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ORIGINAL ARTICLE

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The effects of climate change on the phenology of winter birds in Yokohama, Japan

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Abstract Observations made largely from summer breeding sites in Europe and North America have been used to document the effects of climate change on many bird species. We extend these studies by examining 23 years of observations between 1986 and 2008 of six winter bird species made by citizens at a city park in Yokohama, Japan. Bird species arrive in autumn and spend the winter in the area, before departing in the late winter or spring. On average, birds species are arriving 9 days later than in the past and are departing on average 21 days earlier, meaning that the average duration of their stay in Yokohama is about 1 month shorter now than in the past. Patterns of changes over time varied among species, but departure dates changed for more species than did arrival dates. Dates of departure and arrival were sometimes correlated with monthly average temperatures—later arrivals and earlier departures were associated with warmer temperatures. In addition, interannual variation in arrival and departure dates were strongly correlated across species, suggesting that species were responding to the same or similar environmental cues. This study provides a clear demonstration of the value of using citizens to make observations that contribute to research in climate change biology.

Keywords Climate change · Phenology · Migratory birds · Wintering site Japan

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Introduction

If the climate changes in the coming decades, as predicted, as much as 30% of the world's species may be threatened with extinction, and ecosystem services will be significantly altered, many in negative ways (IPCC 2007). Climate change is already having dramatic effects on biological systems, including through shifts in species ranges, pest and disease outbreaks, and phenology (Parmesan 2006, 2007). Of all biological phenomena, the phenology of plants and animals provides the most abundant evidence for the impacts of climate change on biological systems with spring activities occurring progressively earlier over the past half century (Walther et al. 2002; Root et al. 2003; Gordo and Sanz 2005; Parmesan 2006; Menzel et al. 2006). For animals, the spring arrival of birds in northern temperate latitudes is particularly well documented. Many, but not all, birds are now arriving earlier at their spring breeding grounds, often due to warmer winter and spring weather (Mason 1995; Loxton et al. 1998; Sokolov et al. 1998; Loxton and Sparks 1999; Jacobs and Wingfield 2000; Sparks and Braslavská 2001; Sparks and Mason 2001; Tryjanowski et al. 2002; Butler 2003; Cotton 2003; Coppack and Both 2003; Strode 2003; Gordo et al. 2005). However, the flowering and leafing out of plants are advancing more rapidly than the arrival of spring migrants, leading to the possibility of ecological mismatches (Parmesan and Yohe 2003; Visser and Both 2005; Parmesan 2006; Primack et al. 2009). For European birds, the earlier arrival of spring bird migrations averages around 2 days/°C, in contrast to plant and invertebrate phenology, which is advancing around 6 days/°C (Sparks and Menzel 2002). There is also some evidence that birds are departing later from their breeding grounds, but these shifts are less pronounced than dates of arrival and show a more heterogeneous pattern (Gatter 1992; Bezzel and Jetz 1995; Vogel and Moritz 1995; Bergmann 1998; Sparks and Mason 2001).

Published studies of bird arrival and departure dates come primarily from North America and Europe

