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Review:

Impacts of Climate Change on Biodiversity

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Rising temperatures brought about by global warming are causing plants to bloom and leaf earlier, and advancing the start of animal breeding seasons. The ranges of some species of plants and animals are also being shifted northwards or to higher elevations. In cities, the heat island effect is raising temperatures still further, accelerating the flowering of plants. The degree of such phenological changes, and of the range in shifts, varies according to species and group, resulting in the distortion or mismatch of biological interactions such as predation, pollination, seed dispersion and parasitism. Rising sea levels due to the rising temperatures is destroying tidal wetlands and wiping out coral reefs and, consequently, killing off the various organisms that live there. It has been predicted that if warming continues, sudden and drastic changes will occur in the structure and functioning of ecosystems around the world, including in Japan, and that such regime shifts, which cannot easily be reversed, will be frequent. These ecological changes would affect a variety of aspects of human life such as housing, diet and health.

Keywords: climate change, phenology, distribution, biological interaction, regime shift

1. Introduction

Global warming is not only profoundly affecting human lifestyles, but is also having many different effects on the lives of plants and animals. Because it is accelerating with time, more serious consequences are predicted. The effect on plants and animals will come back to haunt us, with repercussions for human health and diet.

The earth's surface temperature (average of the near-surface air temperatures above land and sea surface temperatures, hereinafter referred to simply as the "temperature") has so far risen by an average of 0.74 ° C over the last hundred years [1], and is forecast to rise another 1.1 to 6.4 ° C over the next 100 years (the range is due to differences in scenarios). Sea levels are predicted to rise by up to 59 cm over the next 100 years due to increasing temperatures, while snow cover and accumulation decline. The average snow cover in the Northern Hemisphere in the 1930s to 1980s was 36 to 40 million km^2, but has shrunk to between 34 and 37 million km^2 since the 1990s. Snow cover and accumulation are expected to diminish still further in the future.

Such climate change will have consequences for the blooming seasons, breeding seasons and distribution of plants and animals, and affect various aspects of species composition and biological interaction. Rises in temperature hasten blooming and breeding seasons, and push those species inhabiting highland or northern regions to higher altitudes or even further north. Rising sea levels brought about by climbing temperatures may destroy coastal tidal flats and submerge coral islands. Increases in lake water temperature may alter water quality and microbe populations, reshaping entire ecosystems.

In this paper, I will review the impacts of such climate change on plants and animals, and suggests further possible changes. I will also discuss about the effect of phenological changes and range shifts among plants and animals on human housing, diet and health. This article draws from and arranges Higuchi [2].

2. Phenological Changes

Rising temperatures are advancing biological cycles such as the blooming and fruit bearing seasons of plants and the breeding and migration seasons of animals. Here, I examine the relationship between these phenological changes and climate change, focusing on plants and birds for which a comparatively large amount of data has been collected.

2.1. Plant Blooming Season

The records of 78% of 542 plant species investigated throughout Europe from 1971 to 2000 showed an advance in blooming, leafing and fruit bearing seasons [3]. The phenology of spring and summer advanced by an average of 2.5 days over 10 years, a change which was linked to temperature, an advancement of 2.5 days generally corresponding to a 1 ° C increase. This relationship with temperature is more striking in plants that leaf or bloom earlier in the year.

In Japan, information, such as that on blooming season, has been gathered on a variety of plants, particularly on cherry blossom and plum trees. Data collected by the

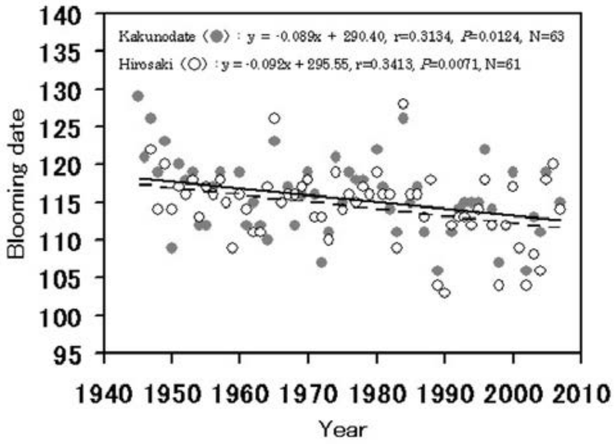


Fig. 1. Annual changer in the blooming date of Somei-Yoshino cherry trees in Kakunodate, Akita Prefecture and Hirosaki Castle Park in Aomori Prefecture (1 = 1st January).

