Impact of weather conditions on bird migration in Suichuan avian passage, China

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Abstract

Weather conditions may impact migratory behaviors, such as the decision of takeoffs and the flight level. In this study, it aimed to investigate effort of ringing intensity conducted in Suichuan, the second largest avian migration passage in China, and explore effects of weather conditions including wind speed and rainfall on local bird migration. Based on field collected data from 2005 through 2010, dominant migrants in Suichuan were Ciconiiformes and Passeriformes, followed by Gruiformes, and the diversity of migrant species peaked in 2007. Correlations of bird ringing intensity with wind speed and rainfall were derived through univariate analysis. Different groups of migrants shared different correlation patterns with each weather condition. Ringing intensity of small-size Passeriformes was most easily affected by adverse weather conditions (daily rainfall ≥15mm or wind speed >2.5ms⁻¹); Gruiformes shared significant correlations with wind speeds <1.5ms⁻¹ and at 1.5-2.5ms⁻¹; whereas the large-size Ciconiiformes showed non-significant relationships with both two meteorological variables. Totally, ringing intensity had significant negative correlations with frequencies of daily rainfall ≥15mm and wind speed>2.5ms⁻¹. Multiple linear regression analysis confirmed that higher rainfall and stronger wind hampered total ringing intensity and these two predictors together could explain 79% of the variation of total ringing intensity. The results of this exploratory study have important implications for assessing the impact of wind and rain on bird migration, especially migration intensity and flight level.

Key words: migrant, wind, rain, ringing intensity, flight level
1. Introduction

Billions of birds migrate seasonally between their breeding grounds and overwintering sites every year. The cost of flight to arrive at a destination hundreds or thousands of kilometers away determines the necessity for fuel accumulation during migration, especially for birds using flapping flight. The path of long migration is usually divided into several segments and stopovers (Taylor et al. 2011; Weber et al. 1999). The time spent at a stopover site and energy restored during this period influence the speed and potential range of subsequent flight, and even the probability of mortality during that flight (Schaub and Jenni 2001). These effects eventually affect the overall flight route and total migration time (Hedenström and Alerstam 1997; Schaub and Jenni 2000). Thus choosing appropriate locations to stop and refuel and achieving an optimal flight route are important for migratory birds. They stimulate migratory birds to survive migration and reach their destinations in suitable physical conditions and in an optimal time window to breed, which thereby ensures maximum reproductive rate for the next generation (Alves et al. 2012; Newton 2006; Schaub et al. 2004).

Migratory behaviors are influenced by weather conditions, including wind, rainfall, temperature, barometric pressure and their derivatives experienced during migration (Able 1973; Alerstam 1976; Marra et al. 2005; Shamoun-Baranes et al. 2010a). Being aware of time restrictions and risk avoidance, migratory birds generally take off under either favorable or marginally adverse weather conditions (Dänhardt and Lindström 2001; Richardson 1978; Van Belle et al. 2007).
In most cases, migrants prefer favorable winds (tailwinds or no wind) for embarking on their flights. Upon encountering strong, unfavorable winds, they would rather remain at the stopover site until favorable or weakly adverse winds (Åkesson and Hedenström 2000; Liechti 2006). For Red Knots that migrate from West Africa to central north Siberian breeding areas via the German Wadden Sea, wind experienced en route is the main driver of the use of one intermediate stopover site as an emergency staging area (Shamoun-Baranes et al. 2010b). The probability of robin's departure from a stopover site is higher during nights when winds aloft (300m) are weaker (Schaub et al. 2004). However, if the probability of occurrence of favorable wind is low, birds take off without wind assistance upon reaching the final day of their "departure time window" (Karlsson et al. 2011; Weber et al. 1998; Weber and Hedenström 2000). Avoiding flight in rain is important for migrants, for the decreased visibility and increased weight bearing caused by rain call for much higher flight costs. When weather conditions are poor with heavy rain, migrants en route usually decrease their flight altitude, or even land (Wang et al. 2012). One study in European robins has shown that daily emigration probability is at least doubled during nights without rain than those with it (Schaub et al. 2004). Whereas in blackcaps, a null or weak effect of rain on their emigration likelihood is suggested (Arizaga et al. 2011).