(Berthold 1991; Lehikoinen et al. 2004; Mills 2005; Sparks et al. 2005, 2007; Jonzén et al. 2007; Miller-Rushing et al. 2008a, b) and are mainly based on observations on arrival at their northern summer breeding grounds or at points along their migration routes (Ahas 1999; Inouye et al. 2000). Relatively few studies have examined the arrival and departure dates of birds in other regions of the world, such as Asia and Africa (Takeshita and Kurechi 2007; Primack et al. 2009). Additionally, few studies have examined changes in the phenology of so-called winter birds, birds that spend the summer in high northern latitudes and overwinter in temperate latitudes. Winter birds might be expected to show particularly strong effects of climate change because temperatures are warming faster at high latitudes relative to other latitudes. While some such studies have been carried out, results are often contradictory or inconclusive, perhaps due to the heterogeneous response of bird species to climate change (Pulido et al. 2001; Sparks and Mason 2004; Gordo et al. 2005). Such studies of winter birds represent an important addition to the more abundant studies of bird arrival times in the temperate regions. For winter birds, warming temperature of breeding grounds might be predicted to delay the arrival of birds at the overwintering site and shorten the time that they remain on their wintering grounds (Moritz 1993; Mason 1995; Sokolov et al. 1998; Jenkins and Watson 2000; Tryjanowski et al. 2002; Hüppop and Hüppop 2003). The climate patterns in the wintering areas, rather than those on breeding grounds, may influence the timing departure from the over wintering grounds and consequent arrival at the breeding grounds (Mason 1995; Huin and Sparks 1998, 2000; Cotton 2003). For example, wet springs in Jamaica are associated with increased food abundance and earlier departure times for American Redstarts *Setophaga ruticilla* that winter there (Studds and Marra 2007).

We examined the timing of arrivals, departures, and duration of stay of winter migratory birds over the past 23 years (1986–2008) in Yokohama, a city in central Japan. In this study, we hypothesize that the autumn arrival of winter birds in Yokohama is occurring later, in association with warming conditions on their breeding grounds, and their spring departure is occurring earlier, in association with warming conditions on their wintering grounds. As a result, we predict that the number of days spent at the wintering ground is now shorter than it was in the past. The six birds used in our analysis were selected because they were observed in at least 20 of the 23 years of the study. These six birds are all passerine birds and their breeding grounds are at mid to high latitudes (Table 1).

Methods

Study area and data sources

Observations were made at the Nature Observatory Forest (hereafter called the Forest) in Yokohama (35°20′41.47; 139°37′38.15), a city with a population of 3.6 million people. The site occupies 42 ha with an average altitude of 120 m, and is dominated by secondary forest with deciduous and evergreen trees. The predominant forest species observed throughout the Nature Observatory Forest include the deciduous trees *Swida controversa*, *Quercus serrate*, and *Prunus jamasakura*, the evergreen tree *Machilus thunbergii*, and the acicular trees *Cryptomeria japonica* and *Chamaecyparis obtusa*; grassland areas were dominated by *Miscanthus sinensis* and *Pennisetum alopecuroides*. Temperature data for 23 years from 1986 to 2008 were obtained from the Yokohama Meteorological Observatory (35°26′23.83, 139°39′12.06), 12 km from the Forest.

Sight-based observations of the first arrival dates in the autumn and final departure dates in the late winter of winter migrant birds were recorded daily on regular transect routes at the Forest and around the visitor center. These observations were made by experienced Forest staff and members of the Wild Bird Society of Japan, together with experienced volunteers and ordinary citizens. We selected for our analyses six common species (Table 1). Yokohama is located in the middle of the winter range of all passerine species examined in this study, except for Black-faced Bunting, for which Yokohama is at the northern edge of Japan's overwintering population. These birds have been observed over 23 years from 1986 to 2008; however, no observations were made in 1997 and 1998 for the first arrival date and 1998 and 1999 for the last departure date, which resulted in 20 years of observation for both the first arrival date and the last departure date. The duration of stay was calculated as the difference between arrival date in one year and the departure date in the following calendar year. The population sizes of all six of these species were reported to be relatively constant in Kanagawa Prefecture, which includes Yokohama, during 1986–2008 (Wild Bird Society, Kanagawa-Branch 2007).

Statistical analysis

We used simple linear regression to test for changes in temperature, arrival dates, departure dates, and duration of winter stay over time. In addition to changes over time, we also tested the relationship between temperature and phenology. Average monthly temperatures for the periods 1, 2, 3, and 4 months prior to arrival and departure were regressed against phenology for each to test whether later arrivals or earlier departures were associated with warmer temperatures in Yokohama.

