

1 **Changes in autumn arrival of long-distance migratory birds in Southeast Asia**

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13 Running head: Tropical bird migration phenology

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20

1 **Abstract**

2 Climate-change-induced phenological changes in migratory birds are predicted from ecological  
3 theory and have been well-documented in temperate-zone breeding areas. By contrast, changes  
4 in arrival date on the tropical wintering grounds have not been reported. To address this gap, we  
5 analysed birdwatchers' records of first arrival dates of nine species of long-distance migratory  
6 birds in Singapore from 1987–2009. The study species included a raptor, three waders, and five  
7 passerines. We compared the relative influence of year, Southern Oscillation Index, and observer  
8 effort on arrival date. There was strong evidence for an arrival delay of approximately two  
9 days/year (95% confidence intervals of 1–3 days) in Japanese sparrowhawk *Accipiter gularis* and  
10 curlew sandpiper *Calidris ferruginea*, but there was no change in arrival date for the other seven  
11 species. We hypothesise that climate change is causing a shift in migration timing for some birds  
12 in Southeast Asia. A mechanism for the delay in these long-distance migrants may be that  
13 warmer temperatures enable species to remain on northern breeding grounds longer. Delayed  
14 arrival on the wintering grounds may have cascading effects on a migratory species' annual  
15 cycle, for example by influencing breeding grounds arrival date, which can impact fitness. These  
16 potential impacts underscore the need for further work on the effects of climate change on  
17 migratory species in the tropics.

18 **Keywords:** *Accipiter gularis*, *Calidris ferruginea*, *citizen science*, *climate change*, *migration*,  
19 *phenology*

1 **Introduction**

2 Changes in phenology are one of the best-documented and most consistently observed impacts of  
3 climate change on animals (Lehikoinen & Sparks 2010). For migratory birds, it is well  
4 established that spring arrival date on the European and North American breeding grounds is  
5 advancing (reviewed in Lehikoinen & Sparks 2010; Knudsen et al. 2011), but responses are  
6 expected to vary regionally (Askeyev et al. 2010). Long-distance migrants are often thought to  
7 have endogenous control of migration timing because they are unaware of weather conditions  
8 where they are headed (Gwinner 1996), while short-distance migrants may be more flexible in  
9 their capacity to alter migration timing based on their perception of regional weather conditions,  
10 especially if they migrate slowly (Hötker 2002; Hurlbert & Liang 2012). Nonetheless, a recent  
11 review found no consistent differences in spring arrival changes between short- and long-  
12 distance migrants (Knudsen et al. 2011).

13 Autumn departure and passage are less studied than spring arrival, and there is much  
14 variation in changes in autumn departure/passage over time, with no clear trend of advances or  
15 delays (Thorup et al. 2007; Lehikoinen & Sparks 2010). Several north-temperate studies found  
16 that long-distance passerines have advanced their autumn departure (Cotton 2003; Jenni & Kéry  
17 2003; Péron et al. 2007; Van Buskirk et al. 2009), while short-distance migrants delayed  
18 departure (Jenni & Kéry 2003; Van Buskirk et al. 2009). Advances of long-distance migrants  
19 could be related to advances in the overall annual cycle associated with earlier spring arrival  
20 (Gilyazov & Sparks 2002; Lehikoinen et al. 2004; Lehikoinen & Sparks 2010; but see Thorup et  
21 al. 2007; Van Buskirk et al. 2009). Other north-temperate passerine studies have found general  
22 delays in autumn passage in short- (Smith & Patton 2010) and long-distance migrants (Smith &  
23 Patton 2010; Kovacs et al. 2011, 2012), while still others have found more variation. For

1 example, Tøttrup et al. (2006) found migration distance was inversely proportional to earlier  
2 autumn departure in European passerines, and Mills (2005) studied passerines in Ontario,  
3 Canada, and found one long-distance and four short-distance migrants delayed passage, while  
4 two long-distance species advanced. In one of the most comprehensive multi-species studies,  
5 Sparks et al. (2007) found significantly delayed autumn departure in 15 species in 20 out of 67  
6 time series that were at least 20 years long.

7         The little research done on non-passerine autumn passage has also found variable  
8 changes. In studies of long-distance migrant waders in Central Europe, Adamík and Pietruszkova  
9 (2008) found three species advanced and three delayed autumn passage, and Anthes (2004)  
10 found three species delayed. Filippi-Codaccioni et al. (2010) found one short-distance and four  
11 long-distance raptors advanced autumn passage, while Van Buskirk (2012) recorded autumn  
12 delays in 10 species and an advance in one species. It is likely that the above variation in autumn  
13 passage is related to differing mechanisms behind changes among species (especially relating to  
14 life-history traits) and regions, but more research is required to better understand these patterns  
15 on a species-specific basis (Rubolini et al. 2007; Møller et al. 2008; Lehikoinen & Sparks 2010;  
16 Végvári et al. 2010).

17         Even less is known of how changes in autumn departure/passage in the northern  
18 hemisphere translate into changes in arrival on the wintering grounds. Studies with light-sensing  
19 geolocators have revealed that migrant departure date is correlated with arrival date on the  
20 wintering grounds, but individual birds vary in their rate of migration and time spent at stopover  
21 sites, so departure date is only a partial predictor of wintering grounds arrival date (Stutchbury et  
22 al. 2011; Stanley et al. 2012). The few southern hemisphere analyses that have measured changes  
23 in time of arrival at wintering grounds found advances in three Siberian breeders in south-eastern

1 Australia (Beaumont et al. 2006), and eight short-distance migrants in southern Australia  
2 (Chambers 2005; Smith & Smith 2012), but no significant changes in timing of arrival for the  
3 long-distance migratory barn swallow (*Hirundo rustica*) in South Africa (Altwegg et al. 2012).  
4 In addition, Kok et al. (1991) presented first arrival dates for spotted flycatchers (*Muscicapa*  
5 *striata*) on their South African wintering grounds from 1950–1986, and it appears that arrival has  
6 delayed over time (pers. obs.), but this observation was not tested by the authors.