Several studies have shown good correspondence between departure decision and pressure change (Åkesson and Hedenström 2000; Gill et al. 2009). In the Northern Hemisphere, the majority of migrating birds in autumn tends to be in the east of high-pressure or west of low-pressure areas, often shortly after the passage of a
cold front (Bruderer 1997; Richardson 1978).

Although results of different statistical methods show clear correlation between migratory behavior and weather, the relative contribution of each meteorological variable is inconclusive. In most cases, once wind and rain conditions are taken into account, effects of other factors on avian migratory behavior are minor (Zehnder et al. 2001).

There are a variety of techniques to study birds, among which ringing is the oldest (Bächler et al. 2010). Being ideal for broad-scale studies, it has the potential to be equal partners as later developed tracking techniques, such as radar (Fiedler 2009). This approach of recapture or recovery of migratory birds can provide important information, such as migration routes for ornithologists.

Although it is the second largest avian migration passage in China, knowledge of migratory behaviors, including flight altitude and decision of active migration, in Sichuan remains scarce. In addition, the local bird data are lack of historical collection until the start of ringing in 2002, and it is firstly analyzed in our study. This study is to test whether and how weather conditions including wind speed and rainfall influence autumn avian ringing intensity in Sichuan. The results indicate the influence mechanism of local weather conditions on migratory behaviors, reflecting the impact of weather conditions on bird migration.

2. Materials and Methods

2.1 Ethics Statement

The ringing of birds was in strict accordance with the administration measures
for bird banding of the People's Republic of China. The work was approved by the
Forestry Bureau of Jiangxi, and diligently carried out by the Forestry Bureau of
Suichuan for bird protection and study of avian migratory behavior and routes.

2.2 Study site

The avian migration passage of Suichuan (25°28’-26°20’N and 113°56’-114°13’E)
is in the southwest of the city of Ji’an in Jiangxi Province, it was discovered through
wild life investigation in 1998. Experts speculate that formation of this passage is
mainly connected to a unique local landform of high mountains, which act as
landmarks. Moreover, the ecological environment of Suichuan is perfect for migrants
to stop for energy restoration. A large number of migratory birds traverse this passage
each year. In autumn, they migrate from northeast Suichuan, passing through villages
including Yingpanxu and Gaoping, and continue south by flying through a concave
channel between Qiyun Mountain and Bamian Mountain. While in summer, migrants
pass this passage in the opposite direction. Visible migration is maximum at dusk or in
early morning, but is low during the day when migrants rest in the jungle. According
to local observations, weather conditions greatly influence avian migration in
Suichuan. Few birds transit the passage during harsh weather. Since the successful
workshop on bird ringing between China and Japan, held in Yingpanxu village in
2002, ringing work has been done annually in the village at peak of migration

2.3 Data collection and statistical method

Bird data used here were collected by bird ringing conducted at Yingpanxu
ringing station in Suichuan from 2005 to 2010. There were two types of mist nets: 'sticky net' and 'fowling net' mounted atop mountain about 1100-1200 meters. The former net was fine; it was about 6 meters high and 15-20 meters wide with small meshes. This type of net was appropriate for capturing birds in small size. The latter net was about 10 meters high and 20-30 meters wide with large intercept area. This type of net was suitable for catching birds in large size, while small birds could easily pass through them. In our study, birds were trapped out of active migratory flight in September and October, when the autumn migration peaked. During ringing, there were totally 10 mist nets (8 'sticky nets' and 2 'fowling nets'). The nets were open whole night when birds flew in the level that they could be easily captured by the mist nets. Once there were birds captured, the physical conditions such as mass were measured before setting metal rings on their feet and releasing them. The ringing work was performed annually by the same team, including bird experts familiar with the particular migration situation in Suichuan. Ringing effort kept the same each day through the ringing work, even in bad weather conditions (e.g., rain). In addition, the number of nets remained the same. Therefore, bias of different ringing intensities caused by ringing efforts was null or weak.

