for the reproduction of this species and its migration, as shown above, we predicted how the Japanese common squid would behave in the event of global warming. Global warming according to IPCC-AIB global warming scenarios

Using predicted sea surface temperatures data from the Rontier Research Center (Kamezawa *et al.*, 2007) are expected to rise by approximately 2°C around Japan in 50 years, and by approximately 4°C in 100 years, in 2050, the area with the lowest water temperature (sea surface temperature of 12 degrees Celsius) during the period of migration during the growth period in search of food will move northward by 2 degrees in latitude in the Sea of Japan. The main reproductive areas have been formed from the Sea of Japan to the Tsushima Strait to the East China Sea throughout the 100 years, and appear to be unchanged from the warm regime period (Figure 10). However, the peak spawning season is currently from October to February (spawning occurs in autumn and winter).

However, 50 years from now, he will be from February to March, and 100 years from now, he will be from February to March. As shown in Figure 11, it is expected that the period will change from February to April (winter-spring spawning group). It is predicted that the spawning season will shift from the current October to February spawning season to November to April in 2050, and December to May in 2100. It is also anticipated that there will be no distinction between autumn-born and spring-born, and spawning grounds will be limited to the East China Sea (Sakurai *et al*., 2007).

2.2. Pollack

Similarly, predictions for pollock were made based on global warming prediction data. Currently, resources off the coast of Sanriku, which are already in decline, and in the northern Sea of Japan, will be drastically reduced by 2050. It is predicted that by 2100, there is a high possibility that all stocks except those in the Pacific Ocean of Hokkaido and the Sea of Okhotsk will become extinct (Figure 11).

2.3. Salmon Japanese salmon (Oncorhynchus spp.)

It is known that there are differences in growth over the long term (upper diagram in Figure 12). Salmon with ocean age 4 (salmon that have been released and overwintered in the ocean four times) decreased in weight until the 1990s, but their weight suddenly increased in the late 1990s. This trend can also be expressed through analysis using a computer-based model experiment (lower panel of Figure 12) (Kamezawa *et al*., 2007). It has been pointed out that this is due to Using the predicted data from the IPCC-A1B global warming scenario mentioned above regarding squid, that examined the growth and survival dynamics of Hokkaido chum salmon in the Sea of Okhotsk and the density-dependent effects in the Bering Sea. The optimal water mixture for chum salmon was determined from the results of rearing experiments and the relationship between CPUE and SST of juvenile chum salmon in the Sea of Okhotsk (Ueno and Ishida, 1996).

The temperature should be 8-12°C during the feeding migration period, and 4-6°C during the wintering period based on Fukuwaka *et al*. (2007). As a result, it is predicted that the Sea of Okhotsk, which is responsible for the survival rate, will lose its suitable water eddy area by August 2050, and will be almost completely destroyed by 2099. It is predicted that in the Bering Sea, it will be able to maintain approximately 80% of its current distribution range by 2050, but will be completely wiped out in 2099 (Figure 13). Marine life Ara is the wintering area from the second year onwards.

In Suka Bay, although the current status quo can be maintained until 2050, it is predicted that competition for food and habitat with American chum salmon will become significant in 2099.

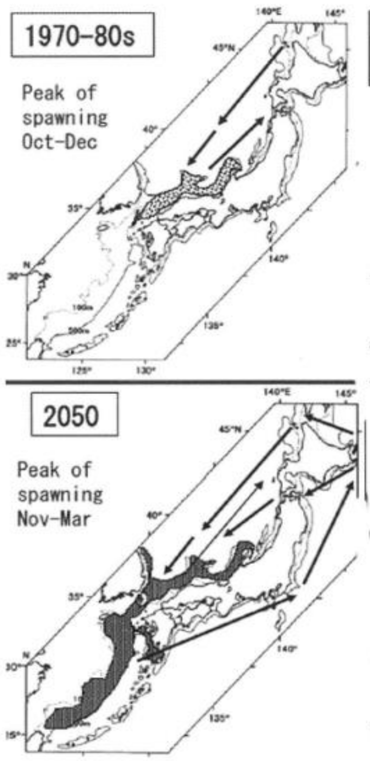

Figure 10. Transition of common squid spawning area corresponding to global warming (Sakurai *et al*. 2007)

