Research paper

Air Temperature Influenced the Vocal Activity of Birds in a Subtropical Forest in Southern Taiwan

Chun-Chieh Liao,[1] Bao-Sen Shieh,[1] Chao-Chieh Chen[1,2]

【Summary】

Singing activities of birds in the early spring are mainly controlled by the photoperiod and other environmental factors such as temperature, food, and rainfall. In this study, we monitored the vocal activity of a forest bird community in the Shan-Ping Forest Ecological Garden, southern Taiwan, to explore the influence of ambient temperature on the vocal behavior of birds. An acoustic monitoring system was set up to record bird sounds throughout the morning hours in March of 2011 and 2012, and the air temperature was recorded on the hour by a data logger. Recorded soundscape files were sampled, transcribed, and analyzed. Results showed that both the number of bird species and vocal activity detected in 10-min intervals sampled from 6 morning hours were positively correlated with the air temperature in both years. At the species level, the relationship between vocal activity and air temperature was found to be significant for 6 of 16 common resident species. Furthermore, air temperature at 10:00 or 11:00 appeared to be a better predictor of vocal activities of birds in the study plot than those measured from 06:00 to 09:00. This study illustrated that the vocal activity of a forest bird community was strongly influenced by air temperature and closely fluctuated with the dynamics of cold fronts. We propose that this relationship could be developed into a bioassay to examine the influence of global warming on spring singing of birds through autonomous recording.

Key words: autonomous recording, bird community, cold front, singing behavior, soundscape.

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研究報告

南臺灣亞熱帶森林氣溫變化對鳥類鳴叫行為之影響

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摘　要

鳥類在繁殖季初期的鳴唱活動除了會受到光週期的調控之外，溫度、食物量及降雨量也都是重要的環境影響因子。本研究在扇平森林生態科學園區藉由自動錄音監測系統探討早春氣溫變化對鳥類鳴叫行為的影響。我們在2011年與2012年的三月份，錄下每天清晨到中午的鳥類鳴叫聲，並放置溫度監測器進行溫度資料取樣。我們選取寒流來襲前後期間約兩週的錄音資料，並以人工方式進行轉錄。野外錄音結果顯示，無論是鳥種數或鳴叫頻度皆與氣溫呈顯著正相關。16種當地常見的鳥類中，有6種的鳴叫頻度與氣溫變化有顯著正相關。此外，本研究也發現每日上午10:00或11:00的溫度較上午06:00到09:00的溫度更適合用來預測鳥類鳴叫頻度受氣溫變化的影響。綜合上述，鳥類群聚的鳴叫行為確實會受到溫度變化的影響，且寒流所帶來的氣溫波動與鳥類鳴叫行為有共振的效應。我們認為自動錄音系統非常適合用來探索氣候變遷對早春鳥類繁殖鳴叫行為的影響。

關鍵詞：自動錄音、鳥類群聚、寒流、鳴叫行為、聲景。

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INTRODUCTION

In spring, most adult males begin to sing for territorial defense and to attract mates for the coming breeding season (Morse 1970, Catchpole and Slater 1995). Although spring singing of birds is mainly controlled by intrinsic mechanisms triggered by photoperiodic changes, fine-scale variations are mediated by other environmental factors such as temperature, food resources, and rainfall (Slagsvold 1977, Ball 1999, Thomas 1999, Wingfield et al. 2003, Dawson 2008). The environmental factor of temperature has been more often studied than other environmental factors. Garson and Hunter (1979) found a strong relationship between the overnight minimum temperature and singing activity the following morning in the Eurasian Wren (*Troglodytes troglodytes*) and Great Tit (*Parus major)*. In addition, Higgins (1979) illustrated that the vocal activity of the Song Thrush (*Turdus philomelos*) was significantly proportional to air temperature in the early morning. These findings indicate that birds might reduce their singing activity in order to save energy during times of low temperature, because a considerable amount of energy and time is required for singing (Thomas 1999, Gil and Gahr 2002).

Previous studies exploring the influence of temperature on the vocal behavior of birds mainly focused on single bird species (Garson and Hunter 1979, Higgins 1979). However, it would be more representative if this relationship could be applied to the entire bird community of a given ecosystem. Hence, we monitored changes in the vocal activity of a bird community in a subtropical forest to examine the effect of temperature on the vocal behaviors of birds. This study was carried out in early spring when cold fronts still prevailed and the fluctuation in temperature remained high. This ensured that a greater range of temperatures was recorded, and its effect on the vocal activity of birds could be clearly demarcated.

This study was feasible through the use of an acoustic monitoring system, which has been used as a tool for estimating bird richness and abundance in other studies (Hobson et al. 2002, Acevedo and Villanueva-Rivera 2006, Brandes 2008, Dawson and Effort 2009). Acoustic monitoring systems have the potential to operate continually around the clock (Acevedo and Villanueva-Rivera 2006, Chen et al. 2011). Therefore, we could monitor changes in the vocal activities of birds across days, and even during the entire period of a cold front.