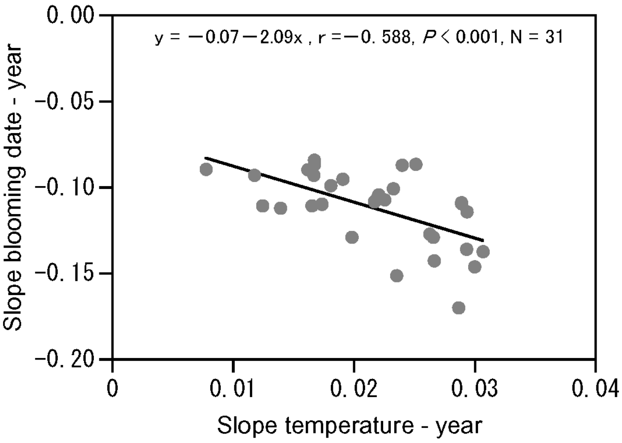


Fig. 2. Relationship between the increase in early spring temperatures and the advancement of Somei-Yoshino cherry tree blooming date in locations around Japan. The rises in temperature and advance in blooming date are each given as annual rates of change, where the annual rate of change is the gradient of the regression line generated by regression of temperature and blooming date versus year. The negative annual change rate of blooming date indicates that blooming is advancing. Based on data collected by the Japan Meteorological Agency (JMA).

Japan Meteorological Agency (JMA) on a national scale since the 1950s show, for example, that the blooming date of Somei-Yoshino cherry (*Cerasus* x *yedoensis*) trees has tended to advance in 31 (38.3%) of the 81 locations surveyed. In the center of Tokyo, it has advanced by an average of 5.3 days in the 54 years since 1953, whereas in Niigata City, it advanced by around 8.5 days over 27 years from 1978. Data have been collected independently since 1940s on Hirosaki Castle Park in Aomori Prefecture as well as in Kakunodate, Akita Prefecture, which are both famous locations for cherry blossom viewing. At both sites, the blooming date has advanced by around 5.5 days in roughly 60 years (**Fig. 1**). There is a high correlation between the cherry tree blooming date at a particular location and the early spring temperatures of February and March; the higher the early spring temperatures are, the earlier the trees bloom. Over the whole of Japan, the Somei-Yoshino cherry blooming date tends to be earlier in areas with more increase in temperatures during the months of February and March (**Fig. 2**).

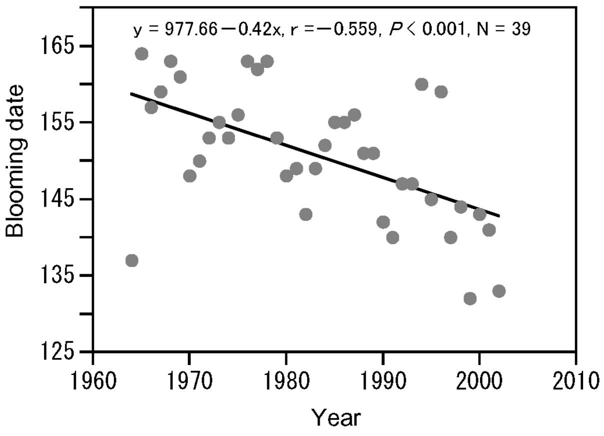


Fig. 3. Annual change in blooming date of the Japanese white-bark magnolia in Takayama City, Gifu Prefecture, over the past 38 years (1 = 1st January), based on data collected by the JMA.

An analysis of data collected by the Japanese Meteorological Agency (JMA) on plum trees in 32 areas for which there are records spanning at least 40 years, showed that they were tending to bloom earlier [4]. There was a significant trend for the blooming season to advance more in the period from 1990 to 2005 than in the period 1953 to 1989. A correlation also exists between the blooming season and the winter temperatures of January to March. The difference in blooming season in each area up to 1989 and from 1990 onwards was greater in areas where there was a stronger correlation between blooming season and winter temperature.

Some plant species growing in more natural habitat were also studied. Analysis of data collected by the JMA showed that the blooming date of Japanese white-bark magnolia (*Magnolia hypoleuca*) in Takayama City, Gifu Prefecture, advanced by 15.8 days in 38 years from 1964 (**Fig. 3**). The phenology of the Erman's birch (*Betula ermanii*) visible from the window of the Shinshu University's facility in Shigakogen, Nagano Prefecture, have been studied since 1986. The birch is showing a gradual trend to leaf earlier [5].