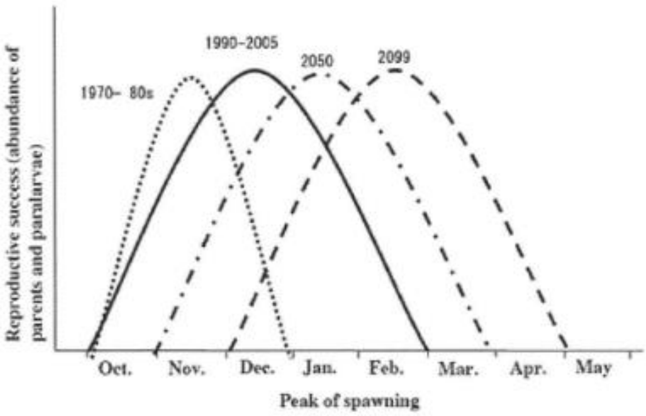

Figure 11. Predicted spawning period of common squid.

3. Management by model

The above is a prediction based on current knowledge about changes in the living space of fish species expected from changes in water temperature after global warming. It must be said that this is extremely dangerous. Predictions of physical phenomena can be made with some accuracy because the "equation of state" and "equation of motion" are accurate formulas, although it may be difficult to precisely predict variations in the earth's ground, which is a boundary condition, but because ecosystem models are formulated based on current experience, it is difficult to predict changes in conditions that are completely different from the current one. However, we can't just leave him alone, so many attempts have been made to consider why past changes occurred and use them to predict the future. There is a research field called ecosystem modeling. This means that in the ocean, for example, when predicting whether plankton will increase or decrease when the environment changes, the "eating and being eaten" relationship between organisms is expressed mathematically. What is important here is that the ecosystem expressed as a formula. The term "ecosystem" here refers not only to the connections between living organisms, but also includes all the surrounding environments such as temperature. The question is not whether or not the "formula" can completely cover the behavior of living things on the entire planet, but whether the changes in living things that it would be great to knowing about which can be predicted using that formula. Figure 14 is from PICES (North Pacific Marine Science Organization). It is an "ecosystem model" created by the Pacific Ocean Science Organization called NEMURO. Although nutrients such as nitric acid and silicic acid exist in the actual ocean, there is no living organism called "phytoplankton". Therefore, this is not an accurate description of the actual marine ecosystem. So, this study did not create the model with the intention of predicting whether a particular type of plankton will increase or decrease, but rather to study the dynamics of lower-order production in the Pacific Ocean as a whole. This model was made because the purpose was to examine how biological production changes. To predict whether biological production in the North Pacific Ocean will increase or decrease in the event of climate change, and whether there will be an increase or decrease in fish abundance as a result (Kishi *et al*., 2007). As the name suggests, this model was created at a study group held in

Nemuro City. A world-famous model was also formed at a study group held in Japan. However, since then, it has been thought that NEMURO was missing the point in discussing climate change and biological production, as it did not take into account the limitation of photosynthesis by iron.

