



## Review

# Ecological impacts of climate change in Japan: The importance of integrating local and international publications

Yuko Ogawa-Onishi<sup>a,b,\*</sup>, Pam M. Berry<sup>a</sup>

<sup>a</sup> Environmental Change Institute, School of Geography and the Environment, The University of Oxford, South Parks Road, Oxford OX1 3QY, UK

<sup>b</sup> National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba-shi, Ibaraki 305-8506, Japan

## ARTICLE INFO

## Article history:

Received 21 February 2012

Received in revised form 11 June 2012

Accepted 23 June 2012

Available online 20 December 2012

## Keywords:

Biodiversity

Climate change

Phenology

Species distribution

Japan

Review

## ABSTRACT

Scientific papers published locally in many Asian countries are often inaccessible to researchers elsewhere due to language barriers or omission from international journal databases. This paper provides the first comprehensive review of the observed and projected impacts of climate change on plant and animal species in Japan, drawing extensively from both local and international publications. There were a number of long-term data sets on phenological and distributional changes covering more than five decades. Observed phenology records showed two characteristic trends in Japan; greater shifts of plant phenology in autumn relative to spring and delays in insect appearance dates in spring. Distribution records of insect and marine species indicated poleward range expansions of 18–140 km per decade. Future projections on phenology suggested varied responses between species and possible disruptions in ecosystem functions, while those on distributions indicated potential significant range reductions and changes in species assemblages and diversity. Some of these responses are not in line with the global trends while others show changes of greater magnitude than for other regions, which highlights the importance of region-specific climate change impact assessments. The research recommends that, to improve the evaluation of climate change impacts in countries where the common languages are not English, search efforts should be expanded to include locally available data and publications. This can be facilitated by using country-specific journal databases and increasing collaboration with local researchers.

© 2012 Elsevier Ltd. All rights reserved.

## Contents

1. Introduction	362
2. Methods	362
3. Climate change in Japan	362
3.1. Observed climate change and the effects of urbanisation	362
3.2. Projected climate change	362
4. Observed impacts of climate change on plants and animals	363
4.1. Changes in phenology	363
4.2. Changes in species distributions	364
4.3. Ecological consequences of phenological and distributional changes	365
5. Projected impacts of climate change on phenology and species distributions	366
6. Research needs	368
7. Implications for conservation research	368
8. Conclusions	369
Acknowledgements	369
Appendix A. Supplementary material	369
References	369

\* Corresponding author at: Center for Social and Environmental Systems Research, National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba-shi, Ibaraki 305-8506, Japan. Tel.: +81 29 850 2982.

E-mail address: [yuko.onishi@lina.ox.ac.uk](mailto:yuko.onishi@lina.ox.ac.uk) (Y. Ogawa-Onishi).

## 1. Introduction

Climate change has been identified as one of the major drivers leading to biodiversity loss (CBD, 2010). There is now ample evidence of climate induced changes in phenology, species distributions, and resulting changes in biotic interactions, species compositions, and ecosystem functioning (reviews available in: Miller-Rushing et al., 2010; Parmesan and Yohe, 2003; Parmesan, 2006; Walther, 2010). Many ecological projections are also available, which suggest that climate change will continue to affect many species in the future and may lead to significant disruptions in ecosystem functions or species' extinctions (Bellard et al., 2012; CBD, 2010).

However, existing evidence and projections exhibit regional concentrations. In the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC, 2007), 28,671 data series of significant observed changes in biological systems were examined, of which 28,115 were in Europe and 455 were in North America, whereas only eight were in Asia. In addition, in reviewing 866 peer-reviewed papers on biological impacts of climate change, Parmesan (2006) pointed out that the largest research gaps were geographic rather than taxonomic, with most studies coming from North America, northern Europe and Russia, and a large deficit in Asia. The regional imbalance in available research may hamper an effective resource allocation to the regions where conservation is most needed.

Situated in the north-east of Asia, Japan is a biodiversity hotspot, which supports exceptionally rich biodiversity with a large proportion of threatened species (Mittermeier et al., 2004). Japan has over 90,000 recognised species in an area of 380,000 km<sup>2</sup> (Ministry of the Environment, 2010). Of these, more than 30% of amphibians, reptiles and freshwater and marine species, and more than 20% of mammals and plants are threatened with extinction (i.e. categorised as either "critically endangered", "endangered", or "vulnerable"), according to the Japanese Red List (Ministry of the Environment, 2011) that follows the IUCN Red List categories (IUCN, 2001). Ecological changes are increasingly reported and climate change is recognised as a major threat to the biodiversity (Ministry of the Environment, 2008, 2011). However, many Japanese studies are not easily accessible to the international research community as they are often written in Japanese and not included in international journal search engines, such as ISI Web of Knowledge. For example, of 3047 scientific journals published in 2008, only 374 (14.0%) were published in English whereas the majority (86.0%) were in Japanese (Tokizane, 2011). The large number of publications in Japanese accounts for constant knowledge gaps between the researchers in Japan and elsewhere.

The aim of this paper is to summarise the observed and projected climate change impacts on biodiversity in Japan, by synthesising recent studies published locally as well as internationally. Firstly, we briefly summarise observed and projected climate change as background information to the ecological changes. We then summarise the climate impacts on species, focusing on the changes in phenology, species distributions, and resulting ecological changes. Finally, we identify research needs in Japan and discuss the implications for conservation research in general.

## 2. Methods

We searched scientific papers on observed and projected changes of plant and animal species in response to climate change. For articles in international journals, we first searched in ISI Web of Knowledge using a combination of the search terms: species, biodiversity, ecology, ecosystem, distribution, phenology, climate change, global warming and Japan, and then checked the reference

lists of relevant papers. Japanese publications were primarily obtained by searching the Japanese academic journal database, CiNii (<http://ci.nii.ac.jp/en>), using the same search terms in Japanese as well as in English. In addition, some publications were identified by checking the reference lists of academic papers or governmental reports, or consulting experts through personal contacts. We limited our search to scientific papers published in peer-reviewed journals or academic books. We focused on recent publications not included in IPCC AR4 (IPCC, 2007) and selected papers published since 2005 in order to try and fill the identified knowledge gap (Parmesan, 2006), although relevant previous research (e.g. records of historical distribution limits) was also examined as necessary.

## 3. Climate change in Japan

### 3.1. Observed climate change and the effects of urbanisation

The Japan Meteorological Agency (JMA) reported that annual average air temperatures in Japan rose by 1.15 °C per century between 1898 and 2010 (JMA, 2011a). No statistically significant long-term trend was observed for annual precipitation, although the inter-annual variability has increased since the 1970s (JMA, 2011a). Greater warming in Japan compared with the global average warming of 0.74 °C ± 0.18 °C per century (1906–2005) (Trenberth et al., 2007), is partly due to urban heat island effects. Although JMA excluded the weather stations in metropolitan areas to calculate the long-term trend, the warming recorded in the selected stations was still higher than that occurring in rural areas, as the JMA stations are typically located near the city centres and include relatively large cities (Nishimori et al., 2009). According to an alternative nation-wide network of 546 weather stations from 1979 to 2008, the temperatures in rural areas with population density under 100 people/km<sup>2</sup> increased by 0.3 °C per decade, while those in the cities with 100–300 people/km<sup>2</sup> and over 3000 people/km<sup>2</sup> showed further increases of 0.03–0.05 °C and 0.12 °C per decade respectively (Fujibe, 2011). Therefore, the urban heat island affects relatively small cities. Accordingly, observed biological changes in urban areas, e.g. phenological changes at the JMA stations, are caused by the combined effects of climate change and urbanisation. On the other hand, residential and industrial areas cover only 5% of the total land area in Japan whereas wilderness areas, forests, and agricultural areas cover 80% (MLIT, 2011). Thus, urban warming has limited effects on the biological changes occurring at the national scale, e.g. distributional shifts.