7       Changes in arrival date on the tropical wintering grounds and passage through the tropics  
8 are unstudied, probably because of the paucity of long-term tropical datasets (Gordo 2007;  
9 Lehtikoinen & Sparks 2010). Yet, analyses from the tropics are urgently needed because  
10 hundreds of species make temperate-tropical journeys, and changes in timing can impact other  
11 stages in the annual cycle (Marra et al. 1998). For example, late arrival on the wintering grounds  
12 may have negative consequences if species compete for non-breeding territories (Faaborg et al.  
13 2010), and birds that occupy poor wintering territories have been shown to arrive later on the  
14 breeding grounds which could force them into lower quality territories, or to expend energy  
15 competing with earlier arrivals (Norris et al. 2004).

16       We studied changes in first arrival date of nine long-distance migrants, comprising  
17 passerines (*Passeriformes*), waders (*Charadriiformes*), and a raptor (*Falconiformes*), from 1987–  
18 2009 in Singapore, a natural bottleneck in the East Asian flyway with diverse habitats and a long  
19 history of birdwatching. Our study examined common, generalist species to evaluate if any  
20 changes in migration timing were evident. Given that much of East Asia has warmed by  $> 0.2$  °C  
21 per decade since the 1960s (IPCC 2007), and that migration timing has been linked to  
22 temperature (Lehtikoinen & Sparks 2010), we hypothesized that some of our study species would  
23 change their migration phenology.

1

## 2 **Methods**

3 First arrival dates came from birdwatchers' records that were verified by local experts and  
4 published monthly in the Singapore Bird Group's newsletter *Singapore Avifauna* (Lim and  
5 Subaraj 1987–1990, 1992, 1997, 1998, 2000–2003, 2006, 2008, 2009). The *Singapore Avifauna*  
6 data come from reports by skilled recreational birdwatchers. More birdwatchers tended to go into  
7 the field during migration and on weekends; approximately 5–30 observers went out each week  
8 during autumn passage from July to December (our study period). Difficult-to-detect species  
9 may require more time to be found, such as is available to birdwatchers on weekends, which can  
10 lead to biased reports of species occurrence—the “weekend effect” (Sparks et al. 2007, 2008);  
11 our focus on common, easily detectable species (see below) should minimize this potential bias  
12 (Ptaszyk et al. 2003; Sparks et al. 2008). All Singaporean sites known to host substantial  
13 numbers of migrants were visited by birdwatchers annually.

14 Full arrival distribution data are preferable to first arrival dates because the latter are an  
15 incomplete sample of the population (Sparks et al. 2001; Tryjanowski et al. 2005; Miller-  
16 Rushing et al. 2008; Van Buskirk et al. 2009; Lehikoinen & Sparks 2010), but first arrival dates  
17 are often the only sources available, especially from poorly studied regions (Lehikoinen et al.  
18 2004; Beaumont et al. 2006; Gordo & Doi 2012). Compared to mean arrival dates, first arrival  
19 dates often suggest stronger shifts in migration timing that may be more variable geographically,  
20 but the sign of change is usually in the same direction as mean arrival dates (Rubolini et al. 2007;  
21 Thorup et al. 2007; Lehikoinen & Sparks 2010).

1 Singapore was originally covered in lowland rainforest with mangroves and tidal flats on  
2 the coast. Over the past 200 years most forests were replaced with cropland and then urban  
3 development, while many coastal wetlands were filled in for urban and shipping development  
4 (Hails 1989; Corlett 1992). These changes caused extinctions of forest-dependent species, but the  
5 country still has a resident avifauna of 146 breeding species and is an important stopover and  
6 wintering site for migratory land and water birds, with at least 115 additional species recorded  
7 annually (Wells 1999, 2007; Brook et al. 2003; Lim 2009; Lim & Lim 2009).

8 Our study species are common birds that were seen each year, and habitat generalists that  
9 should be weakly affected by deforestation (Lim & Lim 2009; Wells 1999, 2007). Habitat  
10 preferences of migratory birds on the Asian wintering grounds are poorly known, but all of our  
11 passerine and raptor study species are able to use a range of habitats and, for most, interior forest  
12 is probably not preferred (e.g., tiger shrike *Lanius tigrinus*; arctic warbler *Phylloscopus borealis*;  
13 Wells 2007). There have been no water bird extirpations in Singapore, despite historic wetland  
14 conversion (Lim & Lim 2009). Most of Singapore's wetland loss occurred before our study period  
15 (Hails 1989; Lim 2009). The small reduction in wetland habitat observed during our study period  
16 would not be expected to affect arrival date of waders because large areas of mudflats and wet  
17 grasslands still exist at sites such as Sungei Buloh, Mandai wetlands, Pulau Ubin, Changi North-  
18 Central, Jurong West and Punggol, and these same focal sites were visited by observers each  
19 year (Lim 2009; Lim & Lim 2009). Highly skilled observers submitted observations to  
20 *Singapore Avifauna* annually, so it is unlikely that changes in identification ability affected  
21 arrival dates (R.S. pers. obs.).

22 Birdwatching effort and reporting in Singapore have varied over time (Wee 2006), which  
23 could potentially confound our analysis. We accounted for this in the following ways. Firstly,

1 Singapore bird experts among the co-authors (D.L.Y. and R.S.) removed records of post-  
2 breeding dispersal and very late “first arrival” records (seen after migration) that were due to  
3 incomplete sampling. Our study species are common migrants and all study species were seen  
4 each year (i.e., changes in population size had no effect on whether or not a species was recorded  
5 that year). Secondly, observer effort in each year was characterised and only well-sampled years  
6 were analysed. We evaluated sampling coverage on an initial pool of 36 potential study species  
7 that had at least eight years with reliable arrival dates (i.e., seen during migration). We made the  
8 *a priori* rule that a year was considered to be adequately sampled when a reliable arrival date  
9 was recorded for >15 of the 36 species, leaving 14 years from the 1987–2009 span for the  
10 analysis. We defined observer effort as the proportion of 36 bird species for which a reliable  
11 arrival date was available that year (Fig. 1). This measure of observer effort was added as a  
12 predictor variable to the candidate model set (see below). As a final step, we chose to analyse  
13 only those species in the pool of 36 potential species with the best data (i.e., having time series of  
14 at least 13 years), which left nine study species. Japanese sparrowhawk *Accipiter gularis*,  
15 common sandpiper *Actitis hypoleucos*, tiger shrike, and Siberian blue robin *Luscinia cyane* had  
16 time series of 13 years; the remaining species had series of 14 years. All of our study species  
17 breed north of c. 25° N, so we considered them to be long-distance migrants.