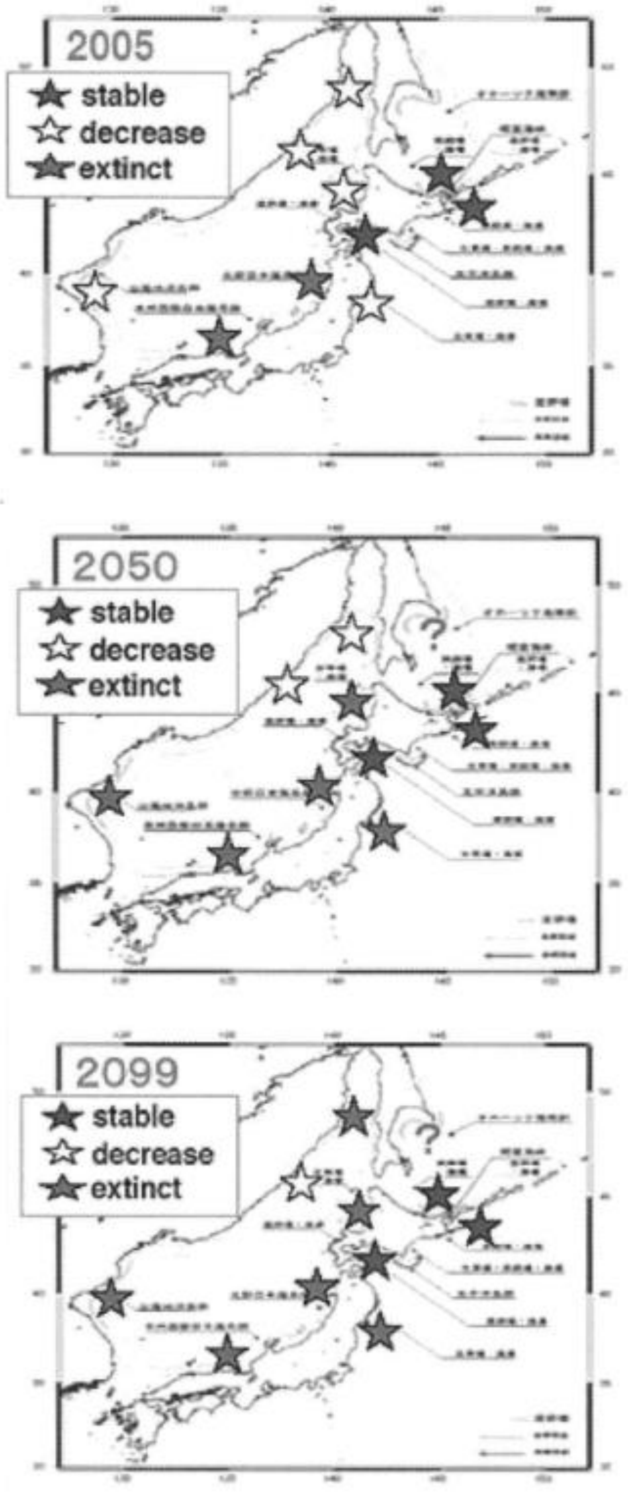

Figure 12. Prediction of wall eye pollack stock (Sakurai *et al*. 2007)

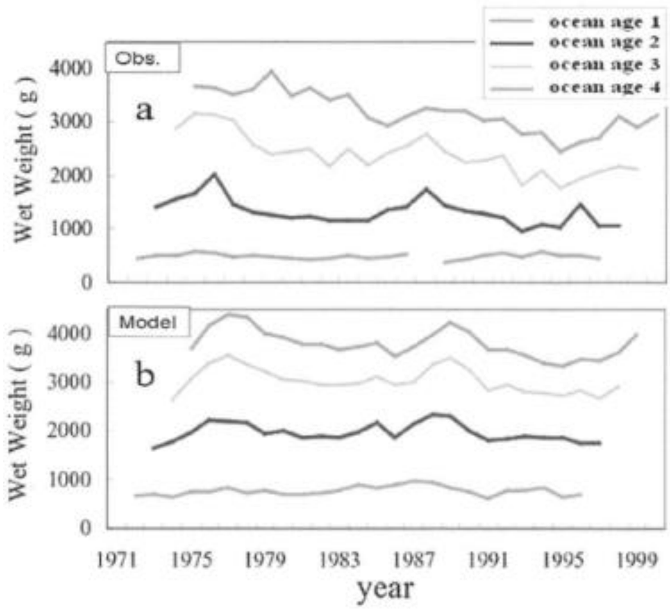

Figure 13. Wet weight of chum salmon in the Bering Sea (Kishi *et al*. 2010)