2.2. Rising City Temperatures

According to the JMA, the average blooming date of Somei-Yoshino cherry trees in six large cities throughout Japan (Sapporo, Sendai, Tokyo, Nagoya, Kyoto and Fukuoka) has advanced by 6.1 days in 50 years, compared to an advancement of

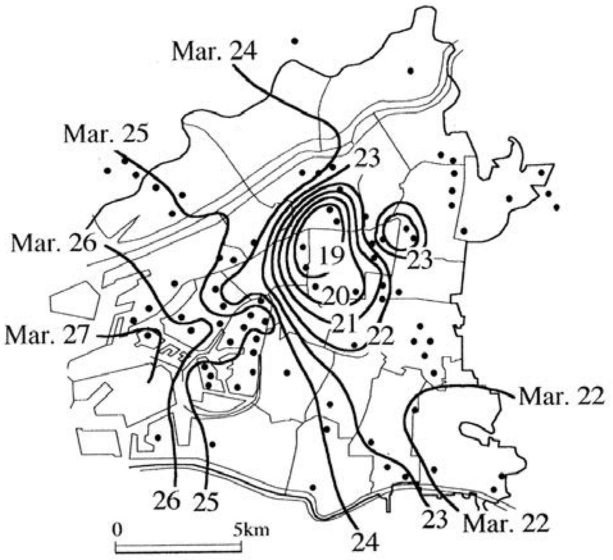


Fig. 4. Difference between the Somei-Yoshino cherry tree blooming date in the center of Osaka and its environs, based on a field survey conducted in 1989. Aono [6].

only 2.8 days in 11 small- to medium-sized cities (http://www.data.kishou.go.jp/climate/cpdinfo/climate_change/2005/2.1.3.html). Moreover, a thorough field survey in Osaka City showed that the blooming date of the Somei-Yoshino cherry tree tended to be earlier towards the center of the urban area (**Fig. 4**).

The results of these surveys demonstrate the heat island effect in large cities, particularly in the city center. The rising temperatures in cities are caused by the accumulation of solar heat in concrete buildings and asphalt roads; heat expelled by vehicles, air conditioners and various industrial activities; and the reduction in water retention, evaporation and transpiration of the land due to the decline in vegetation.

2.3. Bird Breeding Season

In England, 20 species out of 65 showed egg-laying dates advancing an average of 9 days over the 25-year period from 1971 to 1995 [7]. In Germany, the egg-laying date of pied flycatchers (*Ficedula hypoleuca*) became 4 days earlier in the 26 years between 1970 and 1975 [8]. In North America, the Mexican jay's (*Aphelocoma ultramarina*) egg-laying date was around 10 days earlier over the 27-year period between 1971 and 1998 [9]. The egg-laying date of red-cheeked mynas *(Sturnus philippensis)* in Japan advanced by approximately 15 days in the 27 years from 1978 (**Fig. 5**). The actual day (on average) was the 25th May in 1978, but in 2004 it was 10th May.

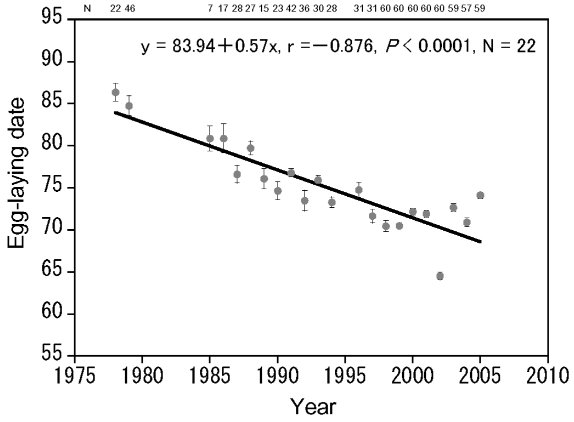


Fig. 5. Change in the first egg-laying date by the red-cheeked myna (1 = 1st March). The yearly value given is the mean ± the standard error, and the figures in the upside indicate the sample size. The results of a one-way ANOVA: $F = 48.12$, df = 21,836, $P < 0.0001$. Koike et al. [10].

