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SPRING MIGRATION OF CHINESE GOSHAWKS (*ACCIPITER SOLOENSIS*) IN TAIWAN

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ABSTRACT.—Little is known about the abundance and distribution of Chinese Goshawks (*Accipiter soloensis*) during spring migration along the Western Pacific flyway around Taiwan. This species is the most numerous migratory raptor in East Asia. In April 2004, we employed weather radar at Kenting and Chiku to study the spatial and temporal distribution and flying behavior of migrants in the Taiwan area. Goshawk flocks migrating across Luzon Strait toward Taiwan (n = 193) averaged 3.1 km in length (SD = 3.41, range 1.0–27.5 km) and 0.7 km in width (SD = 0.30, range 0.3–2.5 km). Using a regression model relating bird numbers to the reflectivity of radar images, we estimated that at least 225 935 Chinese Goshawks passed through the study area during 5 d in the month of April. Flocks crossing the Luzon Strait approached the Hengchun Peninsula, at the southern tip of Taiwan, along several inland and offshore routes, making it difficult to obtain accurate and complete observations from the ground. Farther north at Chiku, we used radar imaging to estimate 150 619 northbound migrants, 67% of the number detected by the Kenting radar. Of these, 24% bypassed Taiwan and flew nonstop to mainland China via the Pescadores, located off the west coast of Taiwan. Another 55% flew over the southern end of Taiwan and then across the Taiwan Strait to the mainland. The remaining 21% continued north over Taiwan after spending up to 2 d in the central mountains of Taiwan. This likely explains why relatively small numbers of goshawks are observed in central and northern Taiwan. Chinese Goshawks flew more slowly and higher over land than over water, and their ground speed increased with favorable winds.

KEY WORDS: *Chinese Goshawk*; Accipiter soloensis; *migration*; *Taiwan*; *weather radar*.

MIGRACIÓN DE PRIMAVERA DE *ACCIPITER SOLOENSIS*

RESUMEN.—Se sabe muy poco sobre la abundancia y distribución de *Accipiter soloensis* durante la migración de primavera a lo largo de la ruta del Pacífico oeste por Taiwán. Esta especie es el ave rapaz más abundante en el este de Asia. En abril de 2004 empleamos radares meteorológicos en Kenting y Chiku para estudiar la distribución espacial y temporal, y el comportamiento de vuelo de individuos migratorios en el área de Taiwán. Las bandadas de *A. soloensis* que se encontraban migrando a través del estrecho de Luzon hacia Taiwán (n = 193) tuvieron en promedio 3.1 km de largo (DE = 3.41, rango 1.0–27.5 km) y 0.7 km de ancho (DE = 0.30, rango 0.3–2.5 km). Utilizando un modelo de regresión que relacionó los números de aves con la reflectividad de las imagines de radar, estimamos que pasaron por lo menos 225 935 individuos por el área de estudio durante un periodo de 5 días en el mes de abril. Las bandadas que cruzaron el estrecho de Luzon llegaron a la Península Hengchun por la punta sur de Taiwán, a lo largo de varias rutas tierra adentro y mar afuera, lo que hace difícil obtener observaciones exactas y completas desde tierra. Más al

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norte en Chiku, usamos imágenes de radar para estimar 150 619 individuos que migraban hacia el norte, 67% del número registrado por el radar de Keanting. De estos, 24% no pasaron por Taiwán y volaron sin parar hasta China continental vía el Pescadores, que se localiza al oeste de Taiwán. El 55% de estos voló sobre el extreme sur de Taiwán y después cruzó el estrecho de Taiwán hacia el continente. El 21% restante continuó hacia el norte sobre Taiwán después de pasar 2 días en las montañas centrales de Taiwán. Esto probablemente explica porqué son observados números relativamente bajos en el centro y norte de Taiwán. Los halcones volaron más lentamente y más alto sobre tierra que sobre agua, y su velocidad de vuelo aumentó con los vientos favorables.