In addition, 80~94% of birds detected during point counts are through sound during the breeding seasons (Best 1981, Scott et al. 1981, DeJong and Emlen 1985), and it is even higher in forest habitats (Brewster and Simons 2009, Celis-Murillo et al. 2012). Similarity indices of point count surveys between personnel and autonomous recording usually reach 80~95% (Hobson et al. 2002, Celis-Murillo et al. 2009). Therefore, the vocal activity of a bird community can substantially be constructed using an acoustic monitoring system with continuous recording.

The particular objectives of this study were to: 1) document the vocal activity of a forest bird community; 2) relate vocal activity with air temperature; and 3) establish an automated acoustic system as a standard bioassay of environmental effects on bird reproductive cycles.

MATERIALS AND METHODS

Study area

The Shan-Ping Forest Ecological Garden, a remote research station of the Taiwan Forestry Research Institute, is located in southern Taiwan (22°58’12”N, 120°41’24”E), with an annual average temperature of 20.6℃ and an annual rainfall of 3500 mm (Lu et al. 2009). Broadleaf forests and montane streams characterize the site, and 134 bird species have been documented (King et al. 1990); however, the species richness apparently decreased in a recent survey (Tsai et al. 2015). The main road to Shan-Ping Forest was heavily damaged by Typhoon Morakot in 2009 and tourism activities were not permitted during the study period. It turned out that Shan-Ping Forest is a very profitable site for acoustic recording research since tourist interference is nearly negligible.

Field procedures

We set up an acoustic monitoring system in the Shan-Ping Forest. The unit consisted of a mini-computer (ASUS, AS-D692, Taipei City, Taiwan), a 3-channel stereo microphone mixer (Rolls, MX54S Promix Plus, Salt Lack City, UT, USA), a microphone (Shure, WL183, Niles, IL, USA), and a temperature and light data logger (HOBO Pendant temp/light, part no. UA-002-64, Microdaq.com (Ltd), Contoocook, NH, USA). The acoustic monitoring system was located 10 m from a trail that runs beside a stream through a riparian forest. A cable line was pulled 15 m further into the forest, and the microphone was fixed under an aluminum roof that was tied to a tree trunk at a height of 3 m above the ground. The acoustic monitoring system automatically recorded files (WAV) at 10-min intervals, from 05:25 to 11:25 every day, through recording software (High Criteria, Total Recorder, Richmond Hill, Ontario, Canada). In a preliminary test, small passerine birds such as Morrison’s Fulvetta (*Alcippe morrisonia*) could be clearly recorded at a distance of approximately 20 m. Larger species such as the Gray Treepie (*Dendrocitta formosae*) could be recorded as far as 100 m away from the recorder (Chen at al. 2011). The air temperature was recorded on the hour by the HOBO pendant data logger, and data were periodically downloaded.

Data analyses

In the lab, we selected soundscape files recorded during 14~28 March 2011 and 10~27 March 2012, each period of which included 2 cold fronts. We retrieved a section of 10-min recording from each morning hour (from 06:05~06:15 to 11:05~11:15), adding up to a total of 60 min of recording segments per day. We took a 1-min interval as a working unit, and species detected by songs or calls each minute were transcribed onto a data sheet. Then, the number of different bird species recorded in the 10-min interval was enumerated. The occurrence of vocalizations of different bird species was summed for each minute, and the grand sum for the 10-min period was taken as a measure of vocal activity. It represents the relative frequency of vocal events of all species occurring in the 10-min period. The air temperature (℃) was retrieved from the HOBO data logger, and the temperature taken at 06:00 was used to represent the temperature for that hour, and the same for the other 5 h.

We used the GLMM procedure of SAS (SAS, Cary, NC, USA) with HOUR (sampling unit) as a repeated-measure to explore the relationship between air temperature and the number of bird species recorded in a 10-min interval each morning hour throughout the study periods of 2011 and 2012. The same analysis was repeated for the relationship between air temperature and vocal activity of birds detected within a 10-min interval for 2011 and 2012, separately. A simple linear regression was applied to formulate the relationship between the average morning air temperature with either the average number of bird species detected or vocal activity on a daily basis. This analysis was separately conducted for the 2011 and 2012 datasets. Following this method, we formulated the relationship between average air temperature and vocal activity for those common bird species that appeared in at least 25 d of recording, considering both 2011 and 2012. Finally, to determine either the maximum or minimum temperature that most influenced the vocal behavior of birds, we used temperatures from different morning hours as the day's temperature and redid the regression analyses.