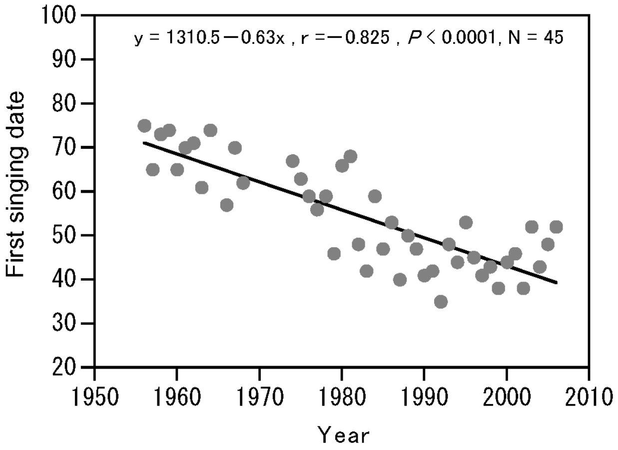


Fig. 6. Change in first day on which the Japanese bush warbler sings in Oita City (1 = 1st January). Based on data collected by the JMA.

Migration seasons and singing seasons, both connected to breeding seasons, are also tending to occur earlier. Analysis of JMA data pertaining to areas on which records had been kept for at least 30 years, showed that Japanese bush warblers (*Cettia diphone*) in Oita City, Kyushu, had started singing some 32 days earlier over the past 50 years (**Fig. 6**). Moreover, the arrival date of barn swallows (*Hirundo rustica*) in Nagoya City of Aichi Prefecture, has become roughly 10 days earlier over the past 52 years.

However, there are many exceptions; in seven regions among 91 regions studied, the first singing day of Japanese bush warblers had advanced, but this date was actually later in 20 regions (no clear trend was found in the remaining regions). The barn swallows arrived earlier in 19 regions, but arrived later in six regions (there was no clear trend in the remaining regions). The relationship to temperature is also rather unusual; in Yokohama, Hiroshima and some other cities, the first singing day of bush warblers became later, even though the temperature was rising.

The tendency of these events to occur earlier or later also seems related to fluctuations in the population and geographical conditions [11]; thus, further studies are needed to address factors other than temperature.

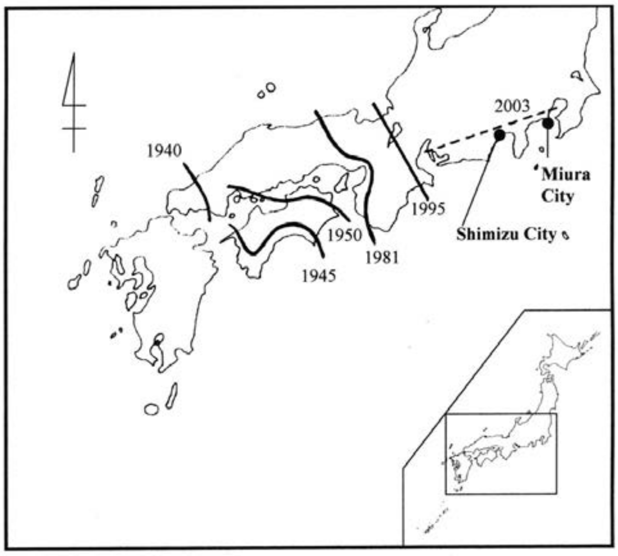


Fig. 7. Change in the distribution of the great mormon in Japan. Yoshio and Ishii [12].

3. Range Shifts

Warming is pushing the ranges of various plant and animal species northwards or to higher altitudes. Until around 1950, the great mormon (*Papilio memnon thunbergii*), a butterfly typical of the southern regions, was not found further north than the Yamaguchi and Ehime prefectures of Japan. However, its distribution has spread in a few decades. The butterfly established itself in the Kinki region during the early 1990s, and could be seen in southern Kanto region, notably in Tokyo and Chiba, by around 2000 (**Fig. 7**). Yoshio and Ishii [12] investigated the dormancy and cold resistance of this butterfly and concluded that the northward movement of its distribution was not linked to an intrinsic cause relating to adaptation to the seasons; instead, the cause was extrinsic – a rise in winter temperatures. In England, the ranges of butterfly species such as the comma (*Polygonia c-album*) are moving northward as warming progresses [13]. However, in the same country, the northern shift of butterfly species such as the silver-studded blue (*Plebeius* sp.) and the dryad (*Minois* sp.), which are more restricted in their mobility and habitat preference, is considerably hindered, probably by the effects of environmental destruction.