[Traducción del equipo editorial]

Chinese Goshawks (*Accipiter soloensis*) breed in southern Ussuriland, Korea, and in central and southeastern China. They are the most numerous migratory raptor in East Asia (Chen 2005, Germi et al. 2009). In autumn, they migrate south via Japan, Taiwan, the Philippines, Thailand, and Malaysia to wintering grounds in Sumatra, Java, Bali, and Sulawesi (Ferguson-Lees and Christie 2001). Along the oceanic flyway of East Asia, they pass the island of Taiwan, which lies 160 km off the southeastern coast of mainland China. During September and October 2004, observers recorded 221 615 migrants at Hengchun Peninsula on the southern tip of Taiwan (Chen 2005), which was the largest migratory concentration of this species ever reported.

Observers have long postulated that Chinese Goshawks flying south in autumn from southeastern China, Korea, and the Okinawan Islands converge over northern Taiwan, continue south along the central mountain range, funnel together as they head down the narrow Hengchun Peninsula of southern Taiwan, and then cross the Luzon Strait to the Philippines (Severinghaus 1992, Tsai 1996, Tsai et al. 2003), with some perhaps continuing farther south to Indonesia (Germi 2005, Germi and Waluyo 2006, Germi et al. 2009). Previous observations suggested that roughly two-thirds fewer migrants returned northward along this route in spring (Severinghaus 1992, Lin 1993, Chen 2004, Liu 2004), with alternative northbound routes unknown prior to our study.

In 2001 and 2002, Taiwan's Central Weather Bureau installed two weather radar stations in southern Taiwan to monitor typhoon activity. These stations allowed us to monitor passage of Chinese Goshawks during spring migration. We applied this remote-sensing technology to determine the abundance, migration routes, and flight behavior of Chinese Goshawks over water and land.

Methods

We used data from two weather-radar stations located at Kenting, Hengchun Peninsula (21°54′N, 120°53′E) and Chiku, Tainan County (23°08′N, 120°04′E) in southern Taiwan (Fig. 1). The heights of the two radar antennas were 48 m and 30 m above mean sea level, respectively. The radar systems were METEOR 1000S S-band (10.3–11.1 cm) Doppler weather radars (AMS-Germatronik, Neuss, Germany) with an operating frequency range of 5.6–5.65 GHz and maximum ranges of 500 km (reflectivity) and 250 km (velocity). Peak transmitter power was 750 kilowatts, the half-power beam width was 1.0°, and the antenna dish diameter was 8.5 m. Computers connected to the radar systems automatically produced radar images at 8-min (Kenting) or 10-min (Chiku) intervals. The resolution of the images was 250 m × 250 m, exceeding the 1 km × 1 km resolution of WSR-88D (Gauthreaux and Belser 1998). We used the base reflectivity product with the lowest elevation angle (0.5°) and a range of 100 km, because we did not detect any goshawks beyond that range. When needed, we also used the base velocity product to sieve small flocks from weather systems (Gauthreaux and Belser 1998).

We examined 5360 radar images taken between 0500 and 1930 H (GMT/UTC + 8:00) during 1–30 April 2004 at the Kenting station. The Kenting radar produced a fan-shaped image because mountains to the north blocked radio waves emitted in that direction. The Chiku radar, located 142 km northwest of Kenting, partially compensated for this topographic limitation, and we examined the same number of images from that site.