Daily meteorological data between 2005 and 2010 were collected from a weather station (114°30'E, 26°19'48''N) in Suichuan. These data can be freely downloaded from the China Meteorological Data Sharing Service System website (http://cdc.cma.gov.cn/home.do). The meteorological data were measured in the altitude of 1261 meters, nearly equal to the altitude where birds were ringed.
Shannon-Wiener index, one of the most commonly used diversity indices, was used to investigate bird species richness in Suichuan (Spellerberg and Fedor 2003). The index is given by:

\[ H = \sum_{i=1}^{n} p_i \ln p_i, \]

Where \( p_i \) is relative abundance of species \( i \) in a sample of \( n \) species.

Correlations between weather conditions and ringing intensity were analyzed by univariate analysis. Statistical analysis of correlation is a preferable and practical method to compare ringing intensity with each meteorological variable, it serves as the prelude of multivariate study (Richardson 1978). Limited by the availability of daily recorded bird data, the total number of birds captured each year, namely annual ringing intensity, from 2005 to 2010 was applied here. Since bird data were yearly recorded in the month of September and October, meteorological data, including daily average wind speed and rainfall of these two corresponding months were derived.

These two meteorological factors were selected because several studies have confirmed that wind and rainfall played major roles on explaining migration intensity (Alerstam 1993; Erni et al. 2002; Schaub et al. 2004). However, wind direction was not considered because it was always favorable related to migration direction during the study period. Based on previous study (Schaub et al. 2004) and our test, these two meteorological variables were separately categorized into different weather conditions and summed the number of days for each weather condition (namely frequency of each weather condition). The intervals for daily average wind speeds were: \(<1.5\text{ms}^{-1}, 1.5-2.5\text{ms}^{-1}\) and \(>2.5\text{ms}^{-1}\), while 0mm, 0-15mm and \(\geq15\text{mm}\) for daily rainfall. Pearson
correlation coefficients between ringing intensity and frequencies of various weather
conditions were calculated, in order to investigate whether or how ringing intensity
was influenced by weather conditions in Suichuan. In addition, mean of daily average
wind speed and total daily rainfall in September and October were calculated for each
year. These values were then put into multiple linear regression model to detect the
combined effect of wind speed and rainfall on annual ringing intensity of different
migrant groups. The linear regression was given by:

\[ R = C_1 \times w + C_2 \times r + C_3 \]

Where \( R \) was the ringing intensity for each group of migrants, \( w \) and \( r \)
corresponded to mean wind speed and total rainfall in September and October, \( C_1 \) and
\( C_2 \) were the regression coefficients of wind speed and rainfall, \( C_3 \) was the constant
term.

3. Results

3.1 Bird ringing intensity in Suichuan

There were totally 167 species and 17039 birds captured at Yingpanxu ringing
station during the period between 2005 and 2010. Ringing intensity of each year
varied obviously. All the species were sorted into four groups: Ciconiiformes,
Passeriformes, Gruiformes, and others. Among them, Ciconiiformes and
Passeriformes kept a high proportion of more than 80% in number each year. Pearson
correlation coefficient revealed significant negative correlation between them
\((r=-0.978, P=0.001)\). Compared with Ciconiiformes and Passeriformes, Gruiformes
with a relatively small peak in number in 2008 were much less. The group of others
contributed little to total ringing intensity (Table 1). The greatest richness was in 2007 (Fig. 1), when the numbers of two dominant groups, Ciconiiformes and Passeriformes were nearly equal, so were those of Gruiformes and the group of others.