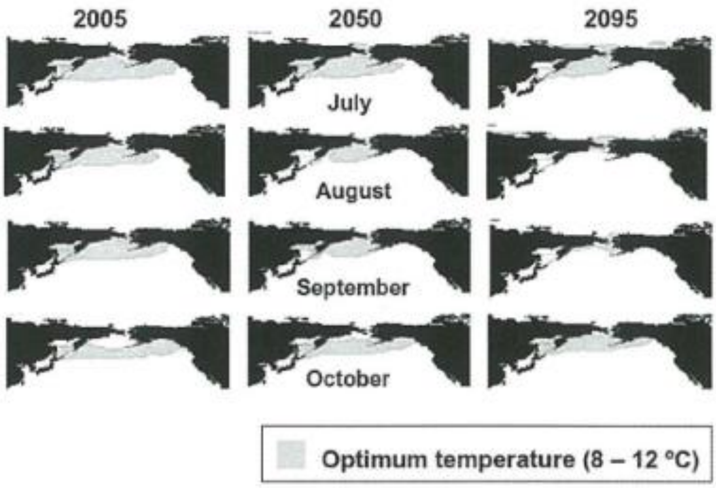

Figure 14. Predicted living area of Japanese chum salmon (Kishi *et al*. 2010)

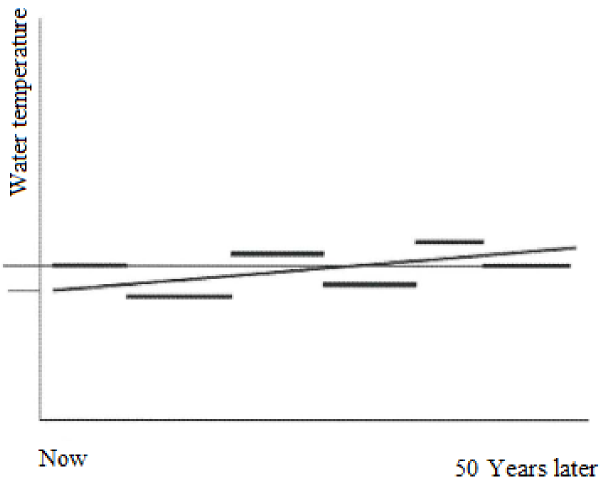

Figure 15. Image of global warming and regime shift

It is known that in addition to iron, there are compounds of metals such as manganese and aluminum that are not needed by the plant but inhibit its growth, such as vitamins. Aita-Noguchi *et al*. (2003 and 2007) incorporated the NEMURO into a 3D Global Model of physics and calculated the model over the last 50 years. First, NEMURO is characterized by the fact that phytoplankton is divided into diatoms (PL in Figure 14) and small flagellates (PS), and copepods (ZL) move vertically seasonally. It was found that vertical movement of zooplankton is effective in areas where this is prevalent, and has the effect of increasing primary production compared to when there is no vertical movement. Furthermore, the regime shifts around of 1975 there was a major climate change in the Earth, and its effects extended to the oceans as well. It is known that this regime shift shows that primary production in the North Pacific differs greatly before and after, and that this is mainly determined by physical factors.

Although these models have been developed in a closed system, organisms are transported by ocean currents, and many species migrate spontaneously. If the ocean currents would be flowing in a week or two weeks, and it was known how the water temperature would change, a model could be created to predict where and how many creatures would live in the ocean. Off course it is not that easy, consider squid. When the seawater flows, squid are carried away with it, and at the same time they swim by themselves. Where does the squid swim towards? Since the squid swims with its own, it is probably impossible to predict unless you know how the squid will be determined. And if the squid will be determined mechanically (for example, "I will always swim towards the area where the water temperature is higher" or "I will always swim towards the area where there are a lot of plankton"), then the model would be able to predict it. However, that doesn't seem to be the case.

As an example, it seems that this is statistically known to be due to a large proportion of people walking to the left due to their dominant foot. I don't know the exact numbers, so let's assume that the percentage of people going to the right is 40%, and the percentage of going to the left is 60%. If there are 100 people, 60 people will move about to the left. Therefore, similarly, the model of the ecosystem in the computer, which are created, ignores the circumstances of each individual squid, and assumes that the squid will migrate to areas with higher water temperatures at a certain rate. It will be trying to create formulas and predict what will happen. For instance, if we express in an equation that plankton undergoes photosynthesis when it is exposed to sunlight, the stronger the light, the more it photosynthesizes, produces oxygen, and produces nutrients, which increases the number of people. On the other hand, one plankton may be eaten by a fish, or get stuck on the side of a ship, or be involved in such an incident, but such things are a matter of probability, for example, "10% of the total, a relationship such as "the person will die in the future" is written in an equation.