After filtering out echoes of low radial velocity (Gauthreaux et al. 2000), we were able to distinguish flocks of Chinese Goshawks from weather phenomena based on three characteristics: relatively high travel speed (>30 km/hr); movement in disparate directions or not with the wind; and the unique, worm-like shapes of flocks (Lan 2003). During daytime ground observations conducted during the study period in April 2004 at Fenshan Reservoir, 75 km northeast of Kenting, observers identified 99.8% of 53 390 migrants as Chinese Goshawks,

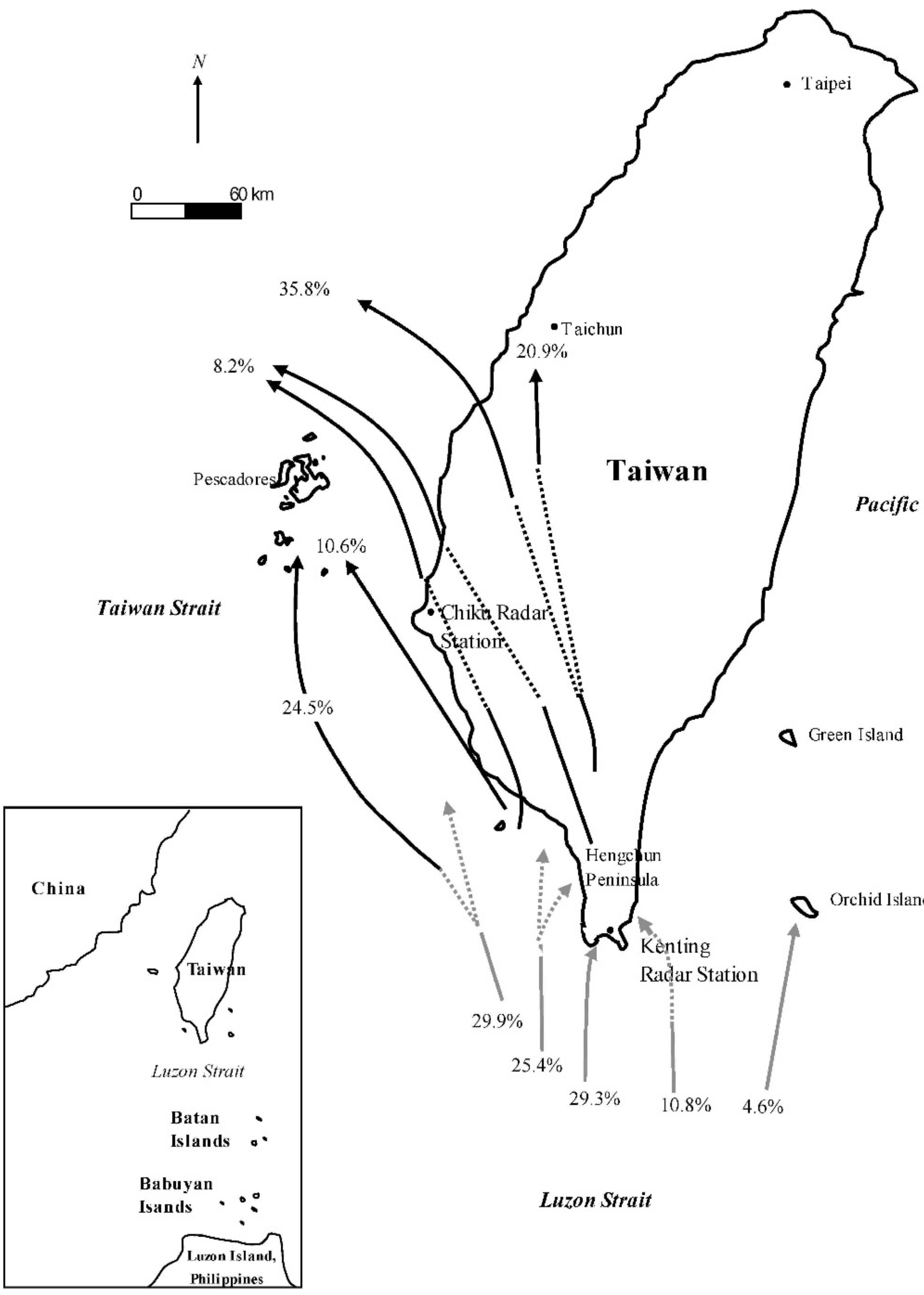

Figure 1. Locations of radar stations in southern Taiwan and percentages of detected Chinese Goshawks on different migratory routes to (gray lines) and over or past (black lines) Taiwan in April 2004. We calculated percentages separately for each part of the two-stage journey.

with the remainder being Gray-faced Buzzards (*Butastur indicus*; Hong 2004).