RESULTS

The number of bird species recorded in 10-min intervals of the 6 morning hours was positively correlated with air temperature in both 2011 ($F_{1,83} = 21.71$, $p < 0.0001$; Fig. 1A) and 2012 ($F_{1,101} = 15.04$, $p < 0.001$; Fig. 1B). In addition, the vocal activity of birds as a whole in the community also showed a significant positive correlation with air temperature in both 2011 ($F_{1,83} = 29.22$, $p < 0.0001$; Fig. 2A) and 2012 ($F_{1,101} = 31.27$, $p < 0.0001$; Fig. 2B). Figure 3 depicts such a linear relationship on a daily basis. The average morning air temperature was highly correlated with the average number of species and vocal activity of birds recorded in a 10-min interval of the 6 morning hours in both 2011 and 2012 (Fig. 3).

We found 30 bird species (excluding nocturnal owls) from 33 days of acoustic recording in both 2011 and 2012. Vocal activity showed a significant positive correlation with air temperature in 6 of the 16 common bird species that appeared in at least

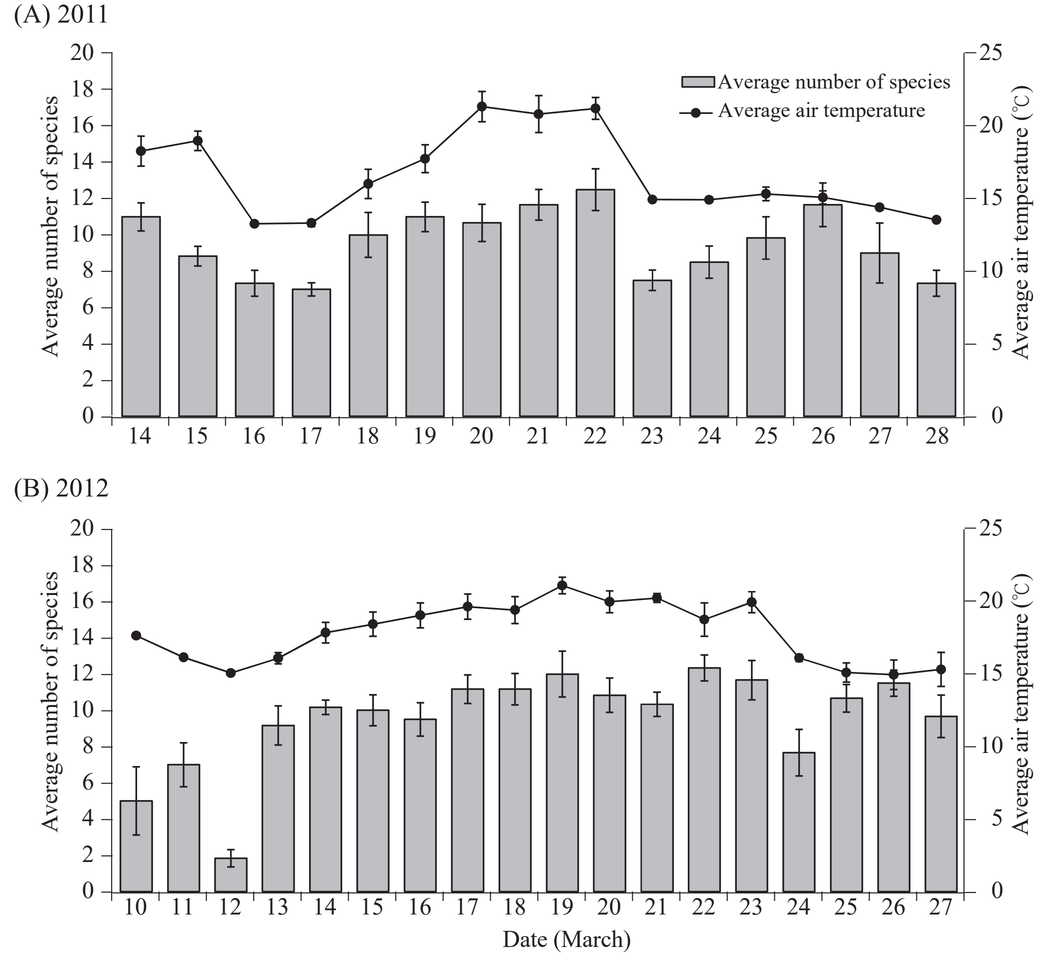
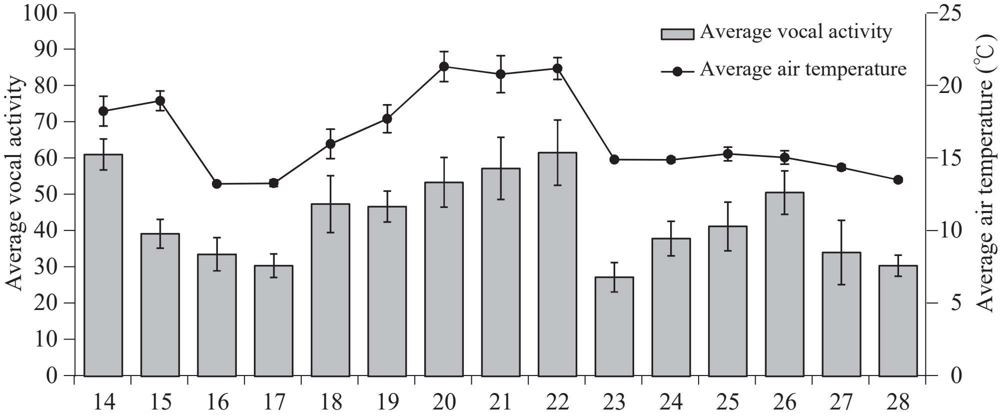