### 3.2. Projected climate change

Climate projections for Japan show that temperatures should continue to rise during the 21st century, although the magnitude of warming differs among climate models and scenarios (Meehl et al., 2007). Most climate change impact studies in Japan are based on climate models developed by Japanese authorities. Many forecasted impacts are based on the Regional Climate Model with a resolution of 20 × 20 km (RCM20) (JMA, 2005). RCM20 follows the SRES A2 storyline, which describes a heterogeneous world with increasing global population, regionally oriented economic development, and slow per capita economic growth and technological change (Nakićenović and Swart, 2000). RCM20 projects that the mean annual temperature in Japan could increase by 2–3 °C by 2100 (2081–2100) relative to the baseline (1981–2000) and that precipitation could increase in summer (June–September) and decrease in other seasons (JMA, 2005; Kurihara et al., 2005). Some studies are based on the high resolution model of Model for Interdisciplinary Research on Climate (MIROC) 3.2 with a resolution of

**Table 1**  
Observed impacts of climate change on phenology.

Species	Location	Period	Indicator	Observed changes	CF <sup>a</sup>	References
Plants and animals	Countrywide	1953–2008	120 Phenological events			JMA (2011b)
<b>Plants</b>						
<i>Prunus mume</i>	Countrywide	1953–2005	Flowering	–7 Days bet. 1961–1989 and 1990–2005	TPP	Doi (2007)
<i>Prunus jamasakura</i>	Kyoto	801–2005	Full bloom	–7 Days bet. 801–2005 and 1971–2000	TPP	Aono and Kazui (2008)
4 Plant species	Countrywide	1953–2005	Leaf budburst	–2.7 Days/decade	TPP	Aono and Saito (2010)
<i>Morus bombycis</i>	Countrywide	1953–2005	Growing season length	+3.6 Days/decade	TPP	Doi and Katano (2008)
12 Plant and animal species	Countrywide	1953–2005	Spring phenology	Vary between species and locations	TPP	Doi (2011)
11 Plant species	Countrywide	1953–2005	Flowering/leaf budburst	Depend on genetic diversity	TPP	Primack et al. (2009b)
<i>Malus pumila</i> var. <i>domestica</i>	Countrywide	1977–2004	Budding/flowering	–2.6 Days/decade	TPP	Doi et al. (2010)
17 Cherry species	Tokyo	1981–2005	Flowering	–2.2 Days/decade	TPP	Fujisawa and Kobayashi (2010)
<b>Birds</b>						
<i>Cettia diphone riukiensis</i>	Ryukyu islands	1953–2005	First singing	+2.6 Days/decade	TPP, HLD	Miller-Rushing et al. (2007)
<i>Sturnia philippensis</i>	Niigata	1978–2005	Egg-laying	–5.5 Days/decade	TPP	Gordo and Doi (2012)
<b>Insects</b>						
<i>Pieris rapae</i>	Countrywide	1958–2005	Butterfly appearance	+0.5 to +6.0 Days/decade	TPP	Koike et al. (2006)
<i>Luciola cruciata</i> M.	Countrywide	1956–2005	Firefly appearance	–6.3 to +3.0 Days/decade	TPP	Kamitani (2010a)
<i>Sympetrum frequens</i>	Countrywide	1956–2005	Dragonfly appearance	–1.8 to +3.8 Days/decade	TPP	Kamitani (2010a)
<i>Orthetrum albistylum speciosum</i>	Countrywide	1953–2005	Dragonfly appearance	+4.7 Days/decade (average)	TPP	Doi (2008)
<i>Cryptotympana facialis</i>	Countrywide	1956–2005	Cicada first song	+2.5 to +4.3 Days/decade	TPP	Kamitani (2010a)
<i>Graptopsaltria nigrofuscata</i>	Countrywide	1956–2005	Cicada first song	–3.8–0.3 Days/decade	TPP	Kamitani (2010a)
<i>Platypleura kaempferi</i>	Countrywide	1956–2005	Cicada first song	+0.4 to +4.8 Days/decade	TPP	Kamitani (2010a)
14 Insect species	Countrywide	1961–2004	First appearance/song	–1.43 to +4.19 Days/decade	TPP	Ellwood et al. (2012)

TPP: temperatures of the period preceding the phenological event; HLD: habitat loss and degradation.

<sup>a</sup> CF: main controlling factors for the change.

110 × 110 km (K-1 Model Developers, 2004). This model follows the SRES A1B storyline and describes a future world of rapid economic growth, global population that peaks in mid-century and declines thereafter, and high technological advancement based on balanced energy sources (Nakićenović and Swart, 2000). The models project that, by 2100, mean temperature would increase by 4.8 °C in Japan (4.4 °C globally) and mean precipitation would increase by 10% compared with reference levels of 1971–2000 (Kimoto et al., 2005; Project Team for Comprehensive Projection of Climate Change Impacts, 2008). More recently, newer models are being developed following the representative concentration pathway (RCP) (Masui et al., 2011), although, to date, we found no study using these climate models for impact assessment studies in Japan.

## 4. Observed impacts of climate change on plants and animals

### 4.1. Changes in phenology

Observed impacts of climate change are summarised in Tables 1–3. The majority of phenological studies were derived from the phenological observations of JMA (Table 1). JMA has recorded over 120 phenological events since 1953 at their 102 observatories nation-wide, located along the latitudinal range of 24.20°N–45.24°N and covering climatic ranges from sub-tropical to boreal (JMA, 2011b). Timing of phenological events (e.g. flowering, leaf budding, etc.) in Japan is strongly correlated with air temperatures of the 1–2 months prior to the events and rising temperatures during this period are considered as the primary cause of observed phenological shifts (Doi and Katano, 2008; JMA, 2005). In other regions, it has been reported that other environmental factors, such as precipitation, CO<sub>2</sub> and nitrogen deposition, could

also affect phenology, although the effects are small relative to the temperature effects (Badeck et al., 2004; Cleland et al., 2006; Throop and Lerdau, 2004).

According to the recent JMA data set (JMA, 2011b), the spring flowering of *Prunus mume* (Japanese apricot), *Prunus x yedoensis* (Yoshino cherry), *Taraxacum* spp. (dandelion), *Wisteria floribunda* (Japanese wisteria) advanced nationally on average by 0.8, 0.7, 1.1, 0.7 days/decade respectively between 1953 and 2008 (Table S1 and Fig. S1 in Electronic Supplementary material). Autumn phenological events were delayed, e.g. leaf colouring of *Acer palmatum* (Japanese maple) and *Ginkgo biloba* (maidenhair) were delayed by 3.3 days and 2.0 days/decade respectively. In addition, the growing season length (GSL) of *Morus bombycis* (mulberry) was extended by 3.6 days/decade, with an advance of budburst by 1.3 days/decade and a delay of leaf fall by 2.4 days/decade over the period 1953–2005 (Doi, 2011), indicating a similar trend to *G. biloba*, the GSL of which was extended by 2.4 days/decade with the advancement of budburst by 0.8 days and the delay of leaf fall by 1.6 days (Matsumoto et al., 2003). Thus, both the recent records and the studies on GSL show that autumn delays were more significant than spring advancements and this trend was largely consistent across different locations, although the temperature and phenological changes varied between the observation sites (Ibanez et al., 2010). In contrast, a European wide study showed that the spring events became earlier by 2.5 days/decade on average and autumn events became later by 1.3 days/decade on average between 1971 and 2000 for 542 plant and 19 animal species (Menzel et al., 2006). Thus, spring advancements were more prominent than autumn changes in Europe while the opposite trend was found in Japan. Suggested possible reasons for this difference are the inclusion of arid areas in European data where precipitation strongly affects phenological timings (Ibanez et al., 2010), or species-specific leaf responses and leaf life spans (Doi, 2011).

**Table 2**  
Observed impacts of climate change on species distributions.

Species	Changes	Year	Location	Distance	CF <sup>a</sup>	References
<b>Insects</b>						
<i>Papilio memnon</i>	Northeastward range expansion	1940s–2000s	Honshu	130 km/decade <sup>b</sup>	TW	Kitahara (2008) Yoshio and Ishii (2010)
<i>Narathura bazalus</i>	Northeastward range expansion	1970s–2000s	Honshu		TW	Inoue (2005) Shiota (2006)
<i>Argyreus hyperbius</i>	Northeastward range expansion	1970s–2000s	Honshu		TW, pansy transport	Shiota (2006) Tsubuki (2008)
<i>Melanitis phedima oitensis</i>	Northeastward range expansion	1950s–2000s	Honshu	48 km/decade <sup>b</sup>	TW	Takahashi (1982) Shiota (2006)
<i>Junonia almanac almanac</i>	Northward range expansion	1950s–2000s	Kyushu	58 km/decade <sup>b</sup>	TA	Kamitani (2010b)
<i>Nezara viridula</i>	Northward range expansion	1957–2005	Kyushu	West: 18 km/decade; East: 30 km/decade	TW	Yukawa et al. (2007) Kiritani (2011)
		1972–2008	Shikoku and Honshu		TW	Yukawa et al. (2009)
		1962–2007	Kinki	19 km/decade	TW, NCD	Musolin (2007) Tougou et al. (2009)
<b>Birds</b>						
<i>Anser albifrons</i>	Northward shift of wintering range	1987/88–2003/04	Tohoku	180 km	TW	Shimada et al. (2005)
<b>Mammals</b>						
<i>Cerbus nippon centralis</i>	Northward range expansion	1978–2003	Tohoku		Snow, grassland area	Yamauchi et al. (2007)
<b>Marine species</b>						
Reef corals (9 species)	Northward range expansion	1930s–1990s 1955–1995	Japan Sea/ Pacific Ocean	20–140 km/decade	SST, warm currents	Nojima and Okamoto (2008) Yamano et al. (2011)
<i>Seriola quinqueradiata</i>	Northward extension of distribution and overwintering areas	1894–2008	Japan Sea		SST	Tian et al. (2012)

TW: winter temperature; TA: annual temperature; NCD: number of cold days (mean temperature below 5 °C); SST: sea surface temperature.

<sup>a</sup> CF: main controlling factors for the change.

<sup>b</sup> Approximate distance estimated by the authors based on the locations provided in the reference.