Until the 1980s, only a very few white-fronted geese (*Anser albifrons*) and whistling swans (*Cygnus columbianus*) over-wintered in Hokkaido, northern Japan, but the numbers have recently been increasing rapidly. The northern limit of over-wintering for one species of raptors, the grey-faced buzzard eagle (*Butastur indicus*), moved north from Amami-Oshima Island to the southern part of Kyushu at the beginning of the first decade of the 21st century. Mammals – deer and monkeys – are extending their habitats to higher elevations as the warming reduces winter snow accumulation [14]. In Okunikko, Tochigi Prefecture, and the Oze Marshland, Gunma Prefecture, the number of deer is soaring, resulting in conspicuous grazing damage to the forest trees and marsh plants.

A definite effect on alpine plants and animals has not yet been clearly established, but it is highly probable that species whose habitat is limited to the high mountains, such as the rock ptarmigan (*Lagopus mutus*) and alpine plants, will become extinct due to the contracting of those habitats if warming continues [15]. Animals and plants that inhabit the extremities may well share the same fate. The habitats of polar bears are physically diminishing as the ice recedes.

Warming will cause the sea level to rise, which, in turn, will result in the dwindling of other habitats. Costal tidal flats and the coral islands of the oceans will contract. In regions that have been urbanized, the majority of the coast has been protected with concrete, preventing the tidal flats from retreating inland. Sometimes an entire coral island protrudes only slightly from the sea. Such tidal flats and coral islands may all but disappear. The contraction and disappearance of tidal flats will cause great numbers of bottom-dwelling animals and migratory birds, such as shorebirds, to diminish. The disappearance of entire islands will also wipe out native species.

4. Distortion of Biological Interactions

Plants and animals that inhabit the same area respond to temperature changes in different ways. Generally, plants are slower to respond than animals. Analysis of the phenology of 203 plant and animal species of the Northern Hemisphere showed that the amphibian breeding season had advanced at least twice as much as the breeding seasons of plants, birds or butterflies [16]. Moreover, the dates when butterflies appeared and migratory birds returned had advanced three times as much as the blooming seasons of herbs.

The breeding season of the red-cheeked myna and the blooming season of the Somei-Yoshino cherry in Niigata City, described previously, have both advanced during the past 27 years, but the breeding season of the myna has advanced twice as much [10]. As a result, the fruit of the cherry on which the myna had relied to feed its chicks until around the 1970s, can now be provided only in small quantities, since the cherries are not sufficiently in fruit while the chicks are in the nest. The fruit of the Japanese honeysuckle (*Lonicera sachalinensis*) provides an even clearer example. This fruit was used to make up a large portion of the chicks' diet; however, recently, none can be found in their diet, because the honeysuckle is not yet in fruit while there are chicks. However, detailed data on the changes in blooming and fruiting of the honeysuckle have not been retained.

Information on the occurrence of an insect example, the small white (*Pieris rapae crucivora*), was collected in Niigata City. During the past 27 years, no tendency for the first appearance of this species of butterfly to occur earlier has been found [10]. No information is available on the proportion of insect species included in the diets of myna chicks, but it is expected to have changed a great deal.

The change in diet suggests that there will be an effect on breeding success in the raising of chicks, but currently no decline in breeding success in Niigata City has been found. However, in different areas of Europe, discrepancies have occurred between the breeding season of the pied flycatcher and the timing of the occurrence of lepidopteran insects, and the bird population declines more remarkably in areas with greater discrepancy [17]. Probably the birds that breed when the insects are not available have lower breeding success, which results in the population decline.

Different responses to temperature changes by species or groups are not only limited to the predator and prey relationship. They will also influence plant pollination by insects and birds, the dispersion of plant seeds by birds and mammals, and parasitism between plants and insects or different insect species. Shifts and distortions in such biological interactions will become more prominent if warming continues still further in the future.

Meanwhile, different responses to temperature changes by different species of animals and plants are also becoming apparent in their shifts in range or habitat. The situation has occurred where one species is sensitive to warming, and moves north, while others are not so sensitive. As a result, the species composition of an area may change, giving rise to the possibility of shifts and distortions in biological interactions related to predation, pollination, seed dispersal and parasitism. If these shifts and distortions become more marked, they will lead to the decline or extinction of a number of affected species.