Fig. 1. The number of bird species recorded in a 10-min interval was significantly correlated with the air temperature (℃) of the 6 morning hours in both A) 2011 ($F_{1,83} = 21.71$, $p < 0.0001$) and B) 2012 ($F_{1,101} = 15.04$, $p < 0.001$) at Shan-Ping Forest Ecological Garden, southern Taiwan.

25 d of recording (Table 1). These included *Psilopogon nuchalis* ($r^2 = 0.55$, $p < 0.0001$; Fig. 4A), *Stachyridopsis ruficeps* ($r^2 = 0.27$, $p < 0.01$; Fig. 4B), *Hypothymis azurea* ($r^2 = 0.27$, $p < 0.01$), *Dendrocitta formosae* ($r^2 = 0.18$, $p < 0.05$), *Hypsipetes leucocephalus* ($r^2 = 0.18$, $p < 0.05$), and *Alcippe brunnea* ($r^2 = 0.17$, $p < 0.05$).

When the air temperature on the hour was replaced by the temperature from different morning hours, the coefficient of determination (r^2) of the regression analyses increased from 06:00 to 11:00 (Fig. 5). The value of r^2 reached a plateau at 10:00. Although both years contained 2 cold fronts in the sampled period, the fluctuation of temperature in 2011 (coefficient of variation (CV) = 17.44) was greater than that in 2012 (CV = 11.59). The influence of air temperature on the vocal behavior of birds in 2011 appeared to be stronger and thus resulted in a higher r^2 than that in 2012 (Fig. 5).

(A) 2011



(B) 2012

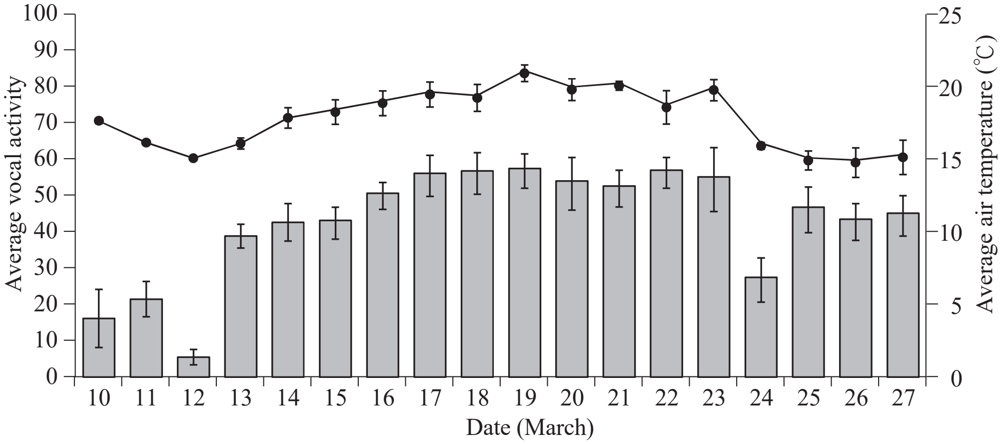


Fig. 2. The vocal activity of birds recorded in a 10-min interval was significantly correlated with the air temperature (℃) of 6 morning hours in both A) 2011 ($F_{1,83} = 29.22$, $p < 0.0001$) and B) 2012 ($F_{1,101} = 31.27$, $p < 0.0001$) at Shan-Ping Forest Ecological Garden, southern Taiwan.