Advancements of spring phenology were also evident in other phenological records (e.g. Fujisawa and Kobayashi, 2010; Miller-Rushing et al., 2007). The most notable is the time series records from 801 to 2008 for *Prunus jamasakura* (Japanese mountain cherry), retrieved from the ancient record of traditional cherry blossom festivals and representing the longest phenological records in the world (Aono and Kazui, 2008; Aono and Saito, 2010; Fig. S2 in Electronic Supplementary material). The records show that the full-flowering dates of *P. jamasakura* became progressively earlier from the mid 19th century, and that recently (1971–2000) the average flowering date has advanced by 7 days relative to the average of the whole period (Aono and Kazui, 2008). In addition, Aono and Saito (2010) retrieved the full flowering dates of *W. floribunda* and *P. mume* since the tenth century and *Kerria japonica* (Japanese kerria) and *Paeonia suffruticosa* (tree peony) since the 12th century and found that the full flowering dates of *W. floribunda* and *P. mume* were significantly correlated with those of *P. jamasakura*.

In contrast to plant phenology that shows a general advancing trend in spring, changes in animal phenology are variable between species and locations (Kamitani, 2010a; Primack et al., 2009a). However, by examining six plant and six animal species over the period 1953–2005 at up to 160 observation sites across Japan and Korea, Primack et al. (2009a) showed spring phenology of all plants advanced while that of all animals was delayed at over half the sites. Moreover, the first singing date of *Cettia diphone riukiensis* (Ryukyu bush warbler) was delayed by 2.6 days/decade between 1953 and 2005, which was caused by male population declines due to human population increases (Gordo and Doi, 2012). Similarly in South Korea, monitoring of *Hirundo rustica* (barn swallows) between 1971 and 2008 showed that they are

arriving on average 10 days later, with population declines also suggested as a possible reason (Lee et al., 2011). On the other hand, delays in the first appearance of *Orthetrum albistylum speciosum* (common skimmer) (4.8 days/decade) was not influenced by human population density, but by shifts in dragonfly life cycles (Doi, 2008). Further, delays in the first appearances of *Pieris rapae* (small white) were caused by winter warming that delayed timing to meet the chilling requirements for breaking dormancy (Kamitani, 2010a). Thus, although the causes of phenology delays vary among species, these studies clearly indicate that delayed spring events are widespread in Japan for birds and insects, which are contrary to the trends observed elsewhere (e.g. Bertin, 2008; Parmesan, 2007).

#### 4.2. Changes in species distributions

Observation records spanning over six decades are available for *Papilio memnon* (great mormon), a butterfly species ranging from the Asian tropics to the warm-temperate zone in Japan (Table 2). Records from repeated field surveys indicated progressive geographical shifts of the northern range limit, from Yamaguchi in the 1940s to Osaka in the 1980s, and then to Tokyo in the 2000s, approximately 760 km over 60 years, or 130 km/decade (Kitahara, 2008; Yoshio and Ishii, 2004, 2010) (Fig. 1). Statistical analyses showed that the distribution of *P. memnon* was closely related to the minimum temperature of the coldest month, which determines the winter survival of pupae (Kitahara et al., 2001). On the other hand, the populations in different regions including the southern and northern range limits exhibited no difference in the photoperiodic response, diapause intensity or cold tolerance, indicating

**Table 3**  
Observed impacts of climate change on species abundance, assemblages, interactions, and ecosystems.

Species/ecosystems	Location	Period	Observed changes	CF <sup>a</sup>	References
<b>Abundance change</b>					
<i>Pinus parviflora</i> , <i>P. pumila</i>	Hokkaido	1900–2000	Rapid population increase since 1970	TW, fog	Masuzawa et al. (2005)
<i>Cygnus columbianus</i>	Japan	1975–2008	Increases in abundance of overwintering birds	Snow, TMR, TBF	Higuchi et al. (2009)
<b>Ecosystem change</b>					
Moorland	Gunma, Niigata	1971–2004	Area reduction by 10%	TW, snow	Yasuda et al. (2007)
<b>Species assemblage/ composition</b>					
83 Fish species	Japan Sea	1970–2006	Changes in assemblages (increase of southern species)	SST	Masuda (2008)
<i>Oncorhynchus keta</i>	Hokkaido, Okhotsk Sea	1943–2005	Changes in age compositions (increases of juvenile salmon and decreases of mature salmon)	SST	Seo et al. (2011)
<b>Phenological mismatch</b>					
4 <i>Prunus</i> species and <i>P. rapae</i>	Nagano	1953–2002	Earlier flowering and later butterfly appearance	TPP	Doi et al. (2008)
<i>P. x yedoensis</i> , <i>S. philippensis</i> and <i>P. rapae</i>	Niigata	1978–2005	Greater advancement of flowering compared with butterfly appearance	TPP	Koike et al. (2006)
<b>Indirect impacts</b>					
<i>Ultrabasicosaxicolous</i> flora (alpine grasslands)	Hokkaido	1954–2003	Decrease of alpine grasslands by 50–60% due to increased competition with conifers	Upward shifts of <i>P. parviflora</i> and <i>P. pumila</i>	Masuzawa et al. (2005) Watanabe (2005)
<i>Nezara antennata</i>	Kyushu, Shikoku, W. Honshu, Kinki	1957–2008	Retreat from the southern range limit, population reduction due to increased competition and interspecific mating with <i>N. viridula</i>	Northward range expansion of <i>N. viridula</i>	Yukawa et al. (2007) Tougou et al. (2009) Yukawa et al. (2009) Kiritani (2011)

TW: winter temperatures; SST: sea surface temperatures; TPP: temperatures of the period preceding the phenological event.  
TMR: temperatures in migration routes; TBF: temperatures in breeding fields.

<sup>a</sup> CF: main controlling factors for the change.

that evolutionary changes have not occurred (Yoshio and Ishii, 2004). Consequently, recent winter warming is considered as the primary cause of the northward range expansion of *P. memnon* (Yoshio and Ishii, 2010).

Range expansions also have been found for other butterfly species. For example, the range limit of *Junonia almanac almanac* (peacock pansy, butterfly) shifted progressively northward from Tanegashima (30.44°N, 130.00°E) in the 1950s, Miyazaki in the 1970s, Oita in the 1980s, to Fukuoka (33.19°N, 130.31°E) in the 2000s (Kamitani, 2010b), i.e. 290 km over 50 years. The distribution of *J. almanac almanac* is closely related to annual temperatures and thus its northward shifts are considered as the result of climate change (Kamitani, 2010a).

Apart from butterflies, detailed distribution data have been recorded for a major rice pest, *Nezara viridula* (southern green stink bug). Distribution records since 1957 show northward range expansion at the rate of 18 km and 30 km/decade in West and East Kyushu respectively (Kiritani, 2011; Yukawa et al., 2007, 2009) and 19 km/decade in Kinki (Tougou et al., 2009). As *N. viridula* feeds on more than 145 plant species, food and habitat availability are not the major limiting factors for its distributions (Musolin and Numata, 2003). On the other hand, winter survival of *N. viridula* is closely associated with January mean temperature (Yukawa and Kiritani, 2010). In addition, current and past distributions of *N. viridula* correspond well with the +5 °C January isotherm (Tougou et al., 2009; Yukawa et al., 2007). Thus, winter temperature is the principal factor determining the distributions of *N. viridula* and climate change is considered as the primary reason for its northward range expansions (Musolin, 2007; Tougou et al., 2009; Yukawa and Kiritani, 2010).

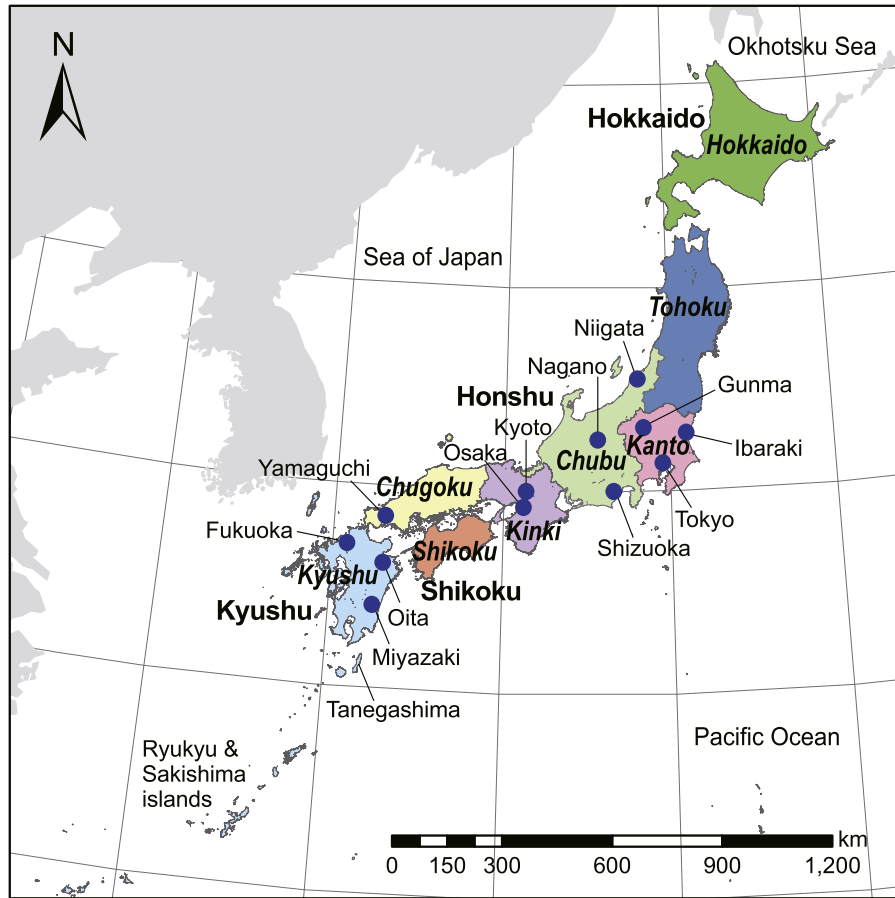
The range expansion rates of Japanese insects reviewed here were faster than those of the global average for terrestrial species (6.1 km/decade; Parmesan and Yohe, 2003). However, the