18 Changes in population size can influence detection probability (Tryjanowski & Sparks  
19 2001), and abundance may also respond to climate change (Sokolov et al. 2000), so we  
20 characterized population trends for our study species. Few high-quality local- or regional-scale  
21 population trend data were available, so we used global measures of population status for most  
22 species (BirdLife International 2011). Global trend information was unavailable for purple-  
23 backed starling *Agropsar sturninus*, so we approximated status for this species based on

1 Singapore trend data in Lim and Lim (2009). In contrast to information from BirdLife  
2 International (2011), data from the Asian-Australasian flyway indicate curlew sandpiper *Calidris*  
3 *ferruginea* is declining (Bamford et al. 2008). The literature indicated Japanese sparrowhawk,  
4 arctic warbler, yellow-rumped flycatcher *Ficedula zanthopygia*, and purple-backed starling are  
5 stable, and curlew sandpiper, ruddy turnstone *Arenaria interpres*, common sandpiper, tiger  
6 shrike, and Siberian blue robin are declining. None of the study species are considered by the  
7 IUCN to be threatened (BirdLife International 2011).

8         The large range of latitudes where our study species breed (c. 25–80° N) made it  
9 unfeasible to include local temperature as a predictor of arrival date. Instead, we opted to use the  
10 Southern Oscillation Index (SOI; Bureau of Meteorology 2011) as a measure of El Niño-related  
11 changes in regional climate. El Niño/Southern Oscillation has been shown to have profound  
12 effects on climate in the Asia-Pacific region (e.g. Wang et al. 2001), and has correlated with  
13 changes in avian migration timing in other studies (Lehikoinen & Sparks 2010).

14         Gaussian general linear models were used to compare the importance of year, SOI, and  
15 observer effort on arrival date using a maximum-likelihood, multi-model inference framework  
16 for statistical inference, implemented in R v2.14.1 (Burnham & Anderson 2002; R Development  
17 Core Team 2012). Julian arrival date was the response variable in our analyses. We ran separate  
18 analyses for each species. For the species with 14 years of arrival dates we used all additive  
19 combinations of predictor variables. In species with 13 years of arrival dates we did not include  
20 the global model (*arrival date* ~ *year* + *observer effort* + *SOI*) to avoid over-fitting (Burnham &  
21 Anderson 2002), because this model's number of parameters (five) is greater than 30% of the  
22 sample size. Constrained sample sizes did not permit testing the effects of population trend. We  
23 tested for correlations among predictors with a Spearman correlation matrix and found that all

1 variables had Spearman coefficients  $< 0.55$ . We checked diagnostic plots of the relationship  
2 between the fitted values and residuals, the quantiles in the data against theoretical normal  
3 quantiles, and the relationship between leverage and standardised residuals to evaluate if the  
4 models met the assumptions of Gaussian regression (Crawley 2007). Bootstrapping (10,000  
5 samples with replacement) was used to generate confidence intervals around slope estimates for  
6 the *arrival date ~ year* relationship in all species (Crawley 2007). For species with evidence for  
7 changed arrival date over time, we calculated model-averaged coefficients of the *arrival date ~*  
8 *year* relationship based on the  $AIC_c$  weights. We used Burnham and Anderson's (2002; p. 152)  
9 first model averaging method where the coefficient (year) is averaged only over models in which  
10 it appears, after weights have been rescaled to sum to unity.

11

## 12 **Results**

13 Two species, Japanese sparrowhawk, and curlew sandpiper, showed a delayed arrival date during  
14 the study period (Fig. 2; Tables 1, 2). The single-variable *year* model was top ranked for the  
15 sparrowhawk and sandpiper, with  $wAIC_c$  of 0.58 and 0.46, respectively. The sum of  $wAIC_c$  for  
16 models including year as a predictor were 0.982 and 0.993 for the sparrowhawk and sandpiper,  
17 respectively. Based on the single-variable *year* model, the effect size was similar between the  
18 two species, a delay of 2.0 days/year (1.1–2.9, 95% confidence interval) for the sparrowhawk,  
19 and a delay of 1.8 days/year (0.9–2.5) for the sandpiper. The model-averaged estimate for the  
20 'year' coefficient was 1.9 days/year for both species.

21 By contrast, the other species showed no change in arrival date over time (Tables 1, 2).

22 The null model was top-ranked in all of these species except for Siberian blue robin, where

1 observer effort was the top model. SOI as a single variable was not a statistically supported  
2 predictor of arrival date for any of the study species. Despite the even split of species (five  
3 stable, including Japanese sparrowhawk, and four declining, including curlew sandpiper), there  
4 was no clear pattern of changed arrival based on population trend. Model diagnostics show the  
5 data met the necessary assumptions for Gaussian-identity link models.

6

## 7 **Discussion**

8 Our results indicate that two long-distance migrants, Japanese sparrowhawk and curlew  
9 sandpiper, have delayed autumn arrival in Singapore. We hypothesise that these changes are  
10 related to warming temperatures because the region has warmed considerably during the study  
11 period (IPCC 2007), the study species are common generalists that should not be strongly  
12 affected by habitat loss in Singapore, and we tested for the effects of changing observer effort.  
13 Nonetheless, our findings should be interpreted with caution because first arrival date studies do  
14 not give information on population wide-changes, and can show stronger (although often  
15 concordant) trends compared to full arrival distribution studies (e.g., Mills 2005; Rubolini et al.  
16 2007; Thorup et al. 2007). This pattern could explain why the slopes of the *arrival date* ~ *year*  
17 relationship are larger than slopes reported in most migration phenology studies (Lehikoinen &  
18 Sparks 2010). In addition, it is possible that the delay observed in curlew sandpiper could be  
19 partially explained by reduced detectability resulting from its declining population (Tryjanowski  
20 & Sparks 2001). Nonetheless, we find this explanation unlikely because the species is still  
21 recorded in large numbers; for example at least 200 individuals were recorded annually from a  
22 single wetland, Sungei Buloh, in recent years (Gan et al. 2012).