Within each group, there were diverse species with quantity proportion more than 1% (Table 2). For Ciconiiformes, there were 12 species ringed. Ardeola bacchus was the dominant species, accounting for more than 70% of this group. The number of total species within Passeriformes was 97. Lonchura punctulata and Emberiza aureola made up nearly 64% of Passeriformes. Within Gruiformes, Gallinula chloropus and Turnix tanki comprised more than 81% of the total 10 species. The remaining species were included in the group of others, each of them was low in number.

3.2 Wind speed and ringing intensity

The distribution of daily average wind speed in September and October indicated that daily average wind speeds during the peak of autumn avian migration were mostly $\leq 2.5 \text{ms}^{-1}$ in Suichuan (Fig. 2). It was moderate or light compared with expected bird airspeed (Bloch and Bruderer 1982). Pearson correlation coefficients between ringing intensities and frequencies of varying daily average wind speeds showed different correlation patterns for each group (Table 3). It showed that ringing intensities of all the four groups of migrants shared positive correlations with wind
speeds $<1.5 \text{ms}^{-1}$, while negative when wind speeds $\geq 1.5 \text{ms}^{-1}$. Wind speeds significantly affecting ringing intensity were various for different groups. Ringing intensity of Passeriformes with small-size was significantly influenced by daily average wind speeds $>2.5 \text{ms}^{-1}$. The more frequent strong wind occurred, the less Passeriformes were ringed [Fig. 3 (a)]. Ringing intensity of Gruiformes with diverse-size was also significantly affected by wind speed, but they were more sensitive to wind speeds $\leq 2.5 \text{ms}^{-1}$. They responded to wind speeds at $1.5–2.5 \text{ms}^{-1}$ as did Passeriformes to wind speeds $>2.5 \text{ms}^{-1}$. On the contrary, there were more Gruiformes ringed with greater frequency of wind speeds $<1.5 \text{ms}^{-1}$ [Fig. 3 (b) and (c)]. Ringing intensity of large-size Ciconiiformes shared non-significant correlation with any wind speed condition, indicating week or null effects of wind speed on migratory behavior of Ciconiiformes. Generally, the total number of birds ringed in Suichuan was significantly negatively related to frequency of daily average wind speeds $> 2.5 \text{ms}^{-1}$, suggesting that migratory behavior was affected by wind speed [Fig. 3 (d)].

3.3 Rainfall and ringing intensity

The distribution of daily rainfall in September and October indicated that rainfall was dominated by 0mm at the height of autumn migration in Suichuan (Fig. 4). Precipitation intensity of rainy day was concentrated in the range of 0-15mm. There was occasionally heavy rain ($\geq 15 \text{mm}$), the frequency of it shared strong and
significant correlation with ringing intensity of small Passeriformes [Table 4 and Fig. 5 (a)]. The more frequent heavy rainfall, the less Passeriformes ringed. Aside from Passeriformes, correlations between rainfall and ringing intensities of the other three groups were weak or null. Generally, ringing intensity in Suichuan was negatively correlated with frequency of heavy rain [Table 4 and Fig. 5 (b)], which was mostly contributed by the Passeriformes group.

3.4 Combined effect of wind speed and rainfall on ringing intensity

The combined effect of wind speed and rainfall on ringing intensity of different groups of migrants was investigated by a more-straight forward method, multiple linear regression analysis (Table 5). Comparison of the normalized coefficients showed greater effect of wind speed on ringing intensity than rainfall. Higher wind speed was related to less ringing intensity of migrants. While for Passeriformes, rainfall and wind speed played similar large impacts on its ringing intensity. The $R^2$ showed that the combined wind speed and rainfall could explain relatively higher variation of Passeriformes and Gruiformes than Ciconiiformes. It confirmed that large-bodied Ciconiiformes were less sensitive to meteorological variables. For total ringing intensity, the combined wind speed and rainfall could model it with highest $R^2$. The negative regression coefficients of wind speed and rainfall while modeling totally
annual ringing intensity further indicated that heavier rainfall and stronger wind hampered ringing intensity. Once combing together, wind speed and rainfall could explain 79% of the variation of total ringing intensity. However, the $P$ value for $C_2$ showed rainfall's effect on total ringing intensity was not significant. Generally, wind speed was obviously negative related to ringing intensity, but it needed more data to support the significant effect of rainfall.