DISCUSSION

In this study, the vocal activity of a forest bird community was found to be highly influenced by the air temperature during waves of cold fronts in early spring of both 2011 and 2012. Such a relationship was found to be stronger in 2011 when temperature fluctuations with the dynamics of cold fronts were greater. These results indicated that air temperature has a clear impact on bird vocal behavior at the community level. Our results confirmed that air temperature can affect the vocal activity of birds as found in other studies (Garson and Hunter 1979, Reid 1987, Thomas 1999, Hasan and Badri 2016). Garson and Hunter (1979) reasoned that having spent much energy in maintaining the body temperature on cold nights, birds would show a greater demand to feed the following morning which would therefore lead to a decline in singing activity. Indeed, singing and foraging

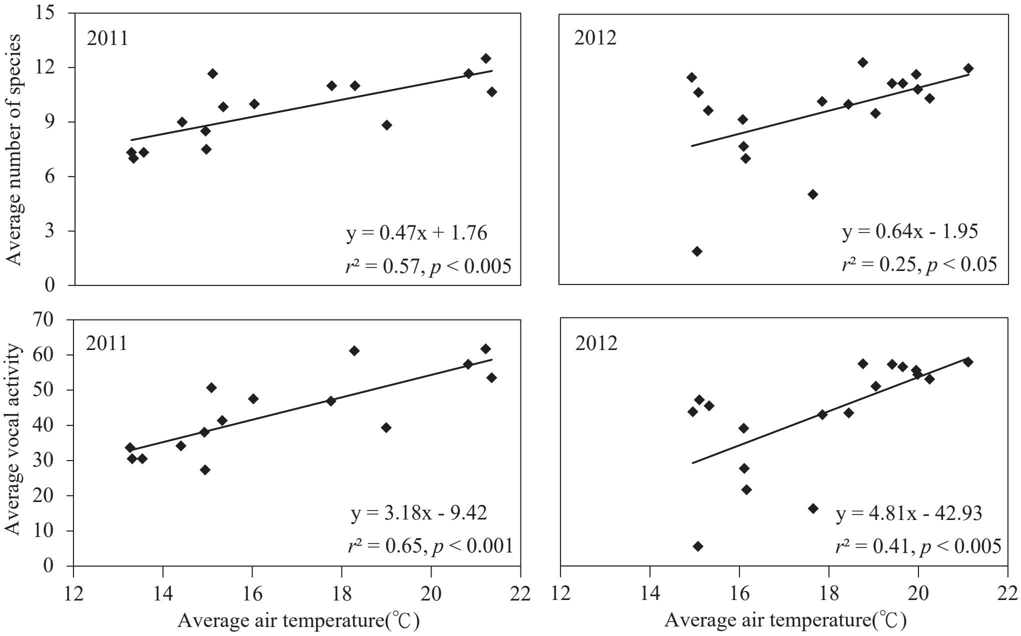


Fig. 3. The simple linear regression depicts the relationship between the daily average number of species and vocal activity of birds recorded in 10-min intervals of 6 morning hours with average morning air temperatures (℃) in both 2011 (*n* = 15 d) and 2012 (*n* = 18 d) at Shan-Ping Forest Ecological Garden, southern Taiwan.

are mutually exclusive or close to being so, and thus a tradeoff might occur between the amount of time that a bird can spend on either behavior (Thomas 1999).

The annual average temperature at our study site was 20.6℃, and the minimum, mean, and maximum temperatures during the study period (March 2011) were 12.6, 16.6, and 25.9℃. These values are much higher compared to those in temperate zones. As a result, the energy spent on maintaining the body temperature at our study site may have been far less than that spent by temperate birds. Therefore, we considered that the strong positive relationship between the vocal activity of birds and air temperature at our study site might have resulted from spring singing instead of energy maintenance. At our study site, birds usually resumed singing immediately after a cold spell had ended. With consecutive days of sunny weather and high temperatures in late winter and early spring, unleashed singing abruptly increased. It seems that birds regard such change as the arrival of spring. The singing continued until the next cold front arrived, and the sudden drop in temperature once again made the forest as quiet as during a normal winter day. The dramatic fluctuation of temperature during waves of cold fronts in early spring clearly illustrates the effect of temperature on bird vocal behavior. A likely explanation for this pattern is spring singing. Breeding males have to sing as early as possible in order to hold a territory (Garson and Hunter 1979), because the security of a territory will contribute greatly to their upcoming reproductive success.

Although the initiation of breeding in birds is mainly controlled by photoperiod changes in early spring (Wingfield et al. 1980,