1           In general, the arrival delays we observed agree with studies showing delayed autumn  
2 passage of long-distance migrants (Anthes 2004; Adamík & Pietruszkova 2008; Smith & Patton  
3 2010; Kovacs et al. 2011, 2012), but as described above, there is much variation among species  
4 and sites (Cotton 2003; Jenni & Kéry 2003; Péron et al. 2007; Sparks et al. 2007; Van Buskirk et  
5 al. 2009). Interestingly, Beaumont et al. (2006) found advances in winter arrival for some long-  
6 distance species in Australia, including curlew sandpiper, which showed a strong delay in our  
7 study. A substantial proportion of the East Asian population of curlew sandpiper winters in  
8 southern Australia (Bamford et al. 2008). It is unclear if we studied the same populations of this  
9 species, but these apparently contradictory results could reflect changes in the rate of migration  
10 between sampling sites (*sensu* Stutchbury et al. 2011; Stanley et al. 2012).

11           The arrival delays in long-distance migrants could be related to warming temperatures  
12 enabling species to remain in northern breeding or passage areas later in the year (Anthes 2004;  
13 Lehikoinen et al. 2004). While the possible mechanism for this pattern is unknown, warmer  
14 temperatures could lengthen the growing season when terrestrial or marine prey would be active,  
15 or decrease the energetic cost of birds remaining in northern latitudes (Zwarts 1990; Bradshaw &  
16 Holzapfel 2006). Japanese sparrowhawk has a markedly different diet, habitat preference, and  
17 migration strategy compared to curlew sandpiper (e.g., *Accipiter* migration is not confined to the  
18 coast, and waders tend to migrate at night; Richardson 1979), which suggests different  
19 mechanisms could underlie the delays we observed. It is unclear why the other species in our  
20 study did not change their migration timing, but this lack of response is consistent with the  
21 mixed results (including no changes) shown in autumn departure/passage studies (Mills 2005;  
22 Thorup et al. 2007; Van Buskirk et al. 2009).

1 Changes in arrival timing have conservation implications for species, and potentially,  
2 ecosystems. Delayed arrival on the wintering grounds may affect territory acquisition, which can  
3 be related to arrival timing on the breeding grounds and, eventually, fitness (Marra et al. 1998).  
4 Furthermore, mistiming can result when species change their phenology at different rates. For  
5 example, populations of pied flycatcher *Ficedula hypoleuca* that arrive after the peak emergence  
6 of their primary food source are prone to decline (Both et al. 2006). Wader prey abundance can  
7 also be related to temperature (Zwarts 1990), which could cause similar mistiming.

8 In conclusion, we conducted the first analysis of changes in avian migratory phenology in  
9 the tropics. We found evidence for arrival delays in Japanese sparrowhawk and curlew  
10 sandpiper, but no changes in our other study species. During our study period the climate  
11 warmed across Asia (IPCC 2007) which suggests the observed changes may be related to  
12 warming temperatures. The effects of changes in migration timing on migratory species' annual  
13 cycles emphasise the need for further analyses on climate change impacts on migratory species  
14 in the tropics.

15

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1 **References**

- 2 Adamík P, Pietruszkova J (2008) Advances in spring but variable autumnal trends in timing of  
3 inland wader migration. *Acta Ornithologica* 43:119–128
- 4 Altwegg R, Broms K, Erni B, barnard P, Midgley GF, Underhill LG (2012) Novel methods  
5 reveal shifts in migration phenology of barn swallows in South Africa. *Proc Roy Soc B*  
6 279:1485–1490
- 7 Askeyev O, Sparks T, Askeyev I, Tishin D, Tryjanowski P (2010) East versus West: contrasts in  
8 phenological patterns? *Global Ecol Biogeogr* 19:783–793
- 9 Bamford M, Watkins D, Bancroft W, Tischler G, Wahl J (2008) Migratory shorebirds of the east  
10 Asian-Australasian flyway: population estimates and internationally important sites.  
11 Wetlands International-Oceania, Canberra, Australia
- 12 Beaumont LJ, McAllan IAW, Hughes L (2006) A matter of timing: changes in the first date of  
13 arrival and last date of departure of Australian migratory birds. *Glob Change Biol*  
14 12:1339–1354
- 15 BirdLife International (2011) BirdLife International data zone.  
16 <http://www.birdlife.org/datazone.html>. Accessed 5 September 2011
- 17 Both C, Bouwhuis S, Lessells CM, Visser ME (2006) Climate change and population declines in  
18 a long-distance migratory bird. *Nature* 441:81–83
- 19 Both C, Van Turnhout CAM, Bijlsma RG, Siepel H, Van Strien AJ, Foppen RPB (2010) Avian  
20 population consequences of climate change are most severe for long-distance migrants in  
21 seasonal habitats. *Proc Roy Soc B* 277:1259–1266.
- 22 Bradshaw WE, Holzapfel CM (2006) Evolutionary response to rapid climate change. *Science*  
23 312:1477–1478

- 1 Brook BW, Sodhi NS, Ng PKL (2003) Catastrophic extinctions follow deforestation in  
2 Singapore. *Nature* 424:420–423
- 3 Bureau of Meteorology (2011) Southern Oscillation Index archives. Bureau of Meteorology,  
4 Australian government. <http://www.bom.gov.au/climate/current/soi2.shtml>. Accessed 1  
5 November 2011
- 6 Burnham KP, Anderson DR (2002) *Model selection and multimodel inference*, 2nd ed. Springer,  
7 New York
- 8 Chambers LE (2005) Migration dates at Eyre Bird Observatory: links with climate change? *Clim*  
9 *Res* 29:157–165
- 10 Corlett RT (1992) The ecological transformation of Singapore, 1819–1990. *J Biogeogr* 19:411–  
11 420
- 12 Cotton PA (2003) Avian migration phenology and global climate change. *Proc Nat Acad Sci*  
13 *USA* 100:12219
- 14 Crawley MJ (2007) *The R book*. Wiley, Chichester, UK
- 15 Faaborg J, Holmes RT, Anders AD et al. (2010) Recent advances in understanding migration  
16 systems of New World land birds. *Ecol Monogr* 80:3–48
- 17 Filippi-Codaccioni O, Moussus J-P, Urcun J-P, Jiguet F (2010) Advanced departure dates in  
18 long-distance migratory raptors. *J Ornithol* 151:687–694
- 19 Gan J, Tan M, Li D (2012) *Migratory birds of Sungei Buloh Wetland Reserve*. 2nd edition.  
20 National Parks Board, Singapore. 92 pp.
- 21 Gilyazov A, Sparks T (2002) Change in the timing of migration of common birds at the Lapland  
22 Nature Reserve (Kola Peninsula, Russia) during 1931–1999. *Avian Ecol Behav* 8:35–47