<Insert Table 5 about here.>

4. Discussion and summary

Migratory behaviors are controlled by both endogenous mechanisms and environmental stimulation. Migrants adjust their endogenous spatiotemporal program and make relevant adaptations in response to the exogenous environment (Berthold 2001; Berthold and Terrill 1991). The external mechanisms, which mostly refer to the impact of weather conditions on migratory behavior, have been extensively studied in different fields. These studies included different migrant species and weather variables, and were based on various analysis methods (Åkesson and Hedenström 2000; Erni et al. 2002; Schaub et al. 2004; Zehnder et al. 2001). Our study showed the effort of bird ringing conducted in Suichuan and the effects of wind speeds and rainfall on it. The result showed significant relationships between frequency of wind speeds and ringing intensity of *Passeriformes* and *Gruiformes*. More frequent stronger wind was related to lower ringing intensity of them. This may be due to two potential reasons: (1) Wind is generally a good predictor of the most preferred flight level. It has been supported
by earlier studies that variable winds stimulated migrants to select an optimal flight altitude (Bruderer et al. 1995; Liechti and Bruderer 1998; Liechti et al. 2000). Local observations in Suichuan indicated that strong enough wind was always accompanied with higher flight altitude of migrants, which could result in less birds ringed; (2) Stronger winds are more easy to cause drift of migrants (Bingman et al. 1982).

Migrants would avoid takeoff under strong winds or change their flight direction if they are on the route. It could cause low migration intensity in the expected migration direction, which results in low ringing intensity. However, ringing intensity of *Gruiformes* was positively correlated with wind speeds <1.5ms\(^{-1}\). This may be due to higher migration intensity with light winds (Schaub et al. 2004), especially constant following winds in our study area. In heavy rain, migration is easily hampered by strong drag and poor visibility (Erni et al. 2002; Richardson 1990), so there is generally less active migrants on routes. This explains that ringing intensity of *Passeriformes* was negatively related to rainfall ≥15mm. For those correlation coefficients without passing the significance test, they may be due to the small sample size of data.

The regression model showed the relatively more effect of wind than rainfall, which is consistent with the studies of paramount effect of wind on migratory behavior (Alerstam 1979; Liechti and Bruderer 1998). While for *Passeriformes*, it was found that both rainfall and wind speed played large influence on its migratory pattern (Lack 1960). The high \(R^2\) of multiple linear regression analysis for total ringing intensity confirmed that migratory behavior was strongly impacted by wind speed and
rainfall. The result of negative values of $\beta_1$ and $\beta_2$ for total ringing intensity was in consistent with the result of univariate analysis. However, the regression model did not pass the significance test, which may be due to the small sample size.

Wind speed and rain interacted differently with each other to explain the variance of ringing intensity of each group. The relatively higher $R^2$ and both negative $\beta_1$ and $\beta_2$ values for Passeriformes were in consistent with the result of univariate analysis. Both intensive rainfall and strong wind decreased ringing intensity of Passeriformes, and they kept their influence patterns when they were combined. While for Gruiformes, regression coefficient of rainfall was positive when it interacted with wind speed. Influence of rainfall on ringing intensity of Gruiformes was obviously associated with wind speed. As for ringing intensity of large-bodied Ciconiiformes, wind speed played a considerable negative effect. And the influence of rainfall was negative when it was combined with wind speed, but to a less degree.