To estimate goshawk flock sizes from the radar images, we developed a linear regression model relating flock size to the reflectivity value of pulse volume (measured in decibels of reflectivity [Z] or dBZ) using data collected from 15–17 September 2002 and 17–18 September 2004. We correlated data collected by ground observers at Sheding, where observers have monitored the autumn raptor migration since 1990 (Tsai et al. 2003), with radar images of goshawk flocks recorded 6 km south of Sheding. Data collected by the ground observers included general flight direction, the number of birds in each flock, and the time the flock passed the observers. To determine the distance from which observers could detect a flock on a clear day using binoculars, we communicated simultaneously by cellular phone with observers at different locations and compared their observations with flock-location information derived from radar images. We included in the regression analysis only flocks detected on radar at distances of <7 km west or east of the observation station, because the probability that birds passing beyond that range could be seen by ground observers was very low.

Because of their size, large flocks were not fully displayed on radar images until they were 50–70 km from the radar station. To calculate a flock's ground speed (km/hr), we measured the distance it moved on consecutive images to the nearest 0.01 mm with calipers. We made measurements at 24-min and 20-min intervals; i.e., the time intervals between three consecutive Kenting radar images and two consecutive Chiku images, respectively. We determined the altitude at which a flock was flying using the formula developed by Rinehart (1997).

To examine the effect of wind on flight speed and altitude, we estimated wind direction with a protractor and wind velocity based on movements of clouds near migrating flocks on radar images. We then classified wind speeds based on the Beaufort scale (Ahrens 2000) and wind directions as follows: tail wind, 337.6° to 22.5°; following crosswind, 22.6° to 67.5° or 292.6° to 337.5°; opposing crosswind, 226° to 270° or 112.6° to 157.5°; and head wind, 157.6° to 202.5°.

We used *t*-tests to compare differences in flight speed and altitude under different wind conditions and during passage over various land and water crossings. We conducted all statistical analyses using SPSS (1997) and equated statistical significance with $P \leq 0.05$.

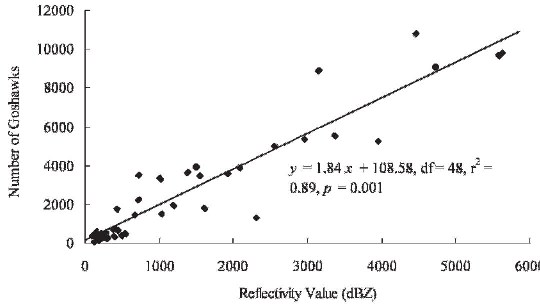

Figure 2. Relationship between numbers of migrating Chinese Goshawks and the reflectivity value of pulse volume (dBZ) shown on radar images from Taiwan. Data were collected from 15–17 September 2002 and 17–18 September 2004.

Results

Goshawk flock size and the reflectivity value of pulse volume were strongly and positively correlated (Fig. 2).

During the April study period, we detected on Kenting radar images 193 flocks of Chinese Goshawks flying over the Luzon Strait. Flocks averaged 3.1 km long (SD 3.41 km, range 1.0–27.5 km) and 0.7 km wide (SD 0.30 km, range 0.3–2.5 km). Using the regression model, we estimated that these flocks contained a total of 225 935 Chinese Goshawks, with flock size averaging 1166 birds (SD 2173, range 181–22 842).

Most (96%) of the migrants detected on Kenting radar images over Luzon Strait passed through on just three days: 74 576 (32% of the whole 5-d count) on 18 April; 13 392 (6%) on 19 April, and 134 652 (58%) on 22 April. The remainder (4%) passed through on 12 and 23 April. The largest flock of about 24 000 birds (27.5 × 2.5 km in size) first appeared 87.5 km southwest of the Kenting radar station at 1524 H on 22 April, took 30 min to fly past the Hengchun Peninsula, and was accompanied by several smaller flocks (Fig. 3).