- 1 Gordo O (2007) Why are bird migration dates shifting? A review of weather and climate effects  
2 on avian migratory phenology. *Clim Res* 35:37–58
- 3 Gordo O, Doi H (2012) Drivers of population variability in phenological responses to climate  
4 change in Japanese birds. *Clim Res* 54:95–112
- 5 Gwinner E (1996) Circannual clocks in avian reproduction and migration. *Ibis* 138:47–63
- 6 Hails CJ (1989) Singapore. In: Scott DA (ed.) A directory of Asian wetlands. IUCN wetland  
7 directories. IUCN, Gland, Switzerland
- 8 Hötker H (2002) Arrival of pied avocets *Recurvirostra avosetta* at the breeding site: effects of  
9 winter quarters and consequences for reproductive success. *Ardea* 90:379–387
- 10 Hurlbert AH, Liang Z (2012) Spatiotemporal variation in avian migration phenology: citizen  
11 science reveals effects of climate change. *PLoS ONE* 7:e31662
- 12 IPCC (2007) Section 3.2, changes in surface climate. in *Climate change 2007: the physical*  
13 *science basis. Contribution of Working Group I to the Fourth Assessment Report of the*  
14 *Intergovernmental Panel on Climate Change*, eds Solomon S , Qin D , Manning M , Chen  
15 Z , Marquis M , Averyt KB , Tignor M , Miller HL. Cambridge University Press,  
16 Cambridge, UK
- 17 Jenni L, Kéry M (2003) Timing of autumn bird migration under climate change: advances in  
18 long-distance migrants, delays in short-distance migrants. *Proc Roy Soc B* 270:1467–  
19 1471
- 20 Kok OB, Van Ee CA, Nel DG (1991) Daylength determines departure date of the spotted  
21 flycatcher *Muscicapa striata* from its winter quarters. *Ardea* 79:63–66
- 22 Kovács S, Csörgő T, Harnos A, Fehérvári P, Nagy K (2011) Change in migration phenology and  
23 biometrics of two conspecific *Sylvia* species in Hungary. *J Ornithol* 152:365–373.

1 Kovács S, Fehérvári P, Nagy K, Harnos A, Csörgő T (2012) Changes in migration phenology  
2 and biometrical traits of Reed, Marsh and Sedge Warblers. *Cent Eur J Biol* 7:115–125.

3 Knudsen E, Lindén A, Both C et al. (2011) Challenging claims in the study of migratory birds  
4 and climate change. *Biol Rev* 86:928–946

5 Lehikoinen E, Sparks T (2010) Changes in migration. In: Møller AP, Fiedler W, Berthold P (eds)  
6 Effects of climate change on birds. Oxford University Press, Oxford, UK, pp 89–112

7 Lehikoinen E, Sparks T, Zalakevicius M (2004) Arrival and departure dates. *Adv Ecol Res* 35:1–  
8 31

9 Lim KC, Lim KS (2009) State of Singapore's wild birds and bird habitats. A review of the annual  
10 bird census 1996–2005. Nature Society (Singapore), Singapore

11 Lim KS (2009) The avifauna of Singapore. Nature Society (Singapore), Singapore

12 Lim KS, Subaraj R (1987–1990, 1992, 1997–1998, 2000–2003, 2006, 2008–2009) Bird reports,  
13 July-December. *Singapore Avifauna* 1–4, 6, 11–12, 14–16, 19, 21–22

14 Marra PP, Hobson KA, Holmes RT (1998) Linking winter and summer events in a migratory  
15 bird by using stable-carbon isotopes. *Science* 282:1884–1886

16 Miller-Rushing AJ, Lloyd-Evans TL, Primack RB, Satzinger P (2008) Bird migration times,  
17 climate change, and changing population sizes. *Glob Change Biol* 14:1959–1972

18 Mills AM (2005) Changes in the timing of spring and autumn migration in North American  
19 migrant passerines during a period of global warming. *Ibis* 147:259–269

20 Møller AP, Rubolini D, Lehikoinen E (2008) Populations of migratory bird species that did not  
21 show a phenological response to climate change are declining. *Proc Nat Acad Sci USA*  
22 105:16195–16200

- 1 Norris DR, Marra PP, Montgomerie R, Kyser TK, Ratcliffe LM (2004) Reproductive effort,  
2 molting latitude, and feather color in a migratory songbird. *Science* 306:2249–2250
- 3 Péron G, Henry PY, Provost P, Dehorter O, Julliard R (2007) Climate changes and post-nuptial  
4 migration strategy by two reedbed passerines. *Clim Res* 35:147–157
- 5 Ptaszyk J, Kosicki J, Sparks T, Tryjanowski P (2003) Changes in the timing and pattern of  
6 arrival of the White Stork (*Ciconia ciconia*) in western Poland. *J Ornithol* 144:323–329
- 7 R Development Core Team (2012) R: A language and environment for statistical computing.  
8 Version 2.14.1. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-  
9 900051-07-0, <http://www.R-project.org>
- 10 Richardson WJ (1979) Southeastward shorebird migration over Nova Scotia and New Brunswick  
11 in autumn: a radar study. *Can J Zool* 57:107–124
- 12 Rubolini D, Møller A, Rainio K, Lehikoinen E (2007) Intraspecific consistency and geographic  
13 variability in temporal trends of spring migration phenology among European bird  
14 species. *Clim Res* 35:135–146
- 15 Smith SB, Paton PWC (2011) Long-term shifts in autumn migration by songbirds at a coastal  
16 eastern north American stopover site. *Wilson J Ornithol* 123:557–566
- 17 Smith P, Smith J (2012) Climate change and bird migration in south-eastern Australia. *Emu*  
18 112:333–342
- 19 Sokolov LV, Yefremov VD, Markovets MY, Shapoval AP, Shumakov ME (2000) Monitoring of  
20 numbers in passage populations of passerines over 42 years (1958–1999) on the Courish  
21 Spit of the Baltic Sea. *Avian Ecol Behav* 4:31–53
- 22 Sparks TH, Roberts DR, Crick HQP (2001) What is the value of first arrival dates of spring  
23 migrants in phenology? *Avian Ecol Behav* 7:75–85

