Among-Species Differences In Seasonal Timing and Weather Correlates of Autumn Raptor Migration At Khao Dinsor, Thailand, 2015–2016

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AMONG-SPECIES DIFFERENCES IN SEASONAL TIMING AND WEATHER CORRELATES OF AUTUMN RAPTOR MIGRATION AT KHAO DINSOR, THAILAND, 2015–2016

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Abstract.—Identifying the drivers of shifts in the abundance of wildlife species has been a central focus of conservation ecology recently. With growing concern about the impacts of global environmental change on biodiversity patterns, ecologists are challenged to better understand the relationships between species' abundance and various environmental factors. Using raptor count data collected following a standardized protocol at Khao Dinsor, southern Thailand, in 2015 and 2016, we characterized the seasonal timing and identified weather associations of the visible migration of representative species, namely the Black Baza (*Aviceda leuphotes*), Chinese Sparrowhawk (*Accipiter soloensis*), and Oriental Honey-Buzzard (*Pernis ptilorhynchus*). We explored the associations of their daily total counts with local weather variables. We found that the magnitude of their migration within the season was linked with the prevailing meteorological conditions. In general, daily counts of all three species were positively associated with predominant wind patterns. Air temperature was positively associated with the daily counts of species that migrated early in the season (Chinese Sparrowhawk and Oriental Honey-Buzzard). Barometric pressure was negatively associated with the daily counts of species whose migration window coincides with the shift in monsoon season (Black Baza and Oriental Honey-Buzzard). These results provide us with a better understanding of the drivers of migration patterns at a representative monitoring site on a globally important and heavily used flyway. They may be useful for making better inferences and predictions on the population trajectories of migrating raptors in future environmental change scenarios.

Key Words: *Black Baza*; Aviceda leuphotes; *Chinese Sparrowhawk*; Accipiter soloensis; *Oriental Honey-Buzzard*; Pernis ptilorhynchus; *Khao Dinsor*; *migration*; *raptor*; *Thailand*; *weather*.

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DIFERENCIAS ENTRE ESPECIES EN LA TEMPORALIDAD ESTACIONAL Y RELACIÓN CON LA METEOROLOGÍA DURANTE LA MIGRACIÓN OTOÑAL DE RAPACES EN KHAO DINSOR, TAILANDIA, 2015–2016

RESUMEN.—Identificar los factores que determinan los cambios en la abundancia de especies silvestres ha sido el foco central de la ecología de la conservación. Con la creciente preocupación por los impactos del cambio ambiental global en los patrones de biodiversidad, los ecólogos se enfrentan el desafío de comprender mejor las relaciones entre la abundancia de especies y varios factores ambientales. Utilizando datos de conteo de rapaces, recopilados siguiendo un protocolo estandarizado en Khao Dinsor, en el sur de Tailandia, en 2015 y 2016, caracterizamos la temporalidad estacional e identificamos la relación con la meteorología durante la migración de especies representativas observables, tales como *Aviceda leuphotes*, *Accipiter soloensis* y *Pernis ptilorhynchus*. Exploramos las relaciones de sus conteos totales diarios con variables meteorológicas locales. Encontramos que la magnitud de sus migraciones dentro de la temporada estuvo relacionada con las condiciones meteorológicas predominantes. En general, los conteos diarios de las tres especies se asociaron positivamente con los patrones de viento predominantes. La temperatura del aire se asoció positivamente con los conteos diarios de las especies que migraron tempranamente en la temporada (*A. soloensis* y *P. ptilorhynchus*). La presión barométrica se asoció negativamente con los conteos diarios de las especies cuya ventana de migración coincide con el cambio en la estación monzónica (*A. leuphotes* y *P. ptilorhynchus*). Estos resultados nos proporcionan una mejor comprensión de los factores que determinan los patrones de migración en un sitio de seguimiento representativo y en una ruta migratoria muy utilizada e importante a nivel mundial. Además, pueden ser útiles para mejorar nuestras inferencias y predicciones sobre las tendencias poblacionales de las rapaces migratorias en futuros escenarios de cambio ambiental.