expansion rate of *N. viridula* is comparable with other Heteroptera species in Britain that shifted northward by 32–42 km/decade between 1970/1980 and 1990/2000 (Hickling et al., 2006). In addition, *P. memnon*'s rapid expansion of its range margin and large increase of its range size is comparable to the butterfly *Sympetrum striolatum* (common darter) in Britain, which expanded its range margin by 138 km/decade between 1960/1970 and 1985/1995 (Hickling et al., 2005). However, a caution is required when comparing with the shifts occurring in other regions, as the latitudinal width of Honshu island is limited in western Japan and the species shift mainly eastward rather than northward. For example, the latitudinal distance between Yamaguchi and Tokyo where *P. memnon* shifted is only about 1.5°.

For marine species, distribution data have been recorded over eight decades. Yamano et al. (2011) collected literature and specimens of nine species of corals at their northern range limits in the Sea of Japan and Pacific Ocean from the 1930s to 1990s, where the sea surface temperature (SST) in winter rose by 1.1–1.6 °C. Out of nine species examined, the range margins of four expanded northward at the maximum rate of 140 km/decade, whereas those of the other five remained stable. Along with the corals, range expansions were also observed for fish species, toxic microalgae, and *Acanthaster planci* (crown-of-thorns starfish) that feed on corals (Nojima and Okamoto, 2008; Yamano et al., 2011).

#### 4.3. Ecological consequences of phenological and distributional changes

Changes in phenology and species distributions may have consequences at the ecosystem level. For example, Koike et al. (2006) found that between 1978 and 2005 egg laying dates of *Sturnus philippensis* (red-cheeked starling) advanced by 15.3 days, while the flowering of cherry advanced by 8.5 days, shortening the gap



**Fig. 1.** Map of Japan with the names of locations referred to in the text and tables. Japan consists of four major islands (Hokkaido, Honshu, Shikoku, Kyushu) and eight regions (Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, Kyushu).

between the dates of flowering and breeding by 6.8 days. As a consequence, the cherries, which were the main food source of the chicks in the 1970s, were not sufficiently in fruit for the chicks by the 2000s. As insufficient food supply may lead to failure in breeding success, widening phenological mismatches have consequences for bird populations through the effects on food webs.

Phenological mismatches also affect mutualistic webs, such as plant pollinator interactions. For example, the flowering of *Prunus* trees became earlier between 1970 and 2002, whereas the appearance of their potential pollinator, *P. rapae*, was delayed (Doi et al., 2008). The flowering of *Prunus* trees and the appearance of this butterfly species were affected by temperatures during different times of the year which increased at different magnitudes. This resulted in a mismatched responsiveness to climate change between plant–insect trophic levels. Disordered phenological timings may lead to the disruption of key plant–animal interactions, such as pollination, herbivory and animal–habitat interactions (Ibanez et al., 2010).

On the other hand, changes in species distributions may affect species assemblages and community composition. In Hokkaido, *Pinus pumila* (Japanese stone pine) and *Pinus parviflora* var. *pentaphylla* (Japanese white pine) on Mt. Apoi have been shifting to higher elevations, which have led reductions of alpine grasslands by 50–60% between 1954 and 2003 (Masuzawa et al., 2005; Watanabe, 2005). Moreover, *Nezara antennata* Scott (oriental green stink bug) was replaced by *N. viridula* in its southern range limits in Kyushu and central Japan (Tougou et al., 2009; Yukawa et al., 2007). For marine species, changes in species assemblages have been found in the Sea of Japan since 1970 due to range expansions

of southern fish species (Masuda, 2008). Also, changes in the age composition of *Oncorhynchus keta* (chum salmon) has occurred since the 1940s, due to the SST increase in the northern seas of Japan (Seo et al., 2011). Further changes in species assemblage and community composition may disrupt ecosystem functions and services. Thus, it is important that these changes are closely monitored and included in the impact assessment.

## 5. Projected impacts of climate change on phenology and species distributions

Primack et al. (2009a) and Ibanez et al. (2010) forecasted phenological changes in Japan and South Korea by constructing a hierarchical model based on a Bayesian approach, in which different curves were fitted at each site and then the data from all the sites were combined to estimate the species' overall response to temperature (Table 4). For example, under a 3 °C increase in temperature, advancement of flowering of *K. japonica* varied from 6 to 21 days and the arrival of *Rana nigromaculata* (black-spotted pond frogs) ranged from an advancement of 12 to a delay of 5 days, depending on the geographical region (Primack et al., 2009a). On the other hand, Maruoka and Itoh (2009) constructed a model for flowering of *P. x yedoensis*, based on the DTS (the number of days transformed to standard temperature) method, which is an accumulation model using an exponential function of daily mean temperature (Aono and Moriya, 2003). The flowering dates were projected to become earlier in Tohoku, the Sea of Japan side of the Japanese archipelago, and high altitude areas, but later in

**Table 4**  
Projected impacts of climate change.

Species	Location	Timeframe	Scenario	Indicator <sup>a</sup>	Methods <sup>b</sup>	Potential impacts	References
<b>Plants</b>							
13 Plant species	Japan	Unspecified	Temperature range	Phenology	Hierarchical Bayesian	Spring: $-7.7 - 0.35$ days/ $^{\circ}$ C autumn: $3.56 - 5.36$ days/ $^{\circ}$ C	Ibanez et al. (2010)
12 Plant and animal species	Countrywide	Unspecified	Temperature range	Phenology	Hierarchical Bayesian	Spring: $-8.36 - 0.43$ days/ $^{\circ}$ C	Primack et al. (2009a)
<i>Prunus yedoensis</i>	Japan	2032–2050; 2082–2100	SRES A2	Phenology	DTS	Delay in Kyushu and Pacific ocean side; advance in Tohoku and Japan sea side	Maruoka and Itoh (2009)
29 Broadleaf species	Shizuoka	Unspecified	+1 to +4 $^{\circ}$ C	Phenology	Cumulative temperature	Spring: $-3.4$ days/ $^{\circ}$ C; autumn: $6.2$ days/ $^{\circ}$ C	Fujimoto (2008)
<i>F. crenata</i>	Japan	2001–2090	110 Hypothetical scenarios bet.SRES A2 and B1	CSA	SDM (CTA)	Precip. decline and temp. increase; negative precip. increase and temp. $\geq +2$ $^{\circ}$ C; negative precip. increase and temp. $< +2$ $^{\circ}$ C: positive	Matsui et al. (2009b)
<i>F. crenata</i>	Japan	2031–2050; 2081–2100	SRES A2 and A1B	CSA	SDM (CTA)	2031–2050: $-53\%$ (A2) and $-68\%$ (A1B); 2081–2100: $-79\%$ (A2) and $-96\%$ (A1B)	Matsui et al. (2009a)
<i>Pinus pumila</i>	Japan	2081–2100	SRES A2 and A1B	CSA	SDM (CTA)	$-75\%$ (A2) and $-85.3\%$ (A1B)	Horikawa et al. (2009)
2 Dwarf bamboo species	Honshu	2081–2100	SRES A2	CSA	SDM (CTA)	$-11.7\%$ and $-53.7\%$	Tsuyama et al. (2008a) Tsuyama et al. (2008b)
25 Conifer species	Japan	2081–2100	SRES A2	CSA	SDM (Ensemble of 4 models)	Altitudinal shifts by 293 m; CSA loss up to 85%; refugia in central Japan	Ogawa-Onishi et al. (2010)
<b>Insects</b>							
<i>N. viridula</i>	Kinki	Unspecified	+2.5 $^{\circ}$ C	Phenology; life history	Incubator experiment	Increased winter and spring survival; advanced post-diapause reproduction; changes in life span of females	Musolin et al. (2010) Takeda et al. (2010)
<i>N. viridula</i>	Kyushu	2100	+1.4 to +5.8 $^{\circ}$ C	Thermal range	Isotherm shift	Range expansion	Yukawa et al. (2007)
<i>Tibicen japonicus</i>	Kinki	Unspecified	+2 $^{\circ}$ C	Thermal range	Isotherm shift	Local extinctions at mountaintops	Shiyake (2008a)
<b>Birds</b>							
<i>Lagopus mutus</i>	Japan	Unspecified	+1 to +3 $^{\circ}$ C	Abundance	Treeline shift	1 $^{\circ}$ C : $-10\%$ , 2 $^{\circ}$ C: $-48.8\%$ , 3 $^{\circ}$ C: $-79.6\%$	Nakamura (2007)
<b>Marine species</b>							
Coral reefs	Japan	2000–2099	SRES A1B	Reef development; bleaching	Isotherm shift; DHM	Northward shift; increases in frequency (once/year in 2100)	Yara et al. (2009)
34 species (a); 171 sub-tropical species (b)	Japan	2030; 2050; 2100	+1.0 $^{\circ}$ C; +1.5 $^{\circ}$ C; +2.9 $^{\circ}$ C	Thermal range	Isotherm shift	Northward shifts (a); northward expansions (88 species) (b)	Kuwahara et al. (2006)
<i>Seriola quinqueradiata</i>	Japan Sea	2025;2050;2100	SRES A1B	Thermal range	Isotherm shift	Northward shift of winter range (3 $^{\circ}$ by 2050)	Tian et al. (2012)

<sup>a</sup> CSA: climatically suitable areas.