1 Sparks TH, Huber K, Bland RL, Crick HQP, Croxton PJ, Flood J, Loxton RG, Mason CF,  
2 Newnham JA, Tryjanowski P (2007) How consistent are trends in arrival (and departure)  
3 dates of migrant birds in the UK? *J Ornithol* 148:503–511

4 Sparks TH, Huber K, Tryjanowski P (2008) Something for the weekend? Examining the bias in  
5 avian phenological recording. *Int J Biometeor* 52:505–510

6 Stanley CQ, MacPherson M, Fraser KC, McKinnon EA, Stutchbury BJM (2012) Repeat tracking  
7 of individual songbirds reveals consistent migration timing but flexibility in route. *PLoS*  
8 *ONE* 7:e40688.

9 Stutchbury BJM, Gow EA, Done T, MacPherson M, Fox JW, Afanasyev V (2011) Effects of  
10 post-breeding moult and energetic condition on timing of songbird migration into the  
11 tropics. *Proc Roy Soc B* 278:131–137

12 Thorup K, Tøttrup A, Rahbek C (2007) Patterns of phenological changes in migratory birds.  
13 *Oecologia* 151:697–703

14 Tøttrup AP, Thorup K, Rahbek C (2006) Changes in timing of autumn migration in North  
15 European songbird populations. *Ardea* 94:527–536

16 Tryjanowski P, Sparks TH (2001) Is the detection of the first arrival date of migrating birds  
17 influenced by population size? A case study of the red-backed shrike *Lanius collurio*. *Int*  
18 *J Biomet* 45:217–219

19 Tryjanowski P, Kuźniak S, Sparks TH (2005) What affects the magnitude of change in first  
20 arrival dates of migrant birds? *J Ornithol* 146:200–205

21 Van Buskirk J, Mulvihill RS, Leberman RC (2009) Variable shifts in spring and autumn  
22 migration phenology in North American songbirds associated with climate change. *Glob*  
23 *Change Biol* 15:760–771

- 1 Van Buskirk J (2012) Changes in the annual cycle of North American raptors associated with  
2 recent shifts in migration timing. *Auk* 129:691–698
- 3 Végvári Z, Bókony V, Barta Z, Kovács G (2010) Life history predicts advancement of avian  
4 spring migration in response to climate change. *Global Change Biol* 16:1–11
- 5 Wang Y, Wang B, Oh J-H (2001) Impact of the preceding El Niño on the East Asian summer  
6 atmosphere circulation. *J Met Soc Japan* 79:575–588
- 7 Wee YC (2006) Forty years of birding and ornithological research in Singapore. *Birding Asia*  
8 5:12–15
- 9 Wells DR (1999, 2007) *The birds of the Thai-Malay peninsula, volumes 1, 2*. Academic press  
10 and Christopher Helm, San Diego, CA, USA and London, UK
- 11 Zwarts L (1990) Increased prey availability drives pre-migration hyperphagia in Whimbrels and  
12 allows them to leave the Banc d'Arguin, Mauritania, in time. *Ardea* 78:279–300
- 13

1 Table 1. Table of Gaussian general linear model results for arrival date in nine study species.  
 2 There was evidence for delayed arrival in Japanese sparrowhawk *Accipiter gularis* and curlew  
 3 sandpiper *Calidris ferruginea*. Yr refers to year, Obs refers to observer effort, and SOI refers to  
 4 the Southern Oscillation Index.

species	model	% DE	evidence ratio	$\Delta AIC_c$	$w_i$	$k$
Japanese						
sparrowhawk	Yr	67.4		0	0.58	3
<i>(Accipiter gularis)</i>						
	Yr + SOI	74.1	2	1.4	0.291	4
	Yr + Obs	69.9	5.2	3.3	0.111	4
	Obs + SOI	56.3	59	8.2	0.01	4
	Obs	32	120	9.6	0.005	3
	null	0	260.1	11.1	0.002	2
	SOI	7.2	906.4	13.6	0.001	3
common sandpiper						
<i>(Actitis hypoleucos)</i>	null	0		0	0.494	2
	Obs	13.8	2.2	1.5	0.23	3
	SOI	1.7	5.1	3.2	0.098	3
	Yr	0.8	5.4	3.4	0.092	3
	Yr + Obs	21.4	10.3	4.7	0.048	4
	Obs + SOI	14.1	18.5	5.8	0.027	4
	Yr + SOI	2.5	42	7.5	0.012	4

ruddy turnstone <i>(Arenaria interpres)</i>	null	0		0	0.316	2
	Obs	21	1	0.01	0.314	3
	Yr + Obs	32.3	2.6	1.9	0.123	4
	Obs + SOI	27.5	4.2	2.9	0.076	4
	SOI	2.3	4.5	3	0.071	3
	Yr	1	4.9	3.2	0.065	3
	Yr + Obs + SOI	41.4	11.8	4.9	0.027	5
	Yr + SOI	3.3	31.3	6.9	0.01	4
curlew sandpiper <i>(Calidris ferruginea)</i>	Yr	58.3		0	0.46	3
	Yr + Obs	68.4	1.1	0.2	0.422	4
	Yr + SOI	58.5	7.3	4	0.063	4
	Yr + Obs + SOI	69.9	9.6	4.5	0.048	5
	null	0	86.9	8.9	0.005	2
	Obs	0.3	445.7	12.2	0.001	3
	SOI	0.1	451.8	12.2	0.001	3
	Obs + SOI	0.3	3354.1	16.2	0	4
tiger shrike ( <i>Lanius tigrinus</i> )	null	0		0	0.478	2
	Obs	13.9	2.1	1.5	0.223	3
	Yr	3.4	4.5	3	0.106	3
	SOI	0.2	5.6	3.4	0.086	3