[Traducción del equipo editorial]

INTRODUCTION

Identifying the patterns and drivers of shifts in the abundance of wildlife species has been a central focus of conservation ecology recently (Dornelas et al. 2014). Various survey techniques are employed to monitor changes in abundance (Marsh and Trenham 2008). Data obtained through population monitoring can be used to estimate trends and assess extinction risks (Goldsmith 2012), test hypotheses on the drivers of abundance patterns (Krebs 2002) and determine the efficacy of management actions for biodiversity conservation (Niemelä 2000). However, effective population monitoring of many species is often challenging to implement because of limited resources and the inherent challenges in observing sparsely distributed species, particularly raptors, during certain periods of their life cycle (Fuller and Mosher 1987).

For raptors, estimating abundance during the migration period is a cost-efficient approach to monitoring their population trends (Bednarz et al. 1990). Migration counts are often used in calculating indices of these population trends (e.g., raptor population index; Farmer and Hussell 2008, Hussell and Inzunza 2008). In fact, consistent monitoring at hawk watch sites along migration bottlenecks has effectively detected population declines and recoveries of some species (Bildstein 2006).

Migration monitoring efforts also involve collecting data on weather variables such as wind speed and direction, temperature, and cloud cover to better understand the effects of environmental factors on species-specific migration patterns (Agostini et al. 2005, Panuccio et al. 2010, Vansteelant et al. 2014, Panuccio et al. 2016, Shamoun-Baranes et al. 2017, Vansteelant et al. 2017). The associations between weather parameters and aspects of species' migration can differ based on the morphology and flight capacities of individual species (Spear and Ainley 1997).

Wingspan is sometimes used as a proxy for estimating flight performance, as it is also correlated with the kinematics of wing motion (Tobalske et al. 2003). Wingspans can allow assessments of soaring and gliding performance (Pennycuick 1990), which in turn are associated with species' behavior and habitat (e.g., long and pointed wings are associated with migratory habits while short, rounded wings characterize species that inhabit densely forested habitats; Videler 2006, Vanhooydonck et al. 2009). However, most of what is known about the differences in the association of species' migrations with weather parameters comes from studying flyways in the Americas, Europe, and Africa (Kirby et al. 2008). Studies that explore these relationships are less common within the East-Asian flyways (Germi et al. 2009, Concepcion et al. 2017).

The East Asian Continental Flyway is one of the major flyways in Asia (Zalles and Bildstein 2000). It is a 7000-km corridor that stretches from eastern Siberia toward the Indonesian Archipelago via the Thai-Malay Peninsula. At least 30 species of migrating raptors use this route, among the most numerous of which are Oriental Honey-Buzzard (*Pernis ptilorhynchus*), Grey-faced Buzzard (*Butastur indicus*), and Chinese Sparrowhawk (*Accipiter soloensis*; Ferguson-Lees and Christie 2005). There are relatively few hawk watch sites where autumn migration is regularly monitored on this flyway (Zalles and Bildstein 2000), of which the best-known is at Khao Dinsor, Chumphon Province, southern Thailand, where >200,000 migrant hawks are recorded annually (Zalles and Bildstein 2000, DeCandido et al. 2004, Limparungpatthanakij et al. 2019).

Standardized raptor migration monitoring at Khao Dinsor was initiated in 2015. However, opportunistic observations have been conducted at this site since 2008. The extent to which local weather patterns, which vary throughout the course of the migration period, can affect the magnitude of migration at this hawk watch site remains little-studied. The present study aimed to address this gap by determining species-specific temporal patterns and responses to local weather variables.

Here, we assessed the effects of wind components, temperature, and barometric pressure on the daily counts of the three most numerous species recorded at Khao Dinsor: Black Baza (*Aviceda leuphotes*), Chinese Sparrowhawk, and Oriental Honey-Buzzard. These weather variables are important drivers of the magnitude and timing of bird migration of other species (Germi et al. 2009, Concepcion et al. 2017, Haest et al. 2019). We characterized the associations between weather variables and the daily counts of representative species that differed in wingspan, because this morphological trait may have implications for flight performance and response to weather patterns (Norberg 1985). By exploring how weather affects the migration of raptors at this site, we can better understand and predict how environmental changes can impact species that use this important yet relatively understudied flyway.

METHODS

Study Area. Khao Dinsor lies in Chumphon Province, southern Thailand, 463 km south of Bangkok (driving distance). The surrounding region is subject to a tropical monsoon climate in which southwesterly winds predominate during the months of May to October and northeasterly winds from mid-October onward. On average, air temperature in Chumphon is around 26.9 ± 3.5°C throughout the year (Climate Data.org 2017).