Moreover, causes other than warming exacerbate the situation regarding shifts in range or habitat. For example, nowadays, many forms of environmental destruction are occurring – the fragmentation of forests, grasslands and tidal flats. Under these circumstances, if mobility or habitat preferences alter, some species may be able to move north more easily than others, even if the responses to temperature change are the same, as shown in British butterflies mentioned earlier. These circumstances will encourage changes in species composition of areas, and consequently promote distortions in biological interactions.

5. The Effect on Human Life

Changes in phenology and distributions, and the accompanying alteration of biological interactions, will have a major impact on human diet, housing and health. As the suitability of regions for agriculture or fishing changes, restructuring of their industries will be inevitable, affecting human diet. Currently, the notable rice-producing areas are in central and northern Honshu, but they may eventually shift to Hokkaido. According to estimates of fish distribution, the resource of fishing industries, the actual fishing seasons and areas close to the coast of Japan in which Pacific saury (*Cololabis saira*) and bastard halibut (*Paralichthys olivaceus*) can be fished, will be considerably restricted in 50 or 100 years' time (**Fig. 8**).

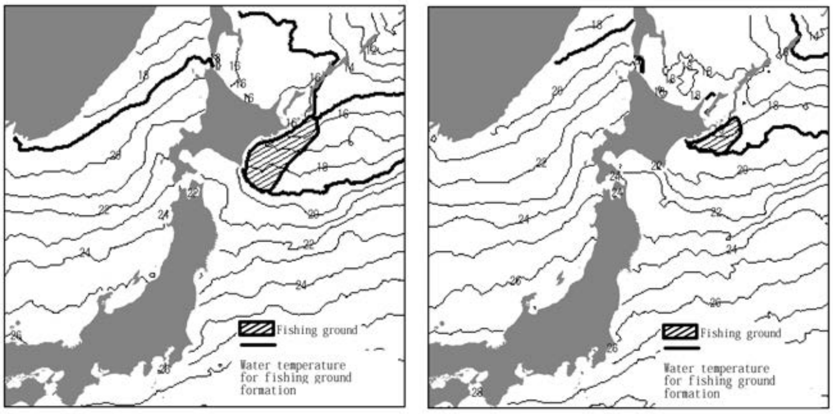
As an example of how housing will be affected, the northerly movement of the southern-dwelling Formosan subterranean termite (*Coptotermes formosanus*) may result in damage to wooden buildings in areas that previously did not suffer. Health may be affected by the appearance in Japan of species that transmit infectious diseases, particularly tropical and subtropical diseases, due to their northward movements. The malaria mosquito, which carries the disease, is one example. Recently, two infectious diseases, West Nile fever and avian influenza, both of major international interest, may be presumed to have behaved as follows.

In February 2007, outbreaks of avian influenza occurred, such as the one in Miyazaki in Kyushu, with a large number of chickens becoming infected. The infection route is not clearly understood, but it may be possible that ducks, such as the mallard, carried the highly pathogenic virus from mainland China or somewhere. In Miyazaki, possibly due to warming, weeds and wheat grow well in and around the fields even during winter; poultry farms are often adjacent to wheat fields. Green grass is a favorite food of another duck species, the Eurasian wigeon (*Anas penelope*), which frequently visits the wheat fields, where it feeds and excretes, after coming into contact with mallards at the waterside. Excreted matter may possibly be carried into the poultry farms by sparrows or crows living in the vicinity, which come into contact with it, thus carrying the virus to chickens. If warming continues, the area in which the grass grows will expand, increasing interaction between ducks and chickens.

West Nile fever is currently rampant in North America. The virus is mosquito-borne and is thought to be spread by crows and migratory birds. As this disease has already reached far-eastern Russia, it would not be surprising if migrating birds brought it to Japan. However, mosquitoes are currently less active at the time when the birds migrate down to Japan, making the infection of people unlikely even if the migrating birds carry the virus. That said, if warming continues, the season when mosquitoes occur and the time migrating birds come may coincide. Thus, the possibility of West Nile fever outbreaks in Japan may arise.