Results

Temperature trends

Temperatures in Yokohama showed a general warming trend during the period of study (Fig. 1). The average annual temperature increased by 0.9°C from 1986 to 2008, as determined by linear regression. This rate of temperature increase in Yokohama is almost three times higher than the increase of average global surface temperatures during the previous 50 years (IPCC 2007), and is due to a combination of global warming and urbanization in Yokohama. The average temperature of the period from August to November, the 4-month period prior to arrival of the six winter birds of this study, has increased by 1.0°C over the past 23 years. The average temperature in February–May, the 4-month period prior to departure time of those birds, has increased by 1.0°C.

Changes over time

The mean first-arrival date in 2008, averaged across all six species, occurred 8.2 days later than it did at the beginning of this study in 1986 ($R^2 = 0.295, p < 0.01$) (Fig. 2; Table 2). The mean departure date of these species also has changed significantly ($R^2 = 0.702$, $p < 0.01$) and now occurs an average of 18.5 days earlier than it did in 1986. As a result, the mean duration of stay of six birds was shortened by 29.7 days ($R^2 = 0.699$, $p < 0.01$).

When considered for individual species, the arrival of two species—Dusky Thrush (*Turdus eunomus*) and Hawfinch (*Coccothraustes coccothraustes*)—occurred significantly later over time (Table 2). The departure dates of four species—Dusky Thrush, Daurian Redstart (*Phoenicurus auroreus*), Black-faced Bunting

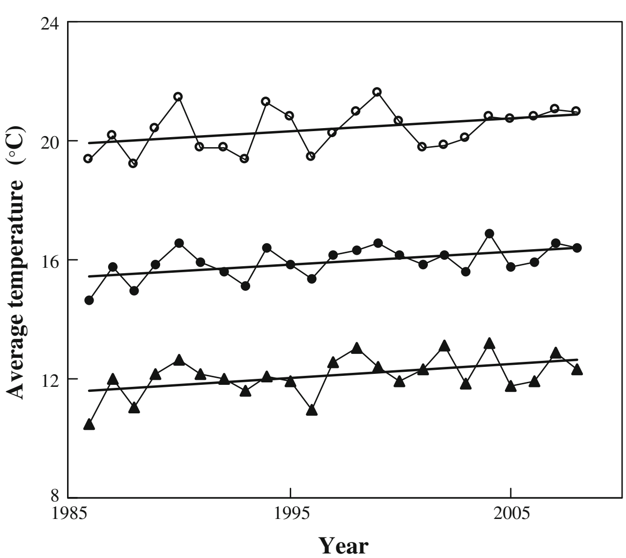

Fig. 1 Temperature changes in Yokohama from 1986 to 2008. Annual average temperature (*black circles*), average temperature August–November (*white circles*), average temperature February–May (*triangles*)

Table 1 The average arrival and departure dates in Yokohama, and the location and habitat of the breeding ranges for the six species examined in this study

Common name	Scientific name	Average arrival date	Average departure date	Summer range (habitat types)[a,b]
Black-faced Bunting	*Emberiza spodocephala*	26 Oct.	1 May	E Siberia and NE China to N Sakhalin and N & S Korea (deciduous forest of lowlands and river valleys, to mid-elevation mountains)
Daurian Redstart	*Phoenicurus auroreus*	22 Oct.	31 Mar.	Lake Baikal and Mongolia east to Amur Estuary, Sakhalin, south to NE China and Korea (open hillsides, very open forest with rocky areas)
Dusky Thrush	*Turdus eunomus*	31 Oct.	3 May	NE Russia east to Yakutia, Chukotka, Kamchatka and Sakhalin (woodland from taiga to edges of lowland tundra)
Eurasian Bullfinch	*Pyrrhula pyrrhula*	9 Nov.	10 Apr.	Across Europe and temperate Asia (montane and lowland mixed and coniferous forests)
Hawfinch	*Coccothraustes coccothraustes*	27 Oct.	4 May	Europe and temperate Asia including northern Japan (montane and lowland deciduous and mixed forests)
Pale Thrush	*Turdus pallidus*	6 Nov.	25 Apr.	Sea of Okhotsk coast through Russian Far East, NE China to Korea (open woodland, deciduous and coniferous forest)