	Yr + Obs	25.9	7	3.9	0.068	4
	Obs + SOI	14.9	17.2	5.7	0.028	4
	Yr + SOI	3.8	38.3	7.3	0.012	4
arctic warbler						
<i>(Phylloscopus borealis)</i>	null	0		0	0.441	2
	Obs	12.5	2.1	1.4	0.214	3
	SOI	7.4	3.1	2.2	0.144	3
	Yr	3.2	4.2	2.9	0.106	3
	Obs + SOI	16.5	11.2	4.8	0.039	4
	Yr + Obs	12.5	15.5	5.5	0.028	4
	Yr + SOI	10.7	17.9	5.8	0.025	4
	Yr + Obs + SOI	16.7	137.5	9.8	0.003	5
purple-backed starling						
<i>(Agropsar sturninus)</i>	null	0		0	0.436	2
	Obs	8.9	2.7	2	0.16	3
	SOI	6.8	3.2	2.3	0.136	3
	Yr	3.6	4	2.8	0.108	3
	Yr + Obs	21.8	7	3.9	0.062	4
	Obs + SOI	20	8.3	4.2	0.052	4
	Yr + SOI	10.6	18	5.8	0.024	4
	Yr + Obs + SOI	36.5	20.7	6.1	0.021	5
Siberian blue robin	Obs	47.8		0	0.564	3

*(Luscinia cyane)*

Yr + Obs	58	2.1	1.5	0.266	4
Obs + SOI	50.2	6.4	3.7	0.088	4
null	0	12	5	0.047	2
SOI	14.8	24.1	6.4	0.023	3
Yr	0.8	64.5	8.3	0.009	3
Yr + SOI	15.7	195.9	10.6	0.003	4

yellow-rumped

flycatcher (*Ficedula  
zanthopygia*)

null	0		0	0.405	2
Yr	18.4	1.3	0.5	0.322	3
Obs	2.6	4.4	2.9	0.093	3
SOI	0.1	5.2	3.3	0.078	3
Yr + Obs	18.5	9.4	4.5	0.043	4
Yr + SOI	18.5	9.4	4.5	0.043	4
Obs + SOI	3.1	31.7	6.9	0.013	4
Yr + Obs + SOI	18.6	117.4	9.5	0.003	5

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$k$  indicates the number of parameters;  $\Delta AIC_c$  shows the difference between the model  $AIC_c$  (Akaike's Information Criterion corrected for small sample sizes) and the minimum  $AIC_c$  in the set of models;  $AIC_c$  weights ( $w_i$ ) show the relative likelihood of model  $i$ ; % DE is per cent deviance explained by the model; an evidence ratio ( $w_{top\ model} / w_i$ ) of 5 indicates that the top-ranked model is 5 times better supported by the data than the reference model.

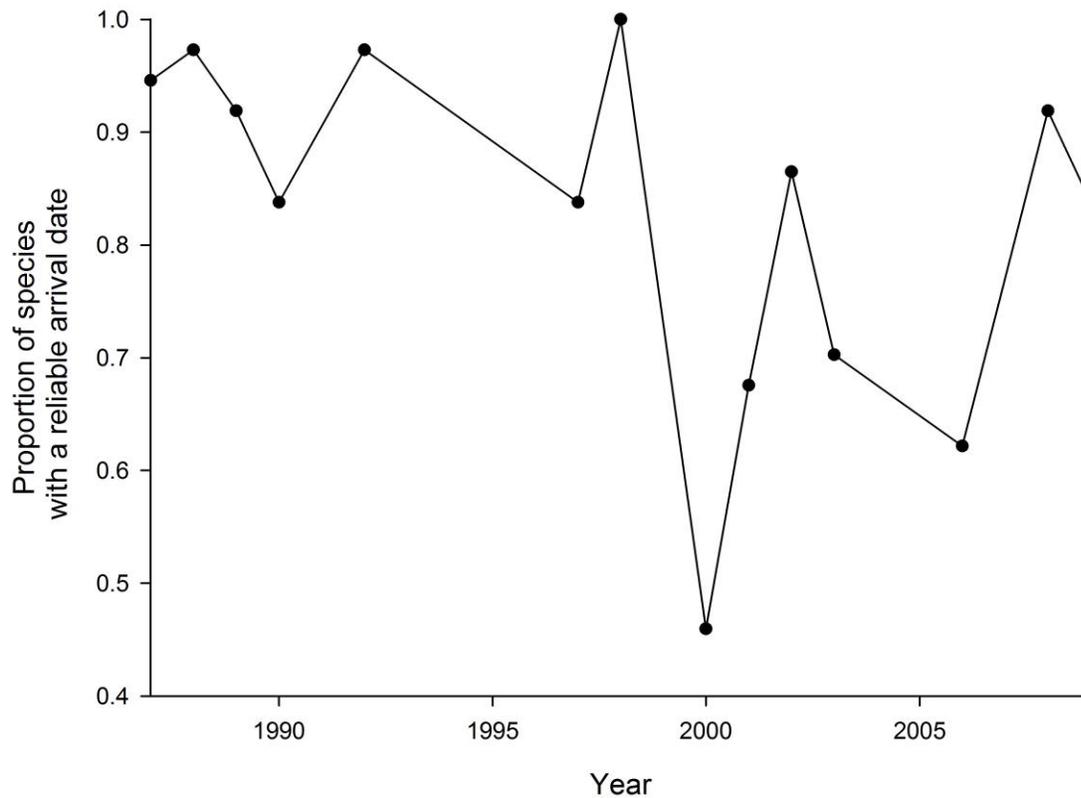
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1 Table 2. Slope of relationship between year and arrival date for our nine study species  
 2 (days/year; ranked by slope). Confidence intervals are based on the percentiles of 10,000  
 3 bootstrapped resamples. Bold indicates evidence for change in arrival date over time (year model  
 4 top-ranked). \* indicates slope confidence interval does not overlap with zero.