The arrival times of Chinese Goshawks along the Hengchun Peninsula ranged from 0948 H to after sundown (1916 H); however, most birds arrived in late afternoon from 1500–1700 H (Fig. 4).

Migrating Chinese Goshawks flew northward over Luzon Strait toward Taiwan across a broad front (Fig. 1). The majority (65%) flew to the Hengchun Peninsula from the south. Roughly one third (30%) flew toward Taiwan, but veered northwest toward the Pescadores and Taiwan Strait. Another 5% remained over the ocean east of Taiwan, heading toward Orchid Island and Green Island.

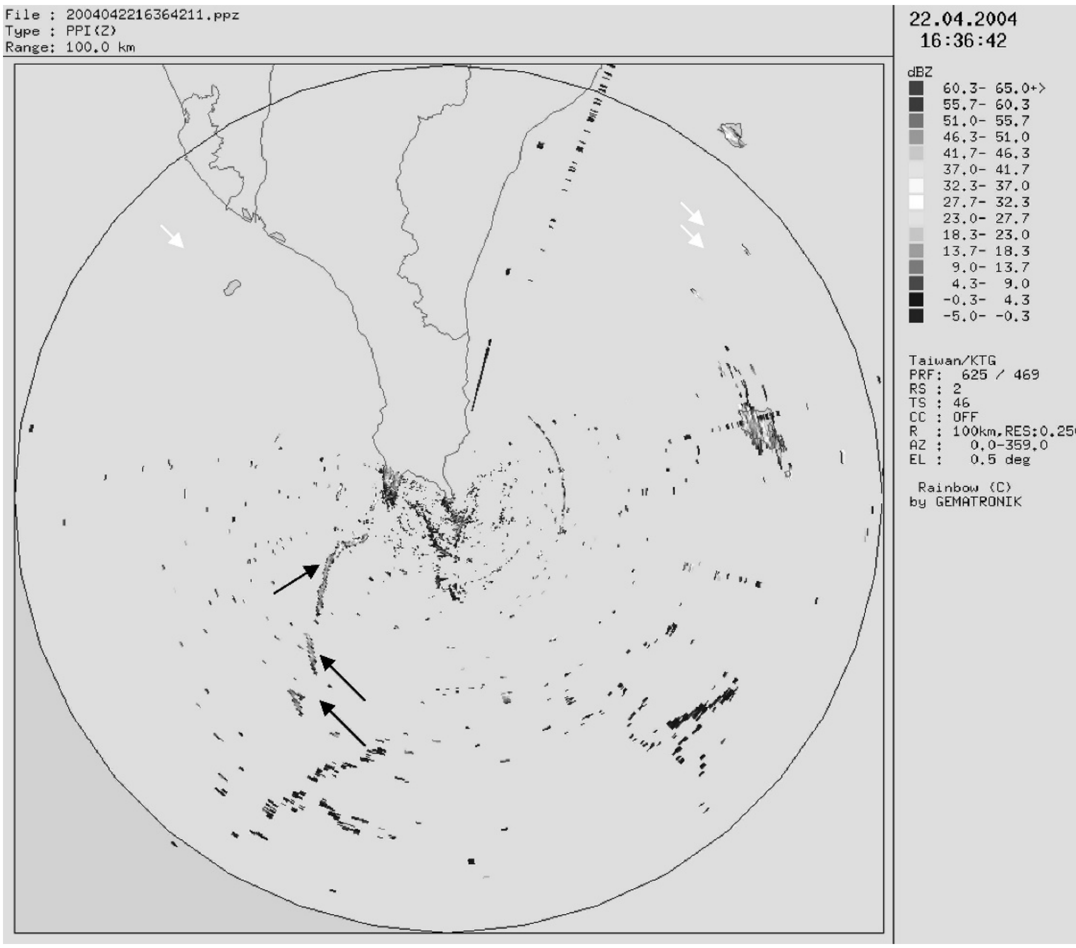

Figure 3. Radar image of the largest flock of migrating Chinese Goshawks (indicated by arrow) observed approaching Hengchun Peninsula, Taiwan, at 1636 H on 22 April 2004. The radius of the ring is 100 km. The flock was accompanied by two smaller flocks.