[a] Data from Brazil (2009)
[b] Data from Iozawa et al. (2004)

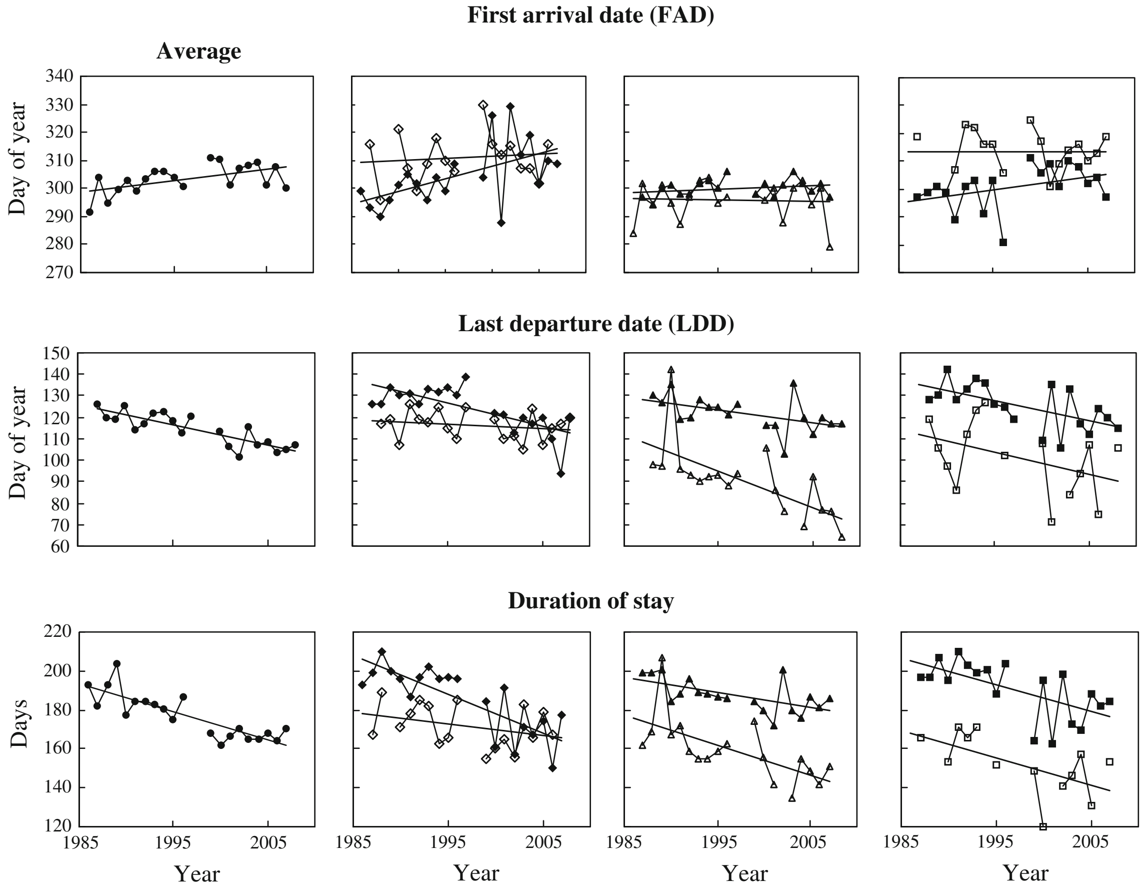

Fig. 2 Patterns in first arrival date, last departure date, and duration of stay for six winter birds observed between 1986 and 2008. Average of six species (*black circles*), Dusky Thrush (*black diamonds*), Pale Thrush (*white diamonds*), Black-faced Bunting (*black triangles*), Daurian Redstart (*white triangles*), Hawfinch (*black squares*), Eurasian Bullfinch (*white squares*)