What will happen if the earth warms in this way? Efforts to predict the future are currently underway. Some theories can be represented about this: (1) Meteorologists predict that seasonal winds will become stronger as the climate warms. This will allow water to mix well at the surface layer of the North Pacific Ocean during the winter. Additionally, when the low pressure in the North Pacific is strong in the winter, a large proportion of the nutrient-rich water in the deep layers of the North Pacific rises from the deep layers to the upper layers. Therefore, stronger seasonal winds have the effect of enriching the surface layer of the North Pacific with nutrients. Additionally, as water temperature rises, phytoplankton will increase photosynthesis. This means that in spring, when there is sufficient sunlight and the water becomes warmer, the rate at which phytoplankton growths called increases that is called spring proliferation (Hashioka and Yamanaka, 2007). (2) Coastal upwelling off the coast of California is also expected to become stronger. This may also increase plankton and floating fish. (3) Warm winters will make it difficult for the sea surface to cool down in the winter. This "winter mixing" becomes smaller as the winter becomes warmer. As the size decreases, it becomes difficult for nutrients to be replenished to the sea surface, which reduces the spring proliferation of phytoplankton (Hashioka and Yamanaka, 2007). Then, there is less food and the survival rate of floating fish is poor. (4) It is known that survival of sardine eggs and larvae is poor in years when the northwest monsoon is strong in the Pacific Ocean (Kasai *et al*., 1992), so sardine stocks decrease as the monsoon becomes stronger. Maybe. But is it true that if the amount of sardines decreases, the amount of anchovies increases? (5) As it was mentioned earlier, higher water temperatures may shrink salmon habitats and reduce salmon stocks. It is unclear whether the rate of warming in water temperatures is outpacing the rate at which salmon can adapt. If there is a possibility that marine life, not just salmon, can adapt in the same way as a frog in a pot. As shown in Figure 11, multi-decadal fluctuations are superimposed on global warming, and it may be difficult to even tell whether or not it has adapted and the prediction is nearly impossible.

Conclusion

Ocean acidification is another consequence of global warming that poses a severe threat to marine ecosystems. As carbon dioxide (CO_2) concentrations rise in the atmosphere, a significant portion is absorbed by seawater, causing a decrease in pH levels. Acidic conditions hinder the ability of many marine organisms, such as corals and shellfish, to build their protective structures or shells. This disruption can have detrimental effects on their survival and overall ecosystem functioning. Melting polar ice caps due to global warming also impact marine ecosystems. The release of freshwater from melting ice alters salinity levels in coastal areas and affects ocean currents. These changes can disrupt nutrient cycling and alter the distribution patterns of planktonic organisms that form the foundation of many marine food chains.

Furthermore, rising sea levels caused by melting glaciers contribute to coastal erosion and habitat loss for numerous species that rely on specific coastal environments for breeding or feeding purposes. Coastal communities are also at risk due to increased vulnerability to storm surges and flooding events. To mitigate these impacts on marine ecosystems, urgent action is required at both local and global scales. Reducing greenhouse gas emissions through sustainable practices is crucial for minimizing further temperature increases and ocean acidification. Additionally, implementing effective conservation measures such as establishing protected areas, promoting sustainable fishing practices, and restoring degraded habitats can enhance the resilience of marine ecosystems to climate change.

In conclusion, global warming is causing significant changes in marine ecosystems, including shifts in species distribution, ocean acidification, melting polar ice caps, and rising sea levels. These changes pose substantial threats to marine biodiversity and ecosystem functioning. Addressing this issue requires immediate action to reduce greenhouse gas emissions and implement conservation measures to safeguard the health and resilience of marine ecosystems for future generations.

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