species	slope (95% confidence interval)
<b>Japanese sparrowhawk (<i>Accipiter gularis</i>)*</b>	1.96 (1.1–2.9)
<b>curlew sandpiper (<i>Calidris ferruginea</i>)*</b>	1.77 (0.89–2.5)
arctic warbler ( <i>Phylloscopus borealis</i> )	0.35 (-0.75–1.8)
ruddy turnstone ( <i>Arenaria interpres</i> )	0.25 (-1.3–1.4)
Siberian blue robin ( <i>Luscinia cyane</i> )	0.15 (-0.89–1.1)
common sandpiper ( <i>Actitis hypoleucos</i> )	-0.09 (-0.63–0.5)
purple-backed starling ( <i>Agropsar sturninus</i> )	-0.35 (-0.99–0.79)
tiger shrike ( <i>Lanius tigrinus</i> )	-0.38 (-1.6–0.46)
yellow-rumped flycatcher ( <i>Ficedula zanthopygia</i> )	-0.97 (-2.0–0.25)

5

6



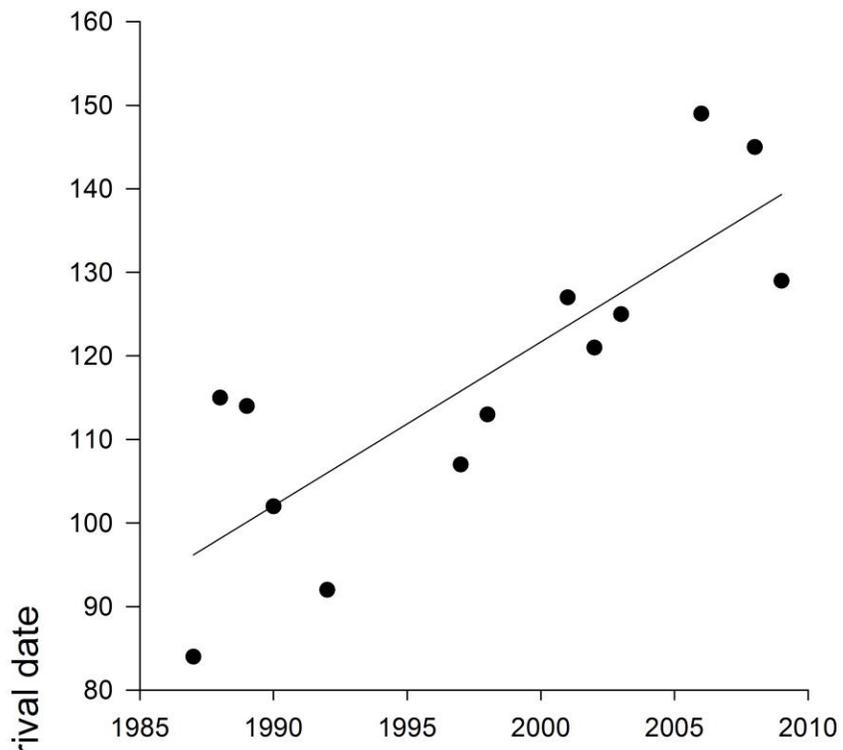
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2 **Fig. 1.** Observer effort during the study, measured by the proportion of 36 bird species for which  
 3 a reliable arrival date was available that year. The 36 species are migratory birds that we  
 4 considered in the initial pool of possible species for the current study. We used the larger pool of  
 5 species to evaluate observer effort, but used the nine species with the longest time series for the  
 6 final arrival date analysis. In years of lower observer effort fewer species were observed during  
 7 migration, but all 36 species were observed annually.

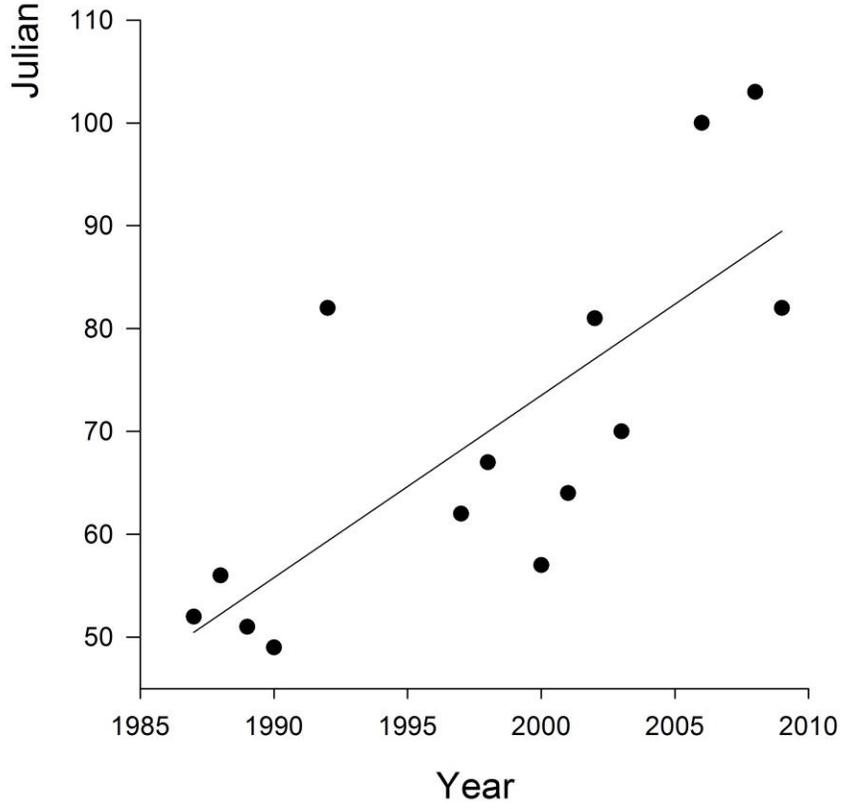
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**A**



**B**



1 **Fig. 2.** Change in arrival date anomaly over time for (A) Japanese sparrowhawk (*Accipiter*  
2 *gularis*) and (B) curlew sandpiper (*Calidris ferruginea*) in Singapore. For the sparrowhawk, the  
3 regression explains 67.4% of the deviance and the slope of this relationship is 2.0 days/year (1.1–  
4 2.9). For the sandpiper, the regression explains 58.3% of the deviance and the slope of this  
5 relationship is 1.8 (0.9–2.5). The 95% confidence intervals are from the percentiles of 10,000  
6 bootstrapped resamples.

7

8