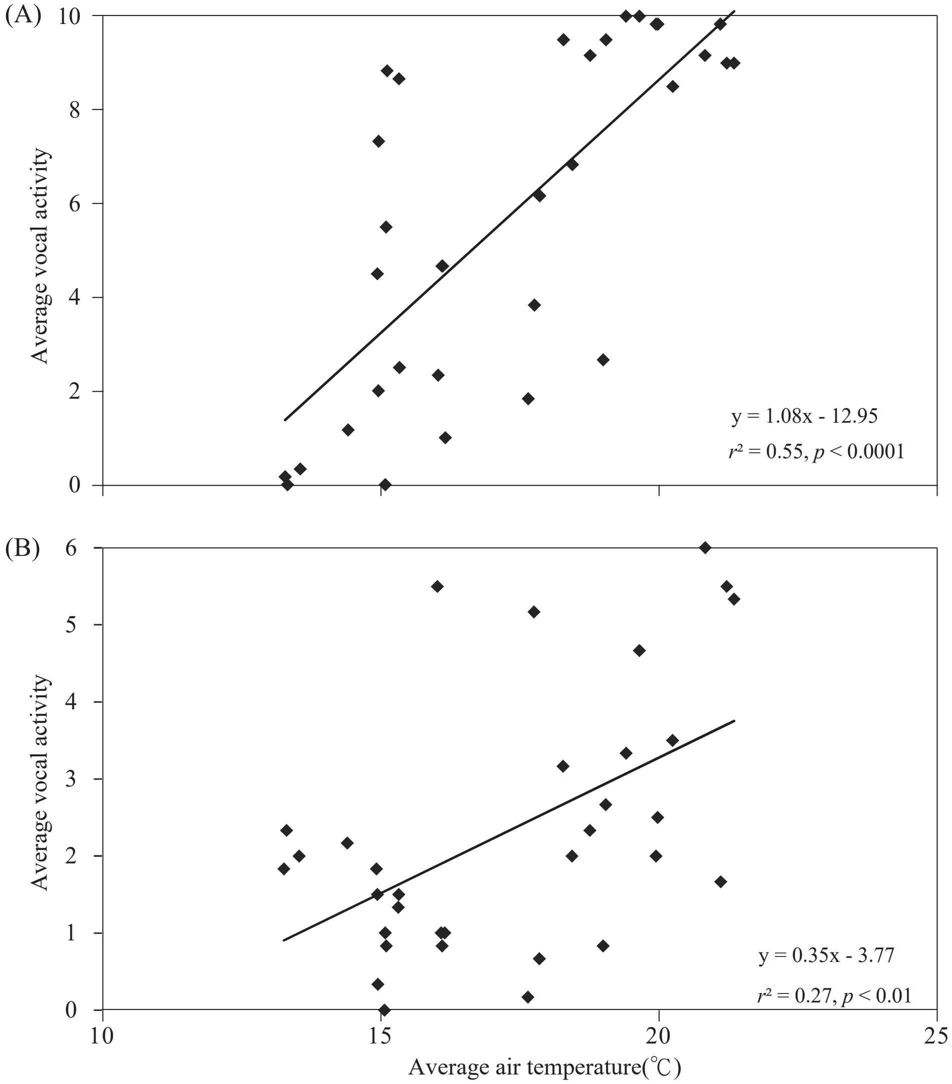


Fig. 4. The average vocal activity in a 10-min interval was significantly correlated with the average air temperature (℃) of the 6 morning hours for (A) *Psilopogon nuchalis* ($r^2 = 0.55$, $n = 31$, $p < 0.0001$) and (B) *Stachyridopsis ruficeps* ($r^2 = 0.27$, $n = 32$, $p < 0.01$). Data from both 2011 and 2012 were pooled for the analyses.

Wingfield and Farner 1993, Hau et al. 1998), environmental factors, such as temperature, food, and rainfall, were proven to play important roles in triggering reproduction (Strain and Mumme 1988, Thomas 1999, Hau 2001, Leitneret al. 2003, Lehmann et al. 2012). Wingfield et al. (2003) found that the breeding cycles of the mountain White-crowned Sparrow (*Zonotrichia leucophrys oriantha*) are consistent among years and controlled by the photoperiod length, but a slight difference in the timing of breeding is mainly attributed to climate variations. Our results showed that the vocal activity of birds at Shan-Ping Forest accordingly fluctuated with air temperatures in early spring. This implies that temperature might play a cru-

Table 1. The relationship between air temperature (℃) and vocal activity for 16 common bird species at Shan-Ping Forest Ecological Garden