The hawk watch sites where counts were conducted were located on the ridges covered in regenerating second-growth forest (Nualsri and DeCandido 2010). Specifically, migration monitoring was conducted at two watch sites, which intercepted the same broad flight line: (1) Seaside Station was closer to the coast (2.1 km distant), at 252 m elevation, and (2) Eagle Cliff Station, which was further inland (670 m west of Seaside Station) at 352 m elevation. Mountain ridges to the west and views over oil-palm plantations to the north were more visible at Eagle Cliff Station, while Seaside Station gave views of the lowland coastal strip. A more detailed description of site topography is given in Limparungpatthanakij et al. (2019). In 2015 and 2016, a combined total of 1,188,444 migratory raptors of 22 species was recorded at Khao Dinsor at both watch sites (Limparungpatthanakij et al. 2019). More migrants (62%) were observed from the Seaside Station than from the Eagle Cliff Station (38%). For this reason, we considered only counts recorded at Seaside Station in our analysis.

Migration Data. Migration monitoring was conducted for 10 hr daily (0700 H to 1700 H) from 1 September (Julian date: 244) to 15 November (Julian date: 320) in both 2015 and 2016. Counts were done by four to five trained counters, with two to three at each count station. Counters used binoculars and cameras fitted with telephoto lens to identify and count diurnal migrant birds including raptors. Only birds flying from the north to south were recorded. To avoid double counting of observed flocks, an arbitrary boundary between the two stations (approximately 300 m distant from each station) was observed. Both counting teams remained in contact via radio to coordinate efforts. In the analyses, we only used data on representative species that differed in wingspans: Black Bazas (64 to 80 cm), Oriental Honey-Buzzards (115 to 155 cm), and Chinese Sparrowhawks (52 to 62 cm; Ferguson-Lees and Christie 2005).

Weather Data. We obtained data on the average air temperature (°C), wind speed (m/s), meteorological wind direction, and barometric pressure (hPa) collected daily at the Chumphon Airport, about 16 km north of the watch site. For our analysis, we calculated the U and V wind components using the daily average wind speed and direction (Wallace and

Hobbs 2006). Using these orthogonal components allowed us to estimate the combined effects of wind magnitude and direction simultaneously. Wind directions were reported as half-wind directions from a 16-point compass (e.g., WSW = west-southwest). In calculating the U and V wind components, we first expressed the meteorological wind direction (i.e., direction from which the wind was blowing) as degree directions. In this case, a west wind (i.e., wind blowing from the west; westerly) was assigned a value of 270°, and an east wind (i.e., wind blowing from the east; easterly) was assigned a value of 90° (National Climate Data Center 2021). U and V wind components were then calculated using the formulas (Wallace and Hobbs 2006):

$$u = -|\sigma|*\sin\left[\frac{\Pi}{180}*\Phi\right] \qquad (Eqn.1)$$

$$v = -|\sigma|*\cos\left[\frac{\Pi}{180}*\Phi\right] \qquad (Eqn.2)$$

where σ is the wind speed (m/s), and Φ is the value of the meteorological wind direction expressed as a degree direction. We followed the convention of interpreting a positive value for the U wind component (Eqn. 1) as a west wind and a positive V wind component (Eqn. 2) as a south wind (southerlies; winds are blowing from the south to north).

Data Analysis. *Generalized linear models.* We evaluated the effects of local weather patterns on the daily counts of representative species recorded at Khao Dinsor, Thailand using generalized linear models (GLMs). GLMs allow for modelling data with different error distributions, which may be appropriate in this case given the overdispersion of the counts within the season. Because we were interested in determining the population-level effects of local weather variables on count data, we created separate GLMs for each species. Each model had the form:

$$Y \sim Negativebinomial(\mu, \varphi) \qquad (Eqn.3)$$

$$\log(\mu) = \alpha_1 + (\beta_1 * T) + \sum_{k=2}^{5}(\beta_k * X_k) \qquad (Eqn.4)$$

In Eqn. 3, Y is the total daily count for a given species, which followed a negative binomial distribution with a mean (μ) and variance parameter (φ; for justification of the use of the negative binomial distribution, refer to the Supplemental Material). We modelled the mean daily count with the following parameters (Eqn. 4): an intercept (α_1, a slope [β_1] for year [T]), and separate slope estimates (β_k) for the different weather variables (X_k; air temperature, U and V wind components, and barometric pressure). We also examined the lag effects of weather variables by creating models that included weather variables lagged by one day. We ensured that the variables included in the model were not correlated with each other using Spearman's correlation test ($|r| < 0.5$). To facilitate interpretation and improve model convergence, we standardized variables by centering the values on the mean and dividing them by two standard deviations (Gelman 2008).