Table 2 Regression results describing changes in first arrival date (FAD), last departure date (LDD), and duration of stay over the 23-year study period (1986–2008)

Common name	FAD		LDD		Duration of stay		
	Slope	R^2	Slope	R^2	Slope	R^2	Days
Pale Thrush	0.151	0.012	−0.200	0.041	−0.588	0.112	−12.3
Dusky Thrush	0.898	0.317**	−1.071	0.499***	−1.969	0.636**	−41.3
Daurian Redstart	−0.050	0.003	−1.713	0.499**	−1.540	0.413**	−32.3
Black-faced Bunting	0.132	0.076	−0.622	0.264*	−0.754	0.346**	−15.8
Eurasian Bullfinch	0.001	0.000	−1.049	0.185	−1.409	0.367*	−29.6
Hawfinch	0.451	0.153*	−0.931	0.358**	−1.382	0.401**	−29.0
Average	0.404	0.295**	−0.926	0.702**	−1.415	0.699**	−29.7

Slope is given as days/year

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(*Emberiza spodocephala*) and Hawfinch—occurred significantly earlier over time (Table 2). Five species, all except Pale Thrush (*Turdus pallidus*), remained at the Forest for significantly shorter durations over time. Species remained at the Forest for 12.3–41.3 fewer days by the end of the 23-year study (5.6–18.3 days earlier per decade) (Table 2).

Relationship of arrival and departure dates to temperature

The mean date of first arrival, averaged across the six species, occurs later with warmer temperatures; mean first arrival occurs 2.7 days later for each 1°C increase in temperature during the 4 months prior to arrival

(Table 3). Of the six species, only the Pale Thrush has an arrival date that is significantly related to temperature in the four preceding months, arriving later by 6.3 days per 1°C increase in temperature. When we tested the relationships of arrival dates with temperatures 1, 2, and 3 months prior to arrival, again only the Pale Thrush showed statistically significant relationships.

The mean date of last departure, averaged across the six species, was not significantly related to temperature (Table 3). However, the dates of last departure for two species—Black-faced Bunting and Hawfinch—are significantly related to temperature, departing 5.3 and 8.0 days later for each 1°C warming in the 4 months prior to departure. These same two species, and no others, also had correlations of departure time with temperatures in the 2 and 4 months preceding departure.

Relationship between species in arrival dates and departure dates

Correlations between pairs of species can indicate whether species are responding in the same way to environmental cues. For arrival dates, there are 15 possible pairs of correlations. Only one of the 15 correlations of arrival dates was significant; the one between Dusky Thrush and Black-faced Bunting ($R^2 = 0.52$, $p < 0.05$) (Table 4). In contrast, seven correlations between species were evident for departure date (Table 5). Most notably, departure dates for the Dusky Thrush were significantly correlated with those of four other species. The departure dates of the Pale Thrush are not correlated with any of the other five species.

Discussion

It is well documented that many migratory birds are arriving earlier at their spring breeding sites (Sparks et al. 2007; Charmantier et al. 2008). The passerine birds breeding at mid to high latitudes also show a trend toward arriving earlier at breeding sites and completing breeding activities earlier in Europe and United States (Coppack and Both 2003). This study shows that passerine birds in Yokohama are both arriving later at the

Table 3 Regression results describing the relationship of first arrival dates (FAD) and last departure dates (LDD) with mean temperature during the 4 months (Aug.–Nov.) prior to first arrival and last departure