<sup>b</sup> DTS: the number of days transformed to standard temperature; SDM: species distribution models (climate envelope models); CTA: classification tree analysis; DHM: degree heating month.

Kyushu and the coastal areas on the Pacific Ocean side by 2032–2050 under the SRES A2 scenario (Maruoka and Itoh, 2009). In addition, the study found that the species may not flower in southern Kyushu by 2082–2100. The projected delays and non-flowering resulted from insufficient chilling accumulation to complete dormancy.

Projections based on species distribution models (Elith and Leathwick, 2009), or bioclimatic envelope models (Heikkinen et al., 2006) are available for several tree species. These models use correlations between climatic parameters (temperature and precipitation) and species distributions and project the climatically suitable areas under the future climate. Matsui et al. (2009b) projected that the climatically suitable area for *F. crenata* forests would decrease by 63% under the SRES A2 scenario and by 79% under the A1B scenario in 2081–2100. In addition, Ogawa-Onishi et al. (2010) projected changes in climatically suitable areas for 25 conifer species from warm-temperate to alpine climate zones.

Their results indicated that endemic sub-alpine species were the most vulnerable group to climate change, and were projected to lose 70–85% of their climatically suitable areas by 2100 under the SRES A2 scenario. Moreover, species' climatically suitable altitudinal range was projected to shift to higher elevations at 24 m per decade on average, which could greatly alter species richness patterns on mountains. Although we did not find any observational evidence of altitudinal shifts in Japan, a recent study in European mountains showed that plants have shifted upslope by 2.7 m on average between 2001 and 2008 (Pauli et al., 2012). Thus, species range is likely to shift toward higher altitude in response to climate change, although the actual distributional shifts may lag behind the changes in climatically suitable areas.

Apart from the modelling, the potential range shifts of insects, birds and marine species were indicated by isotherm shifts in thermal ranges determined from literature or correlation with current distributions. For example, the thermal range of *N. viridula* was

projected to expand to higher elevations in Kyushu, such that all of Kyushu could become suitable if the temperature increased by 5.8 °C (Yukawa et al., 2007). Another insect species, *Tibicen japonicas* (tibicen cicada) was also estimated to shift upward, with consequent local extinctions from many mountains in the Kinki district under a 2 °C increase (Shiyake, 2008a). The abundance of a bird species, *Lagopus mutus* (rock ptarmigan), was estimated to decline by 79.6% assuming an increase of 3 °C and the consequent shifts of treelines (Nakamura, 2007).

Range expansions of marine species were also estimated based on the projected changes in the SST isotherm shifts. Kuwahara et al. (2006) studied the changes in the thermal range of 34 fish, shellfish, and algae species in the seas around Japan. They first constructed a life history database that includes information such as thermal resistance at different life stages based on existing experiments and field surveys, and then identified the maximum and minimum thermal requirements for each species. The study revealed that the thermal ranges of temperate and sub-tropical marine organisms were divided at the 29 °C isothermal line of the maximum annual SST. This line was estimated to shift northward, from southern Kyushu to the Kanto districts in 100 years, assuming a 2.9 °C increase of SST. This northward shift would significantly affect coastal species such as bastard halibut, red sea bream, abalone and sea urchin and the cultivation of Japanese amberjack, puffer, and seaweeds. In addition, based on experimental results, which showed the suitable water temperature for *Seriola quinqueradiata* (Japanese yellow tail) was over 10 °C, Tian et al. (2012) projected a 3° northward shift of the 10 °C SST isothermal line by 2050 under the SRES A1B scenario. Further, the coral reef development limits, which were correlated with 18 °C isotherm of the SST of the coldest month, were projected to shift from the coasts of southern Kyushu in 2000–2009 to the coasts of northern Kyushu by 2090–2099 under the SRES A1B scenario (Yara et al., 2009). Thus, the projections based on the SST isothermal shifts suggest that SST rises would affect many marine organisms around Japan.

## 6. Research needs

The JMA data are available for over 120 phenological events although less than 30 of them have so far been analysed. Thus, the first research need is to utilise this extensive data set. At the same time, it is important that the scientific community supports JMA in continuing the observations, as monitoring of nearly 50 species has been discontinued since 2003. Distributional records are also underutilised and studies investigating the relationship with climate change are available only for a limited number of species. In particular, many insects, such as beetles (Shiyake, 2008b), dragonflies (Matsuzawa, 2008), and butterflies (Kiritani, 2006), have been observed beyond their native ranges that are considered to be the effects of climate change. On the other hand, an experimental study revealed that tolerance to winter temperature was not a limiting factor for the northern range expansion of *Cryptotympana facialis* (bear cicada) (Moriyama and Numata, 2009). Thus, research is needed on the cause of distributional shifts for other species.

In addition, there is a general lack of rigorous modelling studies of the future impacts. Many studies on species distribution changes are based simply on isothermal shifts and the small numbers of available modelling studies include only a selected number of plant species. Moreover, the Japanese studies are also limited by the range of underlining climate scenarios. SRES A1B and A2 are the only scenarios considered and they are based on different climate models, i.e. MIROC 3.2 and RCM20 respectively. Consequently, the existing research fails to address uncertainty of climate models and scenarios (Araújo and New, 2007). The

Japanese researchers rely heavily on these two models because they have higher resolutions than other GCMs and can better incorporate the regional climatic regime and topographic effects that strongly affect the climate of Japan (Sasaki et al., 2005). Development of high resolution climate models including a range of scenarios is necessary to reduce, estimate, or manage uncertainty for adaptation to climate change (Littell et al., 2011). Further, incorporation of dynamic ecological changes, such as acclimation, inter-specific interactions, dispersal limitation and evolutionary adaptation, is necessary for more realistic representation of species' future distributions (Corlett, 2011a).

## 7. Implications for conservation research

Apart from identifying the research needs, this review has important implications for conservation research on the ecological impacts of climate change. Here, we identified over 50 scientific studies, a third of which were obtained from Japanese publications. Interestingly, most phenological studies were published in international journals, whereas many distributional studies, both observed and projected impacts, were published in Japanese sources. Most phenological studies were based on the same data source, i.e. the JMA observations, which are collected nation-wide in a systematic manner over five decades. Such extensive data are globally scarce and enable phenological investigations of international importance (Primack et al., 2009b). Moreover, the data set is distributed at a low cost by JMA. Thus, it has been used widely by both foreign and Japanese researchers. On the other hand, the distribution data are generally collected by a group of researchers and not publicly available. They may not necessarily publish in international journals because Japanese journals have lower rejection rates and a faster turn-around time. In addition, the studies on observed distributions are often descriptive and focused on one or a few species, which may not be of interest for international journals (Sodhi and Liow, 2000). Therefore, local journals include important research in understanding overall ecological changes due to climate change.

The Japanese papers are rarely cited in international reviews nor included in international journal databases. For example, among the Japanese papers we reviewed, only two were included in ISI Web of Knowledge. All the other papers were, however, catalogued in CiNii or J-STAGE (<https://www.jstage.jst.go.jp/>), the database of Japanese academic publications. Similar databases are available for other countries where much work is published in their native languages; e.g. CNKI (<http://eng.cnki.net/>) for China and DBpia (<http://www.dbpia.co.kr/>) and KISS (<http://kiss.kstudy.com/>) for South Korea. Researchers working on non-English speaking countries should be encouraged to make use of these country-specific journal databases to investigate local publications.