There are still some important but unaddressed questions, which need further studies: (1) The result showed that proportions of large bodied Ciconiiformes and small bodied Passeriformes were negatively correlated. Is this relationship biologically meaningful, such as these two types of birds compete with each other for food while taking rest in the stopover site of Suichuan? (2) How to weight the two potential effects of winds on bird migration? Take Gruiformes for example, significant correlations between ringing intensity and wind speeds changed from positive to negative for higher wind speeds. It was speculated that active migration was higher with light winds than with strong winds, and higher flight altitude accompanied with
higher wind speeds was another factor causing less ringing intensity. However, it needs further study to specifically investigate correlations between migration behaviors, including changeable flight altitude and active migration and wind speeds.

(3) Within each group, there are species that respond differently to weather conditions. Therefore, the responses of some representative migrant species to weather should be examined in particular.

In summary, the results of this study showed different effect patterns of wind speed and rain, and the relatively greater effect of wind than rain on migration of various migrants. Among them, migratory behaviors of small-size *Passeriformes* were most easily affected by weather conditions, while large-size *Ciconiiformes* were not significantly controlled by wind speed and rain. The results implicated the impact of wind and rain on migratory behaviors, including migration intensity and flight altitude. Weak winds facilitate more migration intensity, while strong winds hamper active migration and promote higher flight altitude. In addition, heavy rain causes low migration intensity.

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Table 1. Ringing intensity of different groups of migratory birds in Suichuan between 2005 and 2010.

<table>
<thead>
<tr>
<th>Group</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
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<td>3230</td>
<td>2196</td>
<td>798</td>
<td>580</td>
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<td>2073</td>
<td>2048</td>
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<td>116</td>
<td>534</td>
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<td>4513</td>
<td>3432</td>
<td>2086</td>
<td>544</td>
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Table 2. Ringing intensity of different species with quantity proportion more than 1% in each group of migratory birds.

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<tr>
<th>Groups</th>
<th>Species</th>
<th>2005</th>
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<th>2009</th>
<th>2010</th>
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</table>
Table 3. Pearson correlation coefficients between ringing intensity of different groups of migratory birds and frequency of daily average wind speeds.

<table>
<thead>
<tr>
<th>Wind speed</th>
<th>Ciconiiformes</th>
<th>Passeriformes</th>
<th>Gruiformes</th>
<th>Others</th>
<th>All</th>
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</thead>
<tbody>
<tr>
<td>&lt;1.5ms⁻¹</td>
<td>0.424</td>
<td>0.563</td>
<td><strong>0.952</strong></td>
<td>0.487</td>
<td>0.700</td>
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<tr>
<td>1.5–2.5ms⁻¹</td>
<td>−0.347</td>
<td>−0.108</td>
<td><strong>−0.822</strong></td>
<td>−0.375</td>
<td>−0.397</td>
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<tr>
<td>&gt;2.5ms⁻¹</td>
<td>−0.367</td>
<td><strong>−0.949</strong></td>
<td>−0.770</td>
<td>−0.453</td>
<td>−0.838</td>
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</tbody>
</table>

* Bilateral significance test with \( p \leq 0.05 \)
Table 4. Pearson correlation coefficients between ringing intensity of different groups of migratory birds and frequency of daily rainfall.

<table>
<thead>
<tr>
<th>Rainfall</th>
<th>Ciconiiformes</th>
<th>Passeriformes</th>
<th>Gruiformes</th>
<th>Others</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>0mm</td>
<td>0.207</td>
<td>0.766</td>
<td>0.293</td>
<td>0.289</td>
<td>0.575</td>
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<td>0–15mm</td>
<td>−0.107</td>
<td>−0.663</td>
<td>−0.231</td>
<td>−0.189</td>
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<td>≥15mm</td>
<td>−0.482</td>
<td>−0.923*</td>
<td>−0.427</td>
<td>−0.545</td>
<td>−0.862*</td>
</tr>
</tbody>
</table>

* Bilateral significance test with p ≤ 0.05
Table 5. Modeling result of multiple linear regression analysis for different groups of migratory birds. $C_1$ and $C_2$ are the regression coefficients for wind speed and rainfall in the multiple linear regression, modeling ringing intensity for different groups of migratory birds. $\beta_1$ and $\beta_2$ are the normalized $C_1$ and $C_2$.