Common name	FAD			LDD		
	Four months		Days/1°C	Four months		Days/1°C
	Slope	R^2		Slope	R^2	
Pale Thrush	6.290	0.448**	6.3	2.864	0.073	2.9
Dusky Thrush	3.955	0.111	4.0	−6.066	0.112	−6.1
Daurian Redstart	0.326	0.002	0.3	−2.954	0.013	−3.0
Black-faced Bunting	−0.020	0.000	0.0	−5.346	0.170*	−5.3
Eurasian Bullfinch	−0.094	0.000	−0.1	−0.094	0.040	−0.1
Hawfinch	0.853	0.012	0.9	−7.955	0.210*	−8.0
Average	2.694	0.217*	2.7	−3.736	0.085	−3.7

Slope is given as days/°C
* $p < 0.05$, ** $p < 0.01$

Table 4 Correlations of the first arrival date between winter bird species

	Dusky Thrush	Daurian Redstart	Black-faced Bunting	Bullfinch	Hawfinch
Pale Thrush	0.19	0.18	0.15	0.06	0.21
Dusky Thrush	–	−0.18	0.52*	0.06	0.07
Daurian Redstart	–	–	0.36	0.16	0.26
Black-faced Bunting	–	–	–	−0.14	−0.11
Eurasian Bullfinch	–	–	–	–	0.27

* $p < 0.05$, ** $p < 0.01$

Table 5 Correlations of the last departure date between winter bird species

	Dusky Thrush	Daurian Redstart	Black-faced Bunting	Bullfinch	Hawfinch
Pale Thrush	0.24	−0.27	−0.04	0.34	−0.09
Dusky Thrush	–	0.49*	0.47*	0.56*	0.42*
Daurian Redstart	–	–	0.59**	0.13	0.49*
Black-faced Bunting	–	–	–	0.14	0.74***
Eurasian Bullfinch	–	–	–	–	0.01

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

overwintering site as well as leaving earlier, shortening the total duration of their stay. Therefore, it is predicted that the passerine birds observed in this study will show a similar trend toward arriving earlier and earlier breeding at their breeding sites in northern Asia and Russia. These changes at both breeding sites and overwintering sites would result in advancing all life-cycle events of passerine birds. During this 23-year period, winter birds observed in Yokohama showed significant trends towards later arrival, earlier departure, and shorter overall duration of stay over the winter. On average, arrivals occurred 9 days later over the 23-year period, or 4 days later per decade. This rate of change is rapid relative to delays in departure from breeding sites observed for other species in other locations (Mills 2005; Beaumont et al. 2006; MacMynowski and Root 2007). The mean departure date of all six species has advanced 21 days, around 9 days per decade. The greater change in the mean departure date in comparison with the mean arrival date is reflected in the individual species: two of the species show significantly later arrival times, whereas four species show significantly earlier departure dates. The result is also consistent with other studies, which have found that changes in spring migrations to breeding grounds are occurring faster than are changes in the autumn migrations to wintering grounds (Lehikoinen et al. 2004; Mills 2005; MacMynowski and Root 2007).

The combination of later arrival dates and earlier departure dates results in shorter overall duration of five of the six birds over wintering in Yokohama. The mean duration of stay of the six species became significantly shorter by 30 days, or about 14 days per decade. These results suggest that these species may be spending more time at their breeding sites, although these results would be also influenced by changes in the speed of migration and duration of stays at stopover sites during migrations.

While certain of our results suggest that temperature at the wintering site affects the arrival and departure times of certain species in Yokohama, the data are not conclusive. The arrival and departure dates of some bird species do not appear to be affected by temperature, and other climatic factors, such as precipitation and wind direction, may also contribute to interannual variation in arrival and departure dates.

The results obtained in this study are consistent with our hypothesis that passerine winter birds are arriving later, staying for a shorter duration, and departing earlier in a temperate area. Although relatively few reports have been published on the timing of arrival, departure and the duration of stay of winter birds (Jenni and Kéry 2003; Sparks and Mason 2004; Gordo et al. 2005), one comparable study examined the first arrivals and last departures of winter visitors for 21 years in the United Kingdom (Sparks and Mason 2004). This study found some climate-related changes in phenology; however, the results also suggested that species vary substantially in their migratory responses to climate change. One model of five European birds found that spring arrival dates are influenced by climate condition in the wintering area, with species varying greatly in the degree of these influences (Gordo et al. 2005). In another study, Jenni and Kéry (2003) found that autumn passage of European birds wintering south of the Sahara has advanced in recent years, presumably as a result of selection pressure to cross the Sahel before its seasonal dry period; in contrast, migrants wintering north of the Sahara have delayed autumn passage. In contrast, we did not find any obvious relationship between delay of arrival to wintering sites and distance of migration in our study.