Grey literature is another overlooked source of research, although we did not include it in this review. Japan publishes more scientific publications in the form of grey literature (bulletins of university and research centres and medical institutions, conference proceedings, and government reports and white papers) than peer-reviewed journals in a year (Tokizane, 2008, 2011). In addition, much data and research may also be available as unpublished reports and theses (e.g. Onishi, 2010). It has been suggested that for ecology and conservation in the Tropics, valuable information is hidden in grey literature, the volume of which greatly exceeds that of the peer-reviewed scientific literature (Corlett, 2011b). It could take a considerable time and effort to review grey literature sources as they are often not available electronically and their quality varies greatly. However, grey literature sources can provide valuable information on the ecological impacts of climate change in regions where international publications are scarce.



Finally, despite improved accessibility through the internet, knowledge of local ecology and national research context remains critical to fully understanding the content of local publications. Therefore, in order to improve our knowledge of ecological impacts of climate change in non-English speaking countries, it is important to strengthen collaboration with local researchers.

## 8. Conclusions

A number of long-term phenological and distributional records clearly indicate that ecological changes are occurring in response to climate change in Japan. Phenology of many animal species has delayed on average, which is contradictory to observed changes in other regions of the world. As a consequence, the phenology of interacting plants and animals is shifting in opposite directions and the species interactions are changing. Models suggest widening phenological mismatches between plants and animals under a warmer climate, although advancement of spring flowering may turn to delay when warming significantly delays the dormancy break. In addition, rapid expansions of range margins by more than 100 km/decade have been observed for insects and corals. Future projections indicate rapid shifts of plants towards higher elevations and significant losses of climatically suitable areas for high altitude species. Mountainous regions elsewhere would experience similar effects, although the impacts in Japan could be more significant, as the Japanese mountains are very precipitous and greater range losses occur with the same magnitude of altitudinal shifts. Hence, the impacts of climate change on Japanese species are not always consistent with the observations and projections previously reported in other regions. Further investigations in other less known regions are important for improving our understanding of the regional impacts of climate change. This can be facilitated by utilising locally available data and publications, especially in non-English speaking countries.

## Acknowledgements

The authors thank Richard Primack and three anonymous reviewers for their constructive comments on the manuscript. Our thanks extend to Miguel Araújo and Shonil Bhagwat for comments on an earlier draft in YO's Ph.D. dissertation. We also thank Yasuaki Hijioka, Kiyoshi Takahashi, and Naota Hanasaki for advice on the current manuscript. Y.O. was financially supported by the Oxford University Clarendon Scholarship, Japan Weather Association, and Global Environmental Forum. This research was partially supported by the Environment Research and Technology Development Fund (S-8) of the Ministry of the Environment, Japan.

## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.biocon.2012.06.024>.

## References

Aono, Y., Moriya, C., 2003. A generalized model to estimate flowering for cherry tree (*Prunus yedoensis*) considering both processes of endodormancy completion and development. *J. Agric. Meteorol.* 59, 165–177 (in Japanese).  
 Aono, Y., Kazui, K., 2008. Phenological data series of cherry tree flowering in Kyoto, Japan, and its application to reconstruction of springtime temperatures since the 9th century. *Int. J. Climatol.* 28, 905–914.  
 Aono, Y., Saito, S., 2010. Clarifying springtime temperature reconstructions of the medieval period by gap-filling the cherry blossom phenological data series at Kyoto, Japan. *Int. J. Biometeorol.* 54, 211–219.  
 Araújo, M.B., New, M., 2007. Ensemble forecasting of species distributions. *Trends Ecol. Evol.* 22, 42–47.

Badeck, F.W., Bondeau, A., Bottcher, K., Doktor, D., Lucht, W., Schaber, J., Sitch, S., 2004. Responses of spring phenology to climate change. *New Phytol.* 162, 295–309.  
 Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., Courchamp, F., 2012. Impacts of climate change on the future of biodiversity. *Ecol. Lett.* 15, 365–377.  
 Bertin, R.L., 2008. Plant phenology and distribution in relation to recent climate change. *J. Torrey Bot. Soc.* 135, 126–146.  
 CBD, 2010. Global Biodiversity Outlook 3. Secretariat of the Convention on Biological Diversity, Montréal.  
 Cleland, E.E., Chiariello, N.R., Loarie, S.R., Mooney, H.A., Field, C.B., 2006. Diverse responses of phenology to global changes in a grassland ecosystem. *Proc. Natl. Acad. Sci.* 103, 13740–13744.  
 Corlett, R.T., 2011a. Impacts of warming on tropical lowland rainforests. *Trends Ecol. Evol.* 26, 606–613.  
 Corlett, R.T., 2011b. Trouble with the gray literature. *Biotropica* 43, 3–5.  
 Doi, H., 2007. Winter flowering phenology of Japanese apricot *Prunus mume* reflects climate change across Japan. *Clim. Res.* 34, 99–104.  
 Doi, H., 2008. Delayed phenological timing of dragonfly emergence in Japan over five decades. *Biol. Lett.* 4, 388–391.  
 Doi, H., Gordo, O., Katano, I., 2008. Heterogeneous intra-annual climatic changes drive different phenological responses at two trophic levels. *Clim. Res.* 36, 181–190.  
 Doi, H., Katano, I., 2008. Phenological timings of leaf budburst with climate change in Japan. *Agric. Forest Meteorol.* 148, 512–516.  
 Doi, H., Takahashi, M., Katano, I., 2010. Genetic diversity increases regional variation in phenological dates in response to climate change. *Glob. Change Biol.* 16, 373–379.  
 Doi, H., 2011. Response of the *Morus bombycis* growing season to temperature and its latitudinal pattern in Japan. *Int. J. Biometeorol.*, 1–8.  
 Elith, J., Leathwick, J.R., 2009. Species distribution models: ecological explanation and prediction across space and time. *Annu. Rev. Ecol. Syst.* 40, 677–697.  
 Ellwood, E.R., Diez, J.M., Ibanez, I., Primack, R.B., Kobori, H., Higuchi, H., Silander, J.A., 2012. Disentangling the paradox of insect phenology: are temporal trends reflecting the response to warming? *Oecologia* 168, 1161–1171.  
 Fujibe, F., 2011. Urban warming in Japanese cities and its relation to climate change monitoring. *Int. J. Climatol.* 31, 162–173.  
 Fujimoto, S., 2008. Estimating the impact of thermal change on broad-leaved tree leaf phenology in the warm temperate zone. *Jpn. J. Conserv. Ecol.* 13, 75–87 (in Japanese).  
 Fujisawa, M., Kobayashi, K., 2010. Apple (*Malus pumila* var. *domestica*) phenology is advancing due to rising air temperature in northern Japan. *Glob. Change Biol.* 16, 2651–2660.  
 Gordo, O., Doi, H., 2012. Spring phenology delays in an insular subtropical songbird: is response to climate change constrained by population size? *J. Ornithol.* 153, 355–366.  
 Heikkinen, R.K., Luoto, M., Araújo, M.B., Virkkala, R., Thuiller, W., Sykes, M.T., 2006. Methods and uncertainties in bioclimatic envelope modelling under climate change. *Prog. Phys. Geogr.* 30, 751–777.  
 Hickling, R., Roy, D.B., Hill, J.K., Thomas, C.D., 2005. A northward shift of range margins in British Odonata. *Glob. Change Biol.* 11, 502–506.  
 Hickling, R., Roy, D.B., Hill, J.K., Fox, R., Thomas, C.D., 2006. The distributions of a wide range of taxonomic groups are expanding polewards. *Glob. Change Biol.* 12, 450–455.  
 Higuchi, H., Koike, S., Shigeta, M., 2009. Effects of climate on the phenology, distribution, and population of organisms. *Glob. Environ. Res.* 14, 189–198 (in Japanese).  
 Horikawa, M., Tsuyama, I., Matsui, T., Kominami, Y., Tanaka, N., 2009. Assessing the potential impacts of climate change on the alpine habitat suitability of Japanese stone pine (*Pinus pumila*). *Landscape Ecol.* 24, 115–128.  
 Ibanez, I., Primack, R.B., Miller-Rushing, A.J., Ellwood, E., Higuchi, H., Lee, S.D., Kobori, H., Silander, J.A., 2010. Forecasting phenology under global warming. *Philos. Trans. Roy. Soc. B – Biol. Sci.* 365, 3247–3260.  
 Inoue, T., 2005. Spread of the distributional range of *Narathura bazalus* (Hewitson) (Lepidoptera, Lycaenidae) in Ibaraki prefecture, central Japan. *Trans. Lepidopterol. Soc. Jpn.* 56, 287–296 (in Japanese).  
 IPCC, 2007. Climate change 2007: impacts, adaptation and vulnerability. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Contribution of Working Group II to the Fourth Assessment Report of the International Panel on the Climate Change. Cambridge University Press, Cambridge.  
 IUCN, 2001. IUCN Red List Categories and Criteria: Version 3.1, IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.  
 JMA, 2005. Global Warming Projection, vol. 6, Japan Meteorological Agency, Tokyo.  
 JMA, 2011a. Climate Change Monitoring Report 2010. Japan Meteorological Agency, Tokyo.  
 JMA, 2011b. Phenological Observations 1953–2008, CD-ROM, Japan Meteorological Business Support Center, Tokyo. <<http://www.jmbc.or.jp/english/index-e.html>>.  
 K-1 Model Developers, 2004. K-1 Coupled Model (MIROC) Description. In: Hasumi, H., Emori, S. (Eds.), K-1 Technical Report 1. Center for Climate System Research, University of Tokyo, Tokyo.  
 Kamitani, S., 2010a. First appearances and first singing days. In: Kiritani, K., Yukawa, J. (Eds.), Effects of Global Warming on Insects. Japan Rural Education Association, Tokyo, pp. 108–120.  
 Kamitani, S., 2010b. Speculation of expansion and reduction of potential distributional area. In: Kiritani, K., Yukawa, J. (Eds.), Effects of Global