After flocks flew beyond the range of the Kenting radar, the Chiku station picked up the radar echoes sequentially. Using the regression model, we estimated that the Chiku radar detected 150 619 birds or 67% of the number detected by the Kenting radar. Of the number detected by the Chiku radar, we discovered that about 113 717 birds or 75.5% flew inland to roost in the mountains of southern Taiwan for up to 2 d before continuing their journey (Fig. 1). Subsequently, they appeared between 0600–1300 H on the south and southeast sections of the radar. The remaining 36 902 birds or 24.5% did not roost in Taiwan, but made a nonstop flight across the Luzon Strait directly to the Pescadores, located about 50 km west of Taiwan, arriving there between 1710–1820 H. Of the birds that stopped to rest in Taiwan, some 82 840 (or 55% of the total number detected by the Chiku radar) then flew from the southwestern coast of Taiwan across Taiwan Strait toward mainland China (Fig. 1). The remainder, 31 479 birds (or 21% of the total number detected by the Chiku radar), continued north over Taiwan and eventually flew out of radar range.

The ground speed of most Chinese Goshawk flocks migrating over the Luzon Strait averaged 51 km/hr (n = 183, SD = 9.2, range 29–78 km/hr); we were unable to calculate the speed of 10 small flocks due to difficulty following their flight trajectories. At Beaufort IV wind speeds (21–29 km/hr), flocks flew faster with a following crosswind (n

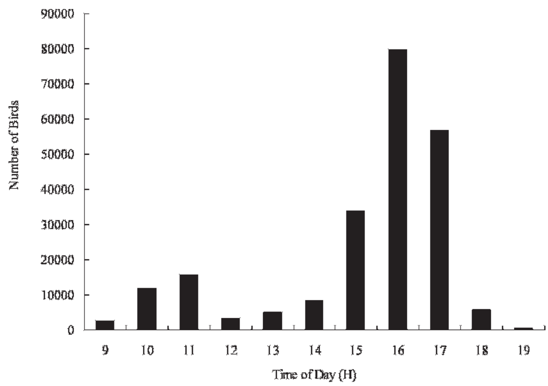

Figure 4. Aggregate numbers of migrating Chinese Goshawks passing near the Hengchun Peninsula, Taiwan, by hour during April 2004.

= 154, 53 ± 7.4 km/hr) than with an opposing crosswind (n = 29, 41 ± 7.6 km/hr; t = 8.44, df = 181, $P < 0.001$). With a weak (Beaufort II) opposing crosswind, flocks flew slower over land (n = 37, 34 ± 6.4 km/hr) than they did over water with an even stronger (Beaufort IV) opposing crosswind (t = 2.68, df = 64, P = 0.009). Flocks flying over the Taiwan Strait toward mainland China flew much faster than flocks flying over land (t = −10.0, df = 87, $P < 0.001$), even under similar wind conditions (e.g., Beaufort III crosswind: 55 ± 5.0 km/hr over water [n = 17] vs. 34 ± 5.3 km/hr over land [n = 14]; t = −11.5, df = 29, $P < 0.001$).