Model implementation, diagnostics, and interpretation. We implemented the models in a Bayesian framework with weakly-informed priors to propagate uncertainty, given that we were only looking at patterns over a 2-yr study period. We based parameter estimates from the models on four chains with 2000 iterations, with 1000 used for the warm-up period. We assessed model convergence based on the Gelman-Rubin (1992) diagnostic ($\hat{R}$) and the effective sample size. We compared the performances of the model variations (i.e., lagged variables vs non-lagged weather variables) using leave-one-out cross-validation information criterion (LOOIC) values (Vehtari et al. 2020). We interpreted the effects of each weather variable on species-specific counts with the probability of direction (PD). PD quantifies the probability of a directional effect of the predictor on the response variable (i.e., either positive or negative; Makowski et al. 2019). PD is based on the posterior draws of the parameter estimates from a Bayesian model. Thus, using PD allows us to effectively utilize the probabilistic properties of these types of models. Here, we evaluated the probability of each weather variable to influence species-specific counts positively or negatively. All statistical analyses were performed using the *rstanarm* package (Goodrich et al. 2020) in R ver 4.1.1 (R Core Team 2021). Code used for the analyses can be accessed at https://doi.org/10.5281/zenodo.6152396.

RESULTS

Migration and Weather Patterns Within the Season. *Migration patterns.* In 2015 and 2016, 167,499 Black Bazas, 93,983 Oriental Honey-Buzzards, and 394,755 Chinese Sparrowhawks were recorded at the Seaside Station. In general, Chinese Sparrowhawk and Oriental Honey-Buzzard migration peaked early

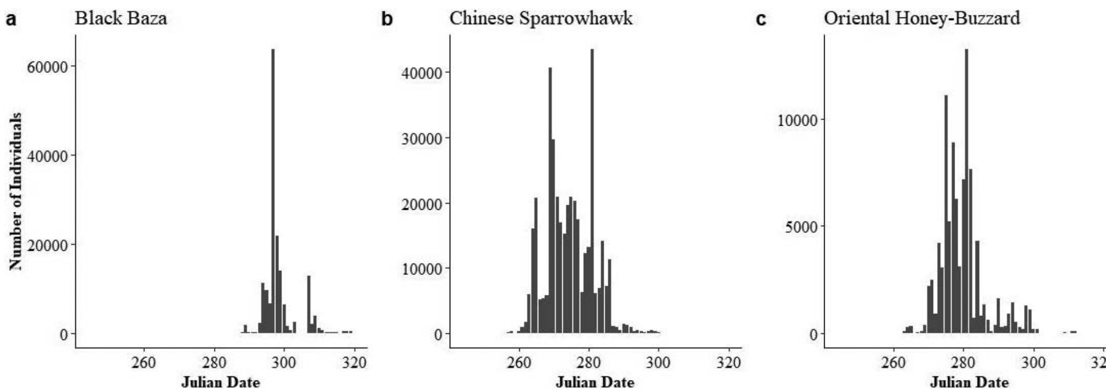

Figure 1. Seasonal timing of autumn migration of representative species: (a) Black Baza, (b) Chinese Sparrowhawk, and (c) Oriental Honey-Buzzard counted in 2015 and 2016 at Khao Dinsor, Thailand. Monitoring period was from 1 September (Julian date: 244) to 15 November (Julian date: 320) each year. Note: Y-axis scales differ among the three graphs.

in the season, from late September to early October (Fig. 1). Specifically, for Chinese Sparrowhawks, the bulk of their seasonal flights (81%) occurred in late September to early October (Julian date: 269–284). The bulk of the Oriental Honey-Buzzards' seasonal flights (85%) were recorded in early October (Julian date: 274–280). Finally, the bulk of Black Baza flights (86%) were recorded late in the season, from mid-to late October (Julian date: 290–315).

Weather patterns. Temperature and barometric pressure levels remained consistent throughout the season. The daily average temperature on site was 27.1 °C (minimum: 24.7 °C, maximum: 29.5 °C) and the daily average barometric pressure was 1010.0 hPa (minimum: 1006.0 hPa, maximum: 1013.0 hPa; Fig. 2). West winds (positive U wind component) were more common earlier in the season, from early September to early October (Julian date: 244–280, Fig. 2). These were replaced with northeasterly winds (negative U and V wind components) later in the season, from late October to mid-November (Julian date: 290–320).