<table>
<thead>
<tr>
<th>Group</th>
<th>Ciconiiformes</th>
<th>Passeriformes</th>
<th>Gruidae</th>
<th>Others</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>$\beta_1$</td>
<td>-0.660</td>
<td>-0.569</td>
<td>-0.732</td>
<td>-0.707</td>
<td>-0.841</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>-0.051</td>
<td>-0.582</td>
<td>0.275</td>
<td>-0.091</td>
<td>-0.302</td>
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<tr>
<td>$P$ value of $C_1$</td>
<td>0.225</td>
<td>0.194</td>
<td>0.132</td>
<td>0.180</td>
<td>0.050</td>
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<tr>
<td>$P$ value of $C_2$</td>
<td>0.914</td>
<td>0.187</td>
<td>0.496</td>
<td>0.837</td>
<td>0.337</td>
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<tr>
<td>$P$ value of $C_3$</td>
<td>0.191</td>
<td>0.125</td>
<td>0.134</td>
<td>0.150</td>
<td>0.035</td>
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<tr>
<td>$P$ value of model</td>
<td>0.422</td>
<td>0.207</td>
<td>0.235</td>
<td>0.347</td>
<td>0.096</td>
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<tr>
<td>$R^2$</td>
<td>0.437</td>
<td>0.650</td>
<td>0.619</td>
<td>0.506</td>
<td>0.790</td>
</tr>
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</table>
Fig. 1 Biodiversity of migratory birds in Suichuan. It shows annual biodiversity calculated by Shannon-Wiener index, which indicates migrant species richness in Suichuan from 2005 to 2010. There are four major groups of migratory birds in Suichuan, including Ciconiiformes, Passeriformes, Gruiformes and others.

Fig. 2 Distribution of daily average wind speeds during September and October in Suichuan. Speeds at migration peak were segregated into three intervals: <1.5 ms\(^{-1}\), 1.5–2.5 ms\(^{-1}\) and >2.5 ms\(^{-1}\). Bars with various gray shades represent number of days with daily average wind speeds <1.5 ms\(^{-1}\), 1.5–2.5 ms\(^{-1}\) and >2.5 ms\(^{-1}\), as shown by text above bars.

Fig. 3 Relationships between ringing intensity and frequency of daily average wind speeds. Panel a shows significant negative correlation between ringing intensity of Passeriformes and number of days with daily average wind speeds >2.5 ms\(^{-1}\), panels b and c show significant correlations between ringing intensity of Gruiformes and numbers of days with corresponding daily average wind speeds in the range of 1.5-2.5 ms\(^{-1}\) and <1.5 ms\(^{-1}\), panel d shows the significant negative correlation between total ringing intensity and number of days with corresponding daily average wind speeds >2.5 ms\(^{-1}\). Points depict the original data, and lines are the linear fit of the points.

Fig. 4 Distribution of daily rainfall during September and October in Suichuan. Rainfalls at peak migration were segregated into three intervals: 0 mm, 0–15 mm and ≥15 mm. Bars with different gray shades symbolize number of days with daily rainfall 0 mm, 0–15 mm and ≥15 mm, as shown by text above bars.
Fig. 5 Relationships between ringing intensity and frequency of daily rainfall. Panels a and b respectively show significant negative correlations between ringing intensity of Passeriformes and total ringing intensity and numbers of days with daily rainfall ≥15mm. Points show the original data, and lines are the linear fits of the points.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.

![Graph showing relationship between number of days with daily rainfall ≥15mm and singing intensity.](Image)