The altitude of Chinese Goshawk flocks flying over the Luzon Strait averaged 313 m (n = 154, SD = 100.8, range 144–742 m). When flying over land, their flight altitude averaged significantly higher (n = 84, 639 ± 149.0 m; t = −20.0, df = 236, $P < 0.001$); however, the altitude of Chinese Goshawk flocks over the Taiwan Strait (n = 93, 608 ± 146.2 m) was not significantly different from their altitude over land (t = 1.36, df = 175, P = 0.174). With a Beaufort IV wind, goshawk flocks flew higher with a following crosswind (n = 125, 307 ± 77.4 m) than they did against an opposing crosswind (n = 24, 270 ± 33.9 m; t = 2.34, df = 147, $P < 0.001$).

Discussion

The predictive power of our linear regression model describing the relationship between Chinese Goshawk flock size and reflectivity was similar to the model developed by Gauthreaux and Belser (1999), who studied the density of birds migrating at night using WSR-88D radar. We did not convert dBZ to Z, as suggested by Black and Donaldson (1999), because the model exhibited satisfactory predictive power using dBZ. In comparing the two models, note that 1 dBZ reflectivity corresponded to a lower density of goshawks (25–37 cm in length; Thiollay 1994) than nocturnal birds (Gauthreaux and Belser 1999), primarily smaller passerines (Gauthreaux 1971). Unexplained variance in our predictive model likely reflects poor air clarity, which can affect the visual range of birders and flock configuration (Diehl and Larkin 2005).

Our regression model likely underestimated the number of Chinese Goshawks migrating along the oceanic flyway of East Asia. We arbitrarily chose a 7-km radius as the maximum distance from which a ground-based observer could spot a goshawk flock using binoculars. The 7-km radius is much larger than that reported by Kerlinger (1989), who determined that hawk flocks may remain unseen at distances of only 2.5–3.0 km. If this is true, the slope of the regression model will be underestimated, and the number derived from the equation will be smaller than the actual number.

If Chinese Goshawks passing through Taiwan migrate to and from their breeding grounds via the same flyway, winter mortality rates could be estimated using data collected by the Kenting radar station. There are no radar images for autumn 2003; however, ground observers counted 94 264 Chinese Goshawks during the 2003 migration season (Y. Tsai pers. comm.), which was significantly fewer than the number estimated by Kenting radar for the 2004 spring migration. Birds missed by ground observers included those flying too far offshore to be seen, such as those heading to Orchid Island about 70 km away, and birds that arrived in the afternoon after observations had ceased.

Chiku radar detected only about two-thirds of the Chinese Goshawks detected by the Kenting radar. Part of the difference reflects the fact that 14% of the flocks detected by the Kenting radar flew east of Taiwan or to the eastern side of the Hengchun Peninsula where they were not detectable by the Chiku radar (see Fig. 1). We also found that Chinese Goshawks flew higher over land in southern Taiwan, where thermals are probably stronger (Wallington 1977), than they did over the Luzon Strait. It is unlikely that radar could detect birds roosting in the mountains and those birds may ride thermals up and out of radar range between scans, which occur at 10-min intervals. This factor also may have contributed to the detection of lower numbers at Chiku.

Using radar, we found that massive numbers of Chinese Goshawks migrate to and past Taiwan in April on their way to breeding grounds north of Taiwan. We determined that their passage in the vicinity of the Hengchun Peninsula of southern Taiwan occurs across a broad front, which means that ground-based observers at Sheding typically detect only a portion of the species' migration (Severinghaus 1992). Furthermore, we discovered that most Chinese Goshawks crossed over to mainland China from the southern coastline of Taiwan, which explains why few birds are seen in northern Taiwan (Lin 1993, Chen 2004, Liu 2004). These results also provide valuable information to Korean researchers concerning potential routes followed on the remaining legs of the species' migration (C. Choi pers. comm.).

With the assistance of radar, we learned that more Chinese Goshawks migrate through southern Taiwan than previously thought. In the autumn, when the northeast monsoon prevails, southbound goshawks fly along the eastern side of the central mountain range, where the prevailing wind creates updrafts. In contrast, the southwest monsoon prevails in the spring and northbound goshawks catch updrafts along the west side of the central mountain range. Such loop migration patterns have been observed among other raptor species (Yossi and Yom-Tov 1998, Meyburg et al. 2003, Bildstein 2006).