Weather Correlates of Species-specific Daily Counts. In general, the models without lagged terms of the weather variables performed better than those that included lagged terms in explaining the variation in the magnitude of migration of all three species (Table 1).

Black Baza. Daily counts of Black Bazas were negatively associated with U and V wind components

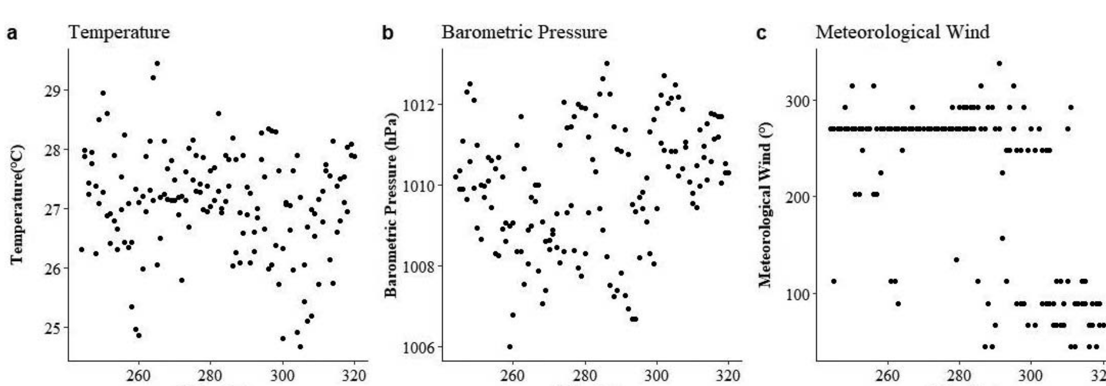

Figure 2. Patterns of weather variables including (a) temperature, (b) barometric pressure, and (c) meteorological wind direction at Khao Dinsor, Thailand, during migration season, from 1 September (Julian date: 244) to 15 November (Julian date: 320) in 2015 and 2016.

Table 1. Model performance of models (LOOIC values) built to explain the variation in the magnitude of migration of Black Bazas, Chinese Sparrowhawks, and Oriental Honey-Buzzards counted in Khao Dinsor, Thailand, from 2015–2016. Model variations involved differences in the type of weather variables included as predictors (lagged by one or without lags).

SPECIES	LAG (0)	LAG (1)
Black Baza	1147.6 ± 111.4	1158.4 ± 111.8
Chinese Sparrowhawk	2022.2 ± 90.1	2022.4 ± 90.4
Oriental Honey-Buzzard	1736.4 ± 71.8	1737.1 ± 71.9

(P [$\beta_{u\ wind} < 0] \geq 0.99$, P [$\beta_{v\ wind} < 0] = 0.83$; Fig. 3a). In this case, the magnitude of Black Baza flights was high when winds were blowing from the northeast (negative U and V wind components). Moreover, we found negative associations between Black Baza counts and air temperature (P [$\beta_{air\ temperature} < 0] = 0.99$), and barometric pressure (P [$\beta_{barometric\ pressure} < 0] = 0.99$; Fig. 3a).

Chinese Sparrowhawk. Daily counts of Chinese Sparrowhawks were positively associated with temperature (P [$\beta_{air\ temperature} > 0] = 0.95$), and U ([P ($\beta_{u\ wind} > 0] \geq 0.99$] and V wind components (P [$\beta_{v\ wind} > 0] = 0.77$; Fig. 3b). In this case, the magnitude of Chinese Sparrowhawk flights was high when winds were blowing from the southwest (positive U and V wind components). We found high uncertainty in the effect of barometric pressure on the magnitude of Chinese Sparrowhawk migration (P [$\beta_{barometric\ pressure} < 0] = 0.57$; Fig. 3b).

Oriental Honey-Buzzard. Daily counts of Oriental Honey-Buzzards were positively associated with air temperature (P [$\beta_{air\ temperature} > 0] = 0.99$), and the U wind component (P [$\beta_{u\ wind} > 0] \geq 0.99$; Fig. 3c). Moreover, we found a negative association between Oriental Honey-Buzzard counts and barometric pressure (P [$\beta_{barometric\ pressure} < 0] = 0.97$), and with the V wind component (P [$\beta_{u\ wind} < 0] = 0.98$; Fig. 3c). In this case, the magnitude of Oriental Honey-Buzzard flights was high when winds were blowing from the west (positive U wind component) and north (negative V wind component).