- Warming on Insects. Japan Rural Education Association, Tokyo, pp. 90–105.
- Kimoto, M., Yasutomi, N., Yokoyama, C., Emori, S., 2005. Projected changes in precipitation characteristics around Japan under the global warming. *SOLA* 1, 85–88.
- Kiritani, K., 2006. Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. *Popul. Ecol.* 48, 5–12.
- Kiritani, K., 2011. Impacts of global warming on *Nezara viridula* and its native congeneric species. *J. Asia-Pac. Entomol.* 14, 221–226.
- Kitahara, M., Iriki, M., Shimizu, G., 2001. On the relationship between the northward distributional expansion of the great mormon butterfly, *Papilio memnon* Linnaeus, and climatic warming in Japan. *Trans. Lepidopterol. Soc. Jpn.* 52, 253–264 (in Japanese).
- Kitahara, M., 2008. Poleward range shift of butterflies under global warming. *The Nat. Insects* 43, 19–23 (in Japanese).
- Koike, S., Fujita, G., Higuchi, H., 2006. Climate change and the phenology of sympatric birds, insects, and plants in Japan. *Glob. Environ. Res.* 10, 167–174.
- Kurihara, K., Ishihara, K., Sasaki, H., Fukuyama, Y., Saitou, H., Takayabu, I., Murazaki, K., Sato, Y., Yukimoto, S., Noda, A., 2005. Projection of climatic change over Japan due to global warming by high-resolution regional climate model in MRI. *SOLA* 1, 97–100.
- Kuwahara, H., Akeda, S., Kobayashi, S., Takeshita, A., Yamashita, Y., Kido, K., 2006. Predicted changes on the distribution areas of marine organisms around Japan caused by the global warming. *Glob. Environ. Res.* 10, 189–199.
- Lee, S.D., Ellwood, E.R., Park, S.Y., Primack, R.B., 2011. Late-arriving barn swallows linked to population declines. *Biol. Conserv.* 144, 2182–2187.
- Littell, J.S., McKenzie, D., Kerns, B.K., Cushman, S., Shaw, C.G., 2011. Managing uncertainty in climate-driven ecological models to inform adaptation to climate change. *Ecosphere* 2, art102.
- Maruoka, T., Itoh, H., 2009. Impact of global warming on flowering of cherry trees (*Prunus yedoensis*) in Japan. *J. Agric. Meteorol.* 65, 283–296 (in Japanese).
- Masuda, R., 2008. Seasonal and interannual variation of subtropical fish assemblages in Wakasa bay with reference to the warming trend in the sea of Japan. *Environ. Biol. Fishes* 82, 387–399.
- Masui, T., Matsumoto, K., Hijioka, Y., Kinoshita, T., Nozawa, T., Ishiwatari, S., Kato, E., Shukla, P.R., Yamagata, Y., Kainuma, M., 2011. An emission pathway for stabilization at 6 Wm<sup>-2</sup> radiative forcing. *Climatic Change* 109, 59–76.
- Masuzawa, T., Mitsuda, H., Tanaka, M., Natori, T., Watanabe, S., 2005. Alpine plant community on Mt. Apoi, Hokkaido: succession of plant community on the ultrabasic soil. *Japanese Journal of Ecology* 55, 85–89 (in Japanese).
- Matsui, M., Tanaka, N., Yagihashi, T., Kominami, Y., Tsuyama, I., Takahashi, K., 2009a. Prediction and impact assessment of the changes in suitable habitats for beech (*Fagus crenata*) forests under climate change scenarios. *Glob. Environ. Res.* 14, 165–174 (in Japanese).
- Matsui, T., Takahashi, K., Tanaka, N., Hijioka, Y., Horikawa, M., Yagihashi, T., Harasawa, H., 2009b. Evaluation of habitat sustainability and vulnerability for beech (*Fagus crenata*) forests under 110 hypothetical climatic change scenarios in Japan. *Appl. Veg. Sci.* 12, 328–339.
- Matsumoto, K., Ohta, T., Irasawa, M., Nakamura, T., 2003. Climate change and extension of the *Ginkgo biloba* L. growing season in Japan. *Glob. Change Biol.* 9, 1634–1642.
- Matsuzawa, T., 2008. Recent trend of dragonfly that is going north from the tropics to the temperate zone. *The Nat. Insects* 43, 4–8 (in Japanese).
- Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J., Zhao, Z.-C., 2007. Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Menzel, A., Sparks, T.H., Estrella, N., Koch, E., Aasa, A., Ahas, R., Alm-Kubler, K., Bissolli, P., Braslavská, O.G., Briede, A., Chmielewski, F.M., Crepinsek, Z., Curnel, Y., Dahl, A., Defila, C., Donnelly, A., Filella, Y., Jatczak, K., Mage, F., Mestre, A., Nordli, O., Penuelas, J., Pirinen, P., Remisova, V., Scheffinger, H., Striz, M., Susnik, A., Van Vliet, A.J.H., Wielgolaski, F.-E., Zach, S., Züst, A.N.A., 2006. European phenological response to climate change matches the warming pattern. *Glob. Change Biol.* 12, 1969–1976.
- Miller-Rushing, A.J., Katsuki, T., Primack, R.B., Ishii, Y., Lee, S.D., Higuchi, H., 2007. Impact of global warming on a group of related species and their hybrids: cherry tree (*Rosaceae*) flowering at Mt. Takao, Japan. *Am. J. Bot.* 94, 1470–1478.
- Miller-Rushing, A.J., Hoyer, T.T., Inouye, D.W., Post, E., 2010. The effects of phenological mismatches on demography. *Philos. Trans. Roy. Soc. B - Biol. Sci.* 365, 3177–3186.
- Ministry of the Environment, 2008. *Smart Adaptation to Climate Change: Report of Influence of Global Warming/Adaptation Research Committee*. Ministry of the Environment, Tokyo (in Japanese).
- Ministry of the Environment, 2010. *National Biodiversity Strategy 2010*. Biocity, Tokyo (in Japanese).
- Ministry of the Environment, 2011. *Annual Report on the Environment, the Sound Material-Cycle Society and the Biodiversity in Japan 2011*. Nikkei Printing Inc., Tokyo (in Japanese).
- Mittermeier, R.A., Gil, P.R., Hoffmann, M., Pilgrim, J., Brooks, T., Mittermeier, C.G., Lamoreux, J., Da Fonseca, G.A.B., 2004. *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Cemex Books on Nature. CEMEX, Mexico City.
- MLIT, 2011. *Land White Paper*. Ministry of Land, Infrastructure, Transport and Tourism, Tokyo (in Japanese).
- Moriyama, M., Numata, H., 2009. Comparison of cold tolerance in eggs of two cicadas, *Cryptotympana facialis* and *Graptosaltria nigrofusca*, in relation to climate warming. *Entomol. Sci.* 12, 162–170.
- Musolin, D.L., Numata, H., 2003. Timing of diapause induction and its life-history consequences in *Nezara viridula*: is it costly to expand the distribution range? *Ecol. Entomol.* 28, 694–703.
- Musolin, D.L., 2007. Insects in a warmer world: ecological, physiological and life-history responses of true bugs (Heteroptera) to climate change. *Glob. Change Biol.* 13, 1565–1585.
- Musolin, D.L., Tougou, D., Fujisaki, K., 2010. Too hot to handle? Phenological and life-history responses to simulated climate change of the southern green stink bug *Nezara viridula* (Heteroptera: Pentatomidae). *Glob. Change Biol.* 16, 73–87.
- Nakamura, H., 2007. Rock Ptarmigan *Lagopus mutus japonicus*. *Jpn. J. Ornithol.* 56, 93–114 (in Japanese).
- Nakićenović, N., Swart, R. (Eds.), 2000. *Special Report on Emissions Scenarios: A special report of working group III of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK.
- Nishimori, M., Kuwagata, T., Ishigooka, Y., Murakami, M., 2009. On the regional and seasonal characteristics of recent surface air temperature changes in Japan with considering urban climate effects. *J. Agric. Meteorol.* 65, 221–227 (in Japanese).
- Nojima, S., Okamoto, M., 2008. Enlargement of habitats of scleractinian corals to north and coral bleaching events. *Bull. Jpn. Soc. Sci. Fish.* 74, 884–888 (in Japanese).
- Ogawa-Onishi, Y., Berry, P.M., Tanaka, N., 2010. Assessing the potential impacts of climate change and their conservation implications in Japan: a case study of conifers. *Biol. Conserv.* 143, 1728–1736.
- Onishi, Y.O., 2010. *Climate Change and the Japanese Flora: The Potential Impacts and the Effects on Protected Areas*. D. Phil Thesis, The University of Oxford, Oxford.
- Parmesan, C., Yohe, G., 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421, 37–42.
- Parmesan, C., 2006. Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Syst.* 37, 637–669.
- Parmesan, C., 2007. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. *Glob. Change Biol.* 13, 1860–1872.
- Pauli, H., Gottfried, M., Dullinger, S., Abdaladze, O., Akhalkatsi, M., Alonso, J.L.B., Coldea, G., Dick, J., Erschbamer, B., Calzadó, R.F., Ghosn, D., Holten, J.I., Kanka, R., Kazakis, G., Kollar, J., Larsson, P., Moiseev, P., Moiseev, D., Molau, U., Mesa, J.M., Nagy, L., Pelino, G., Púscas, M., Rossi, G., Stanisci, A., Syverhuset, A.O., Theurillat, J.P., Tomaselli, M., Unterlugauer, P., Villar, L., Vittoz, P., Grabherr, G., 2012. Recent plant diversity changes on Europe's mountain summits. *Science* 336, 353–355.
- Primack, R.B., Ibanez, I., Higuchi, H., Lee, S.D., Miller-Rushing, A.J., Wilson, A.M., Silander Jr., J.A., 2009a. Spatial and interspecific variability in phenological responses to warming temperatures. *Biol. Conserv.* 142, 2569–2577.
- Primack, R.B., Higuchi, H., Miller-Rushing, A.J., 2009b. The impact of climate change on cherry trees and other species in Japan. *Biol. Conserv.* 142, 1943–1949.
- Project Team for Comprehensive Projection of Climate Change Impacts, 2008. *Global Warming Impacts on Japan – Latest Scientific Findings –*, Ministry of the Environment, Tokyo (in Japanese).
- Sasaki, H., Kurihara, K., Takayabu, I., 2005. Comparison of climatic reproducibility between a super-high-resolution atmosphere general circulation model and a meteorological research institute regional climate model. *Sci. Online Lett. Atmos.* 1, 81–84.
- Seo, H., Kudo, H., Kaeriyama, M., 2011. Long-term climate-related changes in somatic growth and population dynamics of Hokkaido chum salmon. *Environ. Biol. Fishes* 90, 131–142.
- Shimada, T., Hatakeyama, S., Miyabayashi, Y., Kurechi, M., 2005. Effects of climatic conditions on the northward expansion of the wintering range of the greater white-fronted goose in Japan. *Ornithol. Sci.* 4, 155–159.
- Shiota, M., 2006. Recent northward range shift of butterfly species due to winter warming: the situation in Ibaraki prefecture by 2005. *Yadoriga* 209, 37–47 (in Japanese).
- Shiyake, S., 2008a. Global warming and change in cicada distributions. *The Nat. Insects* 43, 6–10 (in Japanese).
- Shiyake, S., 2008b. The influence of global warming on the distribution and life history of a meloid beetle species *Cissites cephalotes* (Olivier). *The Nat. Insects* 43, 9–12 (in Japanese).
- Sodhi, N.S., Liow, L.H., 2000. Improving conservation biology research in southeast Asia. *Conserv. Biol.* 14, 1211–1212.
- Takahashi, M., 1982. The status of *Melantis phedima oitensis* in Shizuoka prefecture and the outbreak in 1980. *Trans. Lepidopterol. Soc. Jpn.* 32, 206–207 (in Japanese).
- Takeda, K., Musolin, D.L., Fujisaki, K., 2010. Dissecting insect responses to climate warming: overwintering and post-diapause performance in the southern green stink bug, *Nezara viridula*, under simulated climate-change conditions. *Physiol. Entomol.* 35, 343–353.
- Throop, H.L., Lerdau, M.T., 2004. Effects of nitrogen deposition on insect herbivory: implications for community and ecosystem processes. *Ecosystems* 7, 109–133.
- Tian, Y.J., Kidokoro, H., Watanabe, T., Igeta, Y., Sakaji, H., Ino, S., 2012. Response of yellowtail, *Seriola quinqueradiata*, a key large predatory fish in the Japan sea, to sea water temperature over the last century and potential effects of global warming. *J. Mar. Syst.* 91, 1–10.