Species name[a)]	Common name	Regression equation[b)]	r^2	F	p	n
Psilopogon nuchalis	Taiwan Barbet	y = 1.08x - 12.95	0.55	38.15	< 0.0001	31
Stachyridopsis ruficeps	Rufous-capped Babbler	y = 0.35x - 3.77	0.27	11.63	< 0.01	32
Hypothymis azurea	Black-naped Monarch	y = 0.36x - 4.36	0.27	11.22	< 0.01	30
Dendrocitta formosae	Gray Treepie	y = 0.35x - 2.79	0.18	6.99	< 0.05	30
Hypsipetes leucocephalus	Black Bulbul	y = 0.32x - 3.26	0.18	6.65	< 0.05	33
Alcippe brunnea	Dusky Fulvetta	y = 0.29x - 1.12	0.17	6.29	< 0.05	32
Pericrocotus solaris	Gray-chinned Minivet	y = 0.26x - 1.49	0.12	4.08	0.05	32
Dicrurus aeneus	Bronzed Drongo	y = 0.18x - 0.76	0.09	2.89	0.10	30
Alcippe morrisonia	Morrison's Fulvetta	y = 0.16x + 1.96	0.06	1.88	0.18	33
Erpornis zantholeuca	White-bellied Erpornis	y = 0.08x - 0.06	0.03	1.10	0.30	28
Pomatorhinus erythrocnemis	Black-necklaced Scimitar-Babbler	y = 0.09x - 0.59	0.03	0.96	0.33	27
Dendrocopos canicapillus	Gray-capped Woodpecker	y = 0.04x + 0.43	0.02	0.52	0.48	31
Myophonus insularis	Taiwan Whistling-Thrush	y = -0.12x + 2.99	0.11	4.00	0.05	29
Arborophila crudigularis	Taiwan Partridge	y = -0.06x + 2.53	0.01	0.43	0.52	32
Bambusicola sonorivox	Taiwan Bamboo-Partridge	y = -0.02x + 0.97	0.01	0.32	0.58	27
Pomatorhinus musicus	Taiwan Scimitar-Babbler	y = -0.003x + 3.26	0.00	0.00	0.97	33

[a)] Species names followed the eBird/Clements Checklist of Birds of the World Version 2017 (Clements et al. 2017).

[b)] x, temperature; y, vocal activity.

cial role in spring singing of birds and act as an important environmental factor in initiating the breeding process of birds.

Increased temperatures due to global climate change might directly or indirectly affect the breeding cycle of birds. The most conspicuous consequence found so far is the forwarded laying date for many northern species (Crick et al. 1997, Dunn and Winkler 1999, Both et al. 2004, Møller et al. 2006, Dolenec et al. 2011). As Carey (2009) pointed out, future studies should incorporate not only temperature data and the timing of the laying date but also the amount of population variability in other life history traits. Hasan (2011) found that the onset of the dawn chorus is highly temperature dependent. The dawn chorus of some passerine birds in North America was shown to begin earlier with increasing temperature at nautical twilight (Bruni et al. 2014). Our study illustrated that the maximum temperature of the morning hours is a better predicator of the vocal behavior of birds than temperatures measured from earlier hours. This implies that the daily maximum temperature has a greater impact on the vocal behavior of birds. Since variations in temperatures in later hours of the morning are greater than those in the early hours, the maximum temperature tends to be a better indicator of the vocal activity of birds in the morning. In other words, birds are more sensitive to the maximum temperature of a day and respond with behavioral changes (Pattinson and Smit 2017). As a consequence, global warming is likely to initiate spring singing at an earlier date and thus advance the breeding cycle of birds (Dunn and Winkler 2010, Møller et al. 2010). We consider that such a relationship can be further revealed through acoustic monitoring studies. Autonomous acoustic systems have been used as monitor-

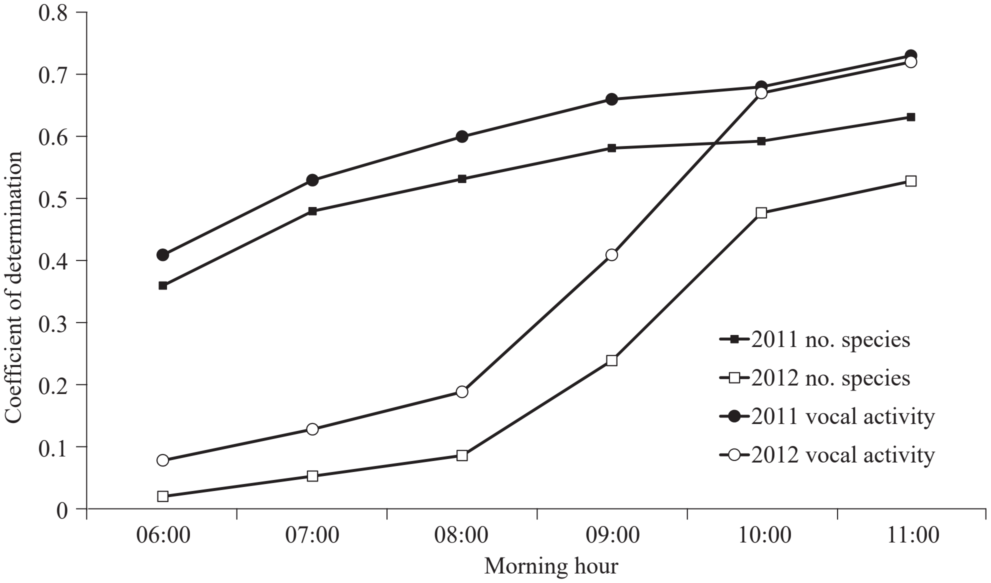


Fig. 5. The trend of the coefficient of determination (r^2) in regression analyses when temperatures (℃) at different morning hours were designated as the day's temperature. Air temperatures at 10:00 and 11:00 had higher r^2 values than those from earlier hours.

ing devices for avian biodiversity surveys (Hobson et al. 2002, Acevedo and Villanueva-Rivera 2006, Celis-Murillo et al. 2012, Snaddon et al. 2013). Advanced recording devices, such as SM4, can be scheduled and record for up to 250 h. Such recorded data could allow us to analyze the effects of climate change on the spring singing of birds.