DISCUSSION

Characterizing the associations between population abundances and environmental variables is important to better understand the consequences of ongoing and rapid global environmental change (McGill et al. 2015). Linking these relationships with morphology may be useful in characterizing the mechanisms underlying population dynamics (Suding et al. 2003). Here, we found interspecific differences in the magnitude of species' migration that coincided with the prevailing meteorological conditions. In general, the counts of all three representative species were positively associated with predominant wind patterns, which may have contributed to reduced energetic costs and/or total duration of their migration journey. We also noted differences in their associations with other weather variables (temperature and barometric pressure), which may be linked to their individual migration

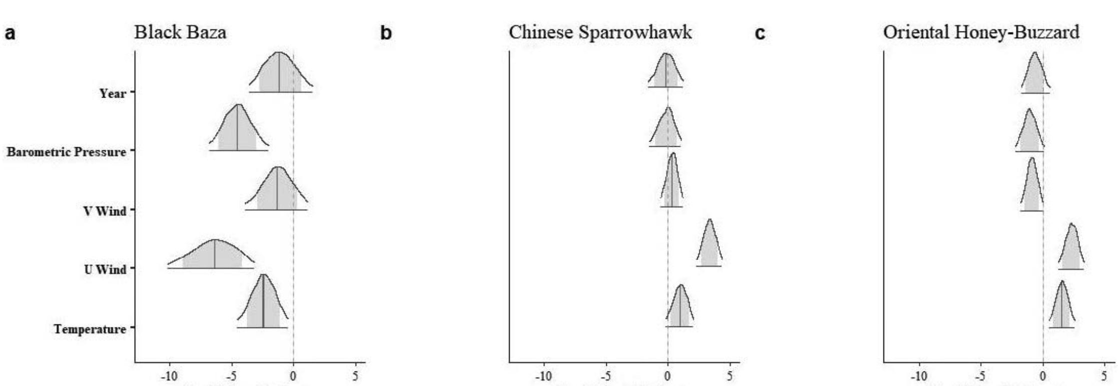

Figure 3. Coefficient estimates of the different associations between external factors and the daily counts of representative species ([a] Black Baza, [b] Chinese Sparrowhawk, and [c] Oriental Honey-Buzzard) recorded at Khao Dinsor, Thailand, in 2015 and 2016. Gray lines indicate median posterior estimate, shaded gray, and unshaded outer region indicate 80% and 95% probability mass, respectively.

strategies to respond to prevailing conditions (Meyer et al. 2000).

Among all the variables we assessed, wind components exhibited the highest probability of influencing daily count records, suggesting their relatively important role in shaping raptor migration patterns. For migrating birds, favorable wind conditions are important as they contribute to the speed of arrival at the overwintering grounds and survival en route (Bildstein 2006). Thus, wind is considered a selective factor during migration (Alerstam 1979, 2011, Liechti and Bruderer 1998). At Khao Dinsor, Chinese Sparrowhawk and Oriental Honey-Buzzard flights were positively associated with headwinds (winds that blew opposite their direction of travel, i.e., southwesterly and westerly winds, respectively), which coincided with the predominant meteorological pattern (the southwest monsoon season). Black Baza flights were positively associated with tailwinds (winds that blew in the direction of their travel, i.e., northeasterly winds), which also coincided with the period when the southwest monsoon transitioned into the northeast monsoon.

Chinese Sparrowhawk and Oriental Honey-Buzzard flights during headwinds may simply be an artifact of the timing of their migration. Given that the currently prevailing meteorological patterns (i.e., monsoons) have existed in the region for at least the past 10,000 yr, and possibly much longer, these species have presumably developed adaptive strategies (e.g., seasonal detours, shifts in flight behavior, shifts in seasonal timing) to exploit the predictability of these environmental variables (Alerstam and Lindström 1990, Klaassen et al. 2011, Vansteelant et al. 2017). Both species may also employ air speed adjustments (i.e., increase air speed into headwinds) to maximize distance covered (Bloch and Bruderer 1982, Pennycuick 1978), or tolerate drift early in the season and compensate as they approach their destination (Alerstam 1979). Additionally, it is possible that the strong thermals that are generated overland are enough to compensate for flying into a headwind (Yamaguchi et al. 2011).