There could be several advantages to species changing their phenology in response to a changing climate. Birds that arrive earlier on their breeding grounds may be able to establish higher-quality breeding territories, leading to greater reproductive fitness (Berthold 1991). Birds may also be under selection to maintain synchrony between their migrations and the timing of food availability. Once on the breeding site, some birds may be able prolong the breeding season and increase the number of broods per year (Jenni and Kéry 2003). All of these factors could contribute to the changes that we observed for wintering birds in Yokohama.

The arrival dates of birds in Yokohama were not strongly correlated among species. This lack of correlation may be caused because these species spend their breeding seasons in different parts of the world. As such, each bird responds to different cues as it leaves its breeding grounds. Even if two species spend their breeding season in the same general area, one species might arrive and depart its breeding grounds earlier in warm years if it had a single brood. In contrast, a second species might remain on the breeding grounds longer if warm conditions allowed it to increase the number of broods that it produced. Further, each species travels along a different migration route and encounters different weather conditions as it migrates, again leading to different dates on which they arrive at their wintering grounds (Table 5). In contrast, the departure dates between winter species are relatively highly correlated. All of the six species encounter the same weather in the Yokohama area before they depart. All six species will experience warm and cold springs together. However, the departure time of the Pale Thrush was not correlated with any of the other five species, indicating that not all species respond to climate in the same way even in one place. Further studies of the feeding habits, behavior, and ecology of the Pale Thrush at both wintering and breeding sites, extending the work of Seki (1998), might help why this species is different from the other species in its departure pattern.

A potential problem with using first arrival dates and final departure dates of migratory birds, as we have done in this study, is that these data may not represent the migratory behavior of the whole population, as errant individuals will affect the first date recorded. Further, such data may be affected by the recording effort of the observers and population size of the species (Mason 1995; Sparks et al. 2001; Tryjanowski and Sparks 2001;

Tryjanowski et al. 2005; Miller-Rushing et al. 2008a, b). For example, a declining population would tend to have later first arrival times and earlier last departure dates due to changes in size alone (Miller-Rushing et al. 2008a). Such effects could either mask the effects of climate change, or falsely exaggerate the effects. In our study, the sampling effort and the population sizes of these species have remained fairly constant over time. As a consequence, we are reasonably confident that we have been able to detect the impacts of climate change on the phenology of these winter birds. However, because the phenological trends that we observed can also be caused by a declining population size, researchers need to be aware of these possible confounding effects.

Many of the data used in this study were gathered by citizens associated with the Wild Bird Society of Japan. Throughout the world, scientists are currently working to establish such networks of citizen scientists who can increase the number of observation sites and frequency of observations needed to detect the effects of climate change. Incorporating citizens in these monitoring effects also contributes to conservation education and promotes an awareness of the impacts of climate change (Kobori 2009).

In conclusion, we observed changes in the phenology of six winter bird species over 23 years in Yokohama, changes that were related to changes in climate during that same time. Although bird species are arriving earlier in autumn, their departure is changing even more rapidly, resulting in a substantial shortening of the overwintering period for these bird species. However, not all bird species are responding in this way—some species show a greater effect than others. An important result is that the dates on which the six bird species depart their wintering grounds in the spring are more synchronized than are the dates on which they arrive in the autumn. And finally, this study demonstrates the value of observations made by dedicated citizens, working in association with scientists, in advancing the field of climate change biology.

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