Vocal activities of over 1/3 of the analyzed species exhibited positive correlations with air temperature in this study. Of these, the Taiwan Barbet had the highest r^2 value. The Taiwan Barbet was recorded almost every hour in the recording, and it can be considered the most vociferous species at the study site. This implies that species with persistent vocal activity are most suitable for autonomous recording studies. Although the use of autonomous devices is sometimes criticized for failing to record as many birds compared to human observers (Huttoand Stutzman 2009), a selected set of vocal species would provide a reliable trend on spring singing to detect possible influences of climate change.

The vocal activity of 4 bird species had a negative relationship with temperature, but it was only significant ($p = 0.05$) in the Taiwan Whistling-Thrush (*Myophonus insularis*). We found this trend might have been due to behavioral features of these species. For example, Fang (2004) indicated that Taiwan Whistling-Thrushes often sing prior to sunrise, and they are almost silent after 09:00. This vocal activity pattern would result in a negative relationship with temperature which normally increases towards noon time.

CONCLUSIONS

This study showed that air temperature in early spring did affect the vocal activity of a forest bird community in Shan-Ping Forest, southern Taiwan. Furthermore, air temperatures close to noon (the maximum air temperature of a day) were better predicators of the vocal output of birds in that day. A bioassay by monitoring the co-occurrence of daily maximum air temperatures and initiation dates of spring singing of birds could be applied to detect the influence of global warming on the advance of spring singing in birds.

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Appendix 1. The mean, minimum, and maximum air temperatures (℃) recorded from 06:00 to 11:00 of each day in March of 2011 and 2012

March	2011			2012		
	Mean±SD	Minimum	Maximum	Mean±SD	Minimum	Maximum
1	17.19±2.30	15.19	20.90	18.17±1.74	16.90	21.09
2	18.35±1.44	16.62	20.14	18.05±1.72	16.62	20.90
3	NULL	NULL	NULL	19.58±1.85	17.86	22.43
4	NULL	NULL	NULL	18.84±1.79	17.48	21.76
5	NULL	NULL	NULL	17.11±2.43	15.28	21.19
6	17.98±2.07	15.57	20.14	18.03±2.03	16.43	21.47
7	18.11±0.92	16.71	18.90	19.32±1.99	17.38	22.62
8	13.19±0.84	12.59	14.80	19.98±1.84	18.33	22.81
9	14.39±1.72	12.79	17.19	20.41±1.28	18.90	21.95
10	15.68±1.35	14.13	17.57	17.65±0.44	17.67	18.52
11	16.12±1.00	14.90	17.48	16.16±0.25	15.76	16.43
12	17.44±2.56	14.90	21.00	15.08±0.18	14.90	15.38
13	17.57±2.63	15.00	21.66	16.09±0.95	14.90	17.19
14	18.28±2.52	15.47	22.24	17.85±1.73	16.24	20.42
15	19.00±1.65	17.67	21.86	18.44±2.06	16.52	21.86
16	13.27±0.17	12.98	13.46	19.05±2.09	16.90	22.24
17	13.32±0.57	12.59	13.94	19.65±2.11	17.76	23.10
18	16.03±2.48	13.85	20.04	19.41±2.27	17.67	23.29
19	17.76±2.34	15.47	21.47	21.11±1.40	19.19	22.72
20	21.35±2.55	19.28	25.42	19.98±1.84	17.95	22.43
21	20.83±3.13	18.14	25.90	20.25±0.75	19.38	21.09
22	21.22±1.85	19.09	23.97	18.76±2.82	16.05	23.29
23	14.95±0.21	14.71	15.28	19.95±1.78	18.24	22.24
24	14.93±0.43	14.33	15.47	16.11±0.58	15.28	16.81
25	15.33±1.16	13.94	17.28	15.10±1.61	13.75	17.76
26	15.09±1.12	13.75	17.00	14.96±2.49	12.30	18.81
27	14.41±0.47	13.85	15.09	15.32±2.88	12.40	19.66
28	13.54±0.35	13.08	13.94	16.65±2.35	14.04	20.23
29	15.98±2.19	13.46	19.19	16.37±2.72	13.46	20.42
30	15.82±1.48	13.85	17.57	17.62±2.55	15.09	21.57
31	14.48±0.65	13.65	15.09	20.22±2.28	17.57	23.48