- Tokizane, S., 2008. Study on scholarly journals published in Japan. *J. Inform. Process. Manage.* 51, 571–579.
- Tokizane, S., 2011. Electronic journal titles in science, technology and medicine published in Japan: changes from 2005 to 2008. *J. Inform. Process. Manage.* 54, 13–20.
- Tougou, D., Musolin, D.L., Fujisaki, K., 2009. Some like it hot! Rapid climate change promotes changes in distribution ranges of *Nezara viridula* and *Nezara antennata* in Japan. *Entomol. Exp. Appl.* 130, 249–258.
- Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Tank, A.K., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B., Zhai, P., 2007. Observations: surface and atmospheric climate change. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the International Panel on the Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Tsubuki, T., 2008. The research on the reason why the argyne butterfly, *Argyreus hyperbius* (Lepidoptera, Nymphalidae) has recently been distributed into the northern areas in Japan: (1) based on the fluctuation of the butterfly, *Argyreus hyperbius* observed in Hino City, Tokyo and the amount of pansy, *Viola wittrockiana* transported into Tokyo and Hino City from other prefectures and how to plant pansy. *Trans. Lepidopterol. Soc. Jpn.* 59, 154–164 (in Japanese).
- Tsuyama, I., Matsui, M., Horikawa, M., Kominami, Y., Tanaka, N., 2008a. Habitat prediction and impact assessment of climate change on dwarf bamboo of the Section Sasa in Japan. *Theory Appl. GIS* 16, 99–113 (in Japanese).
- Tsuyama, I., Matsui, M., Ogawa, M., Kominami, Y., Tanaka, N., 2008b. Habitat prediction and impact assessment of climate change on *Sasa kurilensis* in eastern Honshu, Japan. *Theory Appl. GIS* 16, 11–25 (in Japanese).
- Walther, G.R., 2010. Community and ecosystem responses to recent climate change. *Philos. Trans. Roy. Soc. B: Biol. Sci.* 365, 2019–2024.
- Watanabe, S., 2005. Decline of ultrabasicosaxicolous flora from 1954 to 2003 on Mt. Apoi, Hidaka Province, Hokkaido, Japan. *Jpn. J. Ecol.* 55, 105–110 (in Japanese).
- Yamano, H., Sugihara, K., Nomura, K., 2011. Rapid poleward range expansion of tropical reef corals in response to rising sea surface temperatures. *Geophys. Res. Lett.* 38, 1–6.
- Yamauchi, K., Kuko, M., Takatsuki, S., 2007. The present status of and perspectives on Sika deer management in Iwate prefecture, Japan. *Mammal. Sci.* 47, 39–44 (in Japanese).
- Yara, Y., Fujii, M., Yamanaka, Y., Okada, N., Yamano, H., Oshima, K., 2009. Projected effects of global warming on coral reefs in seas close to Japan. *J. Jpn. Coral Reef Soc.* 11, 131–140 (in Japanese).
- Yasuda, M., Daimaru, H., Okitsu, S., 2007. Detection of alpine moor vegetation change by comparison of orthonized aerophotographs at different times. *Geogr. Rev. Jpn.* 80, 842–856 (in Japanese).
- Yoshio, M., Ishii, M., 2004. Photoperiodic response of two newly established populations of the great mormon butterfly, *Papilio memnon* L. (Lepidoptera, Papilionidae), in Shizuoka and Kanagawa prefectures, central Japan. *Trans. Lepidopterol. Soc. Jpn.* 55, 301–306 (in Japanese).
- Yoshio, M., Ishii, M., 2010. Global warming and range expansion of Great mormon. In: Kiritani, K., Yukawa, J. (Eds.), *Effects of Global Warming on Insects*. Japan Rural Education Association, Tokyo, pp. 54–71 (in Japanese).
- Yukawa, J., Kiritani, K., Gyoutoku, N., Uechi, N., Yamaguchi, D., Kamitani, S., 2007. Distribution range shift of two allied species, *Nezara viridula* and *N-antennata* (Hemiptera: Pentatomidae), in Japan, possibly due to global warming. *Appl. Entomol. Zool.* 42, 205–215.
- Yukawa, J., Kiritani, K., Kawasaki, T., Higashiura, Y., Sawamura, N., Nakada, K., Gyotoku, N., Tanaka, A., Kamitani, S., Matsuo, K., Yamauchi, S., Takematsu, Y., 2009. Northward range expansion by *Nezara viridula* (Hemiptera: Pentatomidae) in Shikoku and Chugoku Districts, Japan, possibly due to global warming. *Appl. Entomol. Zool.* 44, 429–437.
- Yukawa, J., Kiritani, K., 2010. Northward expansion of Southern green sting bug and local extinction of Green sting bug. In: Kiritani, K., Yukawa, J. (Eds.), *Effects of Global Warming on Insects*. Japan Rural Education Association, Tokyo, pp. 72–89.