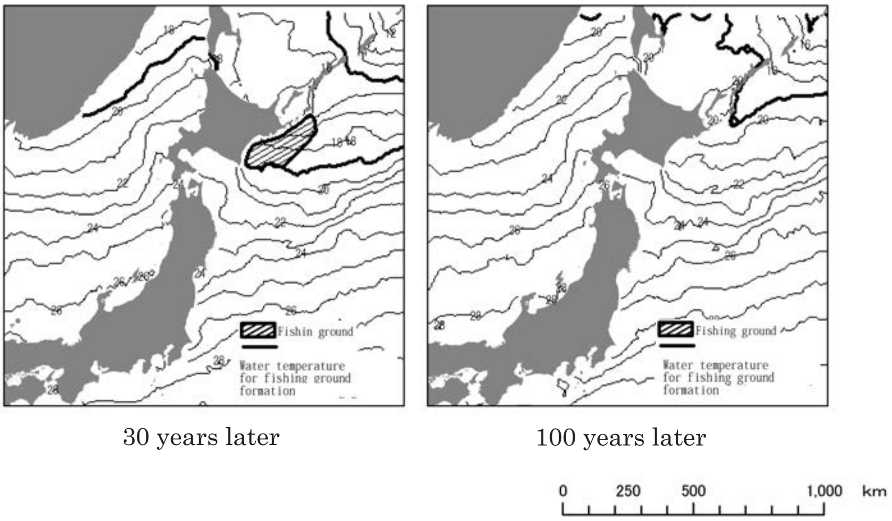
6. Occurrence of Regime Shifts

The occurrence of regime shifts presents an even great danger to ecosystem and human lifestyles. Regime shifts mean the sudden drastic reorganization of ecosystems from one relatively stable state to another due to environmental changes [19, 20]. For example, rising water temperatures due to warming may make lakes, marshes and tidal flats ever richer in nutrients, until at some point, the entire interaction structure of the ecosystem is suddenly transformed. Once such a transformation occurs, the ecosystem cannot be returned to its original state.



Present

50 years later



30 years later

100 years later

Fig. 8. Predicted changes, due to rising sea temperatures (˚C), of the Pacific saury fishing grounds in September. The current, short-term (30 years later), medium-term (50 years later) and long-term (100 years later) fishing grounds (▨) and temperatures suitable for fishing grounds to be formed (—) are shown, assuming that the sea temperature rises by 2.9˚C over the next 100 years. The lower limit and upper limit of sea temperatures for the formation of fishing grounds shown are 15˚C and 19˚C, respectively. Modified from Kuwahara et al. [18].

This dreadful effect is already becoming a reality in Lake Biwa, near Kyoto [21]. Water, which reaches its maximum density at 4˚C, creates seasonal cycles (vertical mixing) in the upper and lower layers of deep lakes in temperate areas, which are reluctant to mix. These cycles bring nutritive salts, which collect near the bottom of the lake (the bottom layer) to the surface layer, where light penetrates more easily. Conversely, these cycles also bring cold water with a concentration of oxygen from the surface layer to the lake bottom. Until now, Lake Biwa's ecosystem has been kept healthy by the complete cycle of the layers during winter. However, there have already been reports that the concentration of oxygen in the bottom layer is decreasing, indicating that the vertical mixing is dwindling. If deoxygenation of the bottom layer continues, the benthos would be all but wiped out. Meanwhile, the dissolved oxygen deficiency in the bottom layer would promote the elution of phosphorus from the bottom mud. If an abnormally cold winter occurred, while this broad warming trend continued, the phosphor, which had become highly concentrated in the bottom layer, would all at once be brought to the surface. The resulting regime shift caused by eutrophication could encompass the entire lake.

7. "Experiments" on a Global Scale

Finally, the rising temperature, and the accompanying warming of the sea, will give rise to or increase the scale of many catastrophic extreme environmental events, such as heat waves, tornados, typhoons and hurricanes. In recent years, disasters that have been attributed to the effects of warming have already occurred around the world, including Japan. These catastrophes strongly affect the whole ecosystem, and many local species are on their way to extinction.

In these ways, global warming is having a range of effects on biodiversity and greatly altering the structure and functioning of ecosystems. Global warming today is brought about by human activity, but it will come back to haunt its creators, greatly affecting human lifestyles. From a cynical point of view, it could be said that we are currently making an experiment on a global scale to investigate when and how our warming of the entire globe will affect the natural world and our own lifestyles.

Thus far, only a fraction of the impact has become clear. If warming continues, the structure and functioning of ecosystems around the world, including Japan, will be greatly altered, and frequent regime shifts have been forecast, from which it would be difficult to return. Very little is yet known about the effect that these will have on plants and animals, or on the lives of humans.

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Academic Societies & Scientific Organizations:

- The Society for Conservation Biology