Chinese Sparrowhawks, specifically, have long and narrow wings, which are adapted to shifting between flapping and soaring flight (Concepcion et al. 2017, Meyer et al. 2000). This may help them adjust flight mechanisms in headwinds. Oriental Honey-Buzzards have large wingspans and are broad-winged, obligate soaring migrants (Bildstein 2006). They are potentially less likely to exhibit flapping behavior and fly into headwinds over land (Nourani and Yamaguchi 2017). Oriental Honey-Buzzards are also known to spend relatively long periods in stopover sites to replenish energy reserves (Yamaguchi et al. 2008).

In contrast, Black Bazas may have evolved to delay migration until late in the season, and to employ energy-minimizing strategies by migrating in tailwinds (Alerstam and Lindström 1990). The extent to which these adaptive strategies are used by species observed at this site is beyond the scope of this study. This may be an avenue for future research to better understand the level of selectivity to wind conditions of these species.

Air temperature was also associated with the magnitude of the daily flights in all three species. The positive association between Chinese Sparrowhawk and Oriental Honey-Buzzard counts and air temperature may be attributed to increased thermal formation under warmer conditions, as both species employ soaring flight strategies. Moreover, weather conditions were generally warmer early in the season, coinciding with the migration window for both species. Greater thermal availability is often linked to increased rate of passage and reduced energetic costs for migrants (Kerlinger 1989, Shamoun-Baranes et al. 2003). Thus, both Chinese Sparrowhawks and Oriental Honey-Buzzards, which are soaring migrants, may have benefitted from greater thermal availability associated with increased air temperature early in the season (Sapir 2010). The broad-winged Oriental Honey-Buzzard had a comparatively greater positive association with air temperature than did the Chinese Sparrowhawk, presumably linked to the honey-buzzard's predominant flight strategy (soaring) and greater body size (Nourani et al. 2016). Finally, the cool northeasterly winds that predominate later in the season (Khedari et al. 2002) may explain the negative association between Black Baza counts and air temperature.

We also found a negative association between barometric pressure and counts of Black Bazas and Oriental Honey-Buzzards. This negative association is rather counterintuitive given that high barometric pressure is associated with fair weather (Wellington 1946), and the ideal soaring conditions which may be more conducive for raptor flights. It is possible that barometric pressure may serve as proximate cue for weather conditions at current and future locations of the migrants (Richardson 1978). For example, large migrating insects use falling barometric pressures as cues of convective storms that precede cold fronts (Wellington 1946). In response, these insects increase their flight activity (Wellington 1946). Likewise, Black Bazas and Oriental Honey-Buzzards may be responding to upcoming negative weather conditions. Finally, Black Bazas are more active in overcast conditions (Clark and Kirwan 2020). This may also be the case for other species of migrating raptors in Khao Dinsor, as large numbers of migrants were counted under overcast skies and with westerly winds (DeCandido et al. 2008).

Inferences made about migration counts, including their associations with local weather variables, often do not account for the effects of different factors on the probability of detection (Berthiaume et al. 2009, Nolte et al. 2016). It is possible that the detectability of migrants by observers may be influenced by weather, as weather variables can influence flight altitude (Richardson 1978, Berthiaume et al. 2009, Kahlert et al. 2012). During the autumn migration season at Khao Dinsor, visible migration is highest when west winds prevail, because raptors tend to drift toward the east coast (DeCandido et al. 2008). In contrast, in spring, when east winds predominate, visible northward migration takes place several kilometers inland of Chumphon (DeCandido et al. 2008). Thus, quantifying site-specific detection probabilities per season and accounting for them in models to explore the associations between weather variables and migration is important for a more accurate estimation of population trends (Berthiaume et al. 2009). Moreover, movement data for several species counted on site might help us refine our understanding of how local and regional weather affect species' migration patterns along the flyway (Robinson et al. 2010, Bouten et al. 2013, Pierce et al. 2021).

Understanding migrant responses to local weather conditions is crucial for characterizing the importance of migration flyways (Alerstam 2001). Here, we report the importance of wind components in driving aspects of raptor migration in a significant yet understudied flyway, the East Asian Continental Flyway. By exploring these weather associations, we contribute to the understanding of the drivers of migration patterns in this flyway and help fill knowledge gaps about global raptor migration.

SUPPLEMENTAL MATERIAL (available online). Statistical analyses.

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