We found that a few Chinese Goshawks roosted on two off-shore islands: Green Island and Orchid Island. These birds probably migrate via Okinawa and Japan to breeding sites in Korea (C. Choi pers. comm.) and may return by the same route, never stopping on the island of Taiwan.

Based on their flight speeds and arrival times at Hengchun Peninsula, we have formed some ideas about where flocks of northbound Chinese Goshawks may depart from the Philippines. Most migrants arrived near the southern shores of Taiwan between 1500–1700 H. This is consistent with an 8–9 hr nonstop journey at 50 km/hr, possibly from Luzon Island, located >400 km to the south. Birds arriving earlier (around midday) may have come from the Babuyan Islands, located 290–350 km away. The few goshawks that arrived at Hengchun Peninsula even earlier in the morning may have flown from the Batan Islands, which lie only 150–200 km away.

Hundreds of Chinese Goshawks arrived about 1 hr after dark. There are a few reports of other diurnal raptors, such as the Peregrine Falcon (*Falco peregrinus*), Northern Harrier (*Circus cyaneus*), Osprey (*Pandion haliaetus*), and Levant Sparrowhawk (*Accipiter brevipes*) migrating at night (Cochran 1985, DeCandido et al. 2006, Russell 1991, Spaar et al. 1998), but this is the first report of such behavior among Chinese Goshawks. We do not think flying after dark is normal behavior for this species. Rather, we suspect it is something individuals must do to survive flights over water that were delayed or longer than expected. Our study site is in a popular tourist area with many coastal resorts and hotels. Perhaps artificial lights help birds find their way and provide illumination for late arrivals.

Chinese Goshawks flew faster over the sea than over land. Gray-faced Buzzards (*Butastur indicus*) in this region (Chen et al. 2007) and other raptors (Meyer et al. 2000) also fly faster over the ocean than over land. We suspect that Chinese Goshawks fly faster over the sea to minimize flight time and to avoid arriving after dark. Moreover, thermals and other updrafts are stronger over land than over the sea (Wallington 1977) and it is easier for migrants to find a safe place to roost over land. Therefore, rather than having to rely primarily on costly powered flight, raptors traveling over land are able to employ slower but more energy-efficient soaring and gliding flight during their cross-country travel (Hedenström 1993, Spaar et al. 1998). Such factors also help explain why Chinese Goshawks flew at higher altitudes over land than over water. Chen et al. (2007) reported similar behavior among Gray-faced Buzzards in the same study area.

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LITERATURE CITED

AHRENS, D.C. 2000. Meteorology today: an introduction to weather, climate and the environment, Sixth Ed. Brooks/Cole Publishing, Pacific Grove, CA U.S.A.

BILDSTEIN, K.L. 2006. Migrating raptors of the world: their ecology and conservation. Cornell University Press, Ithaca, NY U.S.A.

BLACK, J.E. AND N.R. DONALDSON. 1999. Comments on "display of bird movements on the WSR-88D: patterns and quantification." *Weather and Forecasting* 14:1039–1040.

CHEN, C.S. 2004. Spring raptor migration at Guanyin Mt., northern Taiwan, 2004. *Raptor Research of Taiwan* 3: 17–24 (In Chinese with English summary.)

———. 2005. Ground survey of raptor migration at Kenting Naional Park in autumn 2004. *Raptor Research of Taiwan* 4:9–21 (In Chinese with English summary.)

CHEN, Y., Y. SUN, AND T. DENG. 2007. Spring migration of the Gray-faced Buzzard (*Butastur indicus*) in central and southern Taiwan in 2005. *Taiwan Journal of Forest Science* 22:159–167 (In Chinese with English summary.)

COCHRAN, W.W. 1985. Ocean migration of Peregrine Falcons: is the adult male pelagic? Pages 223–237 *in* M. Harwood [ED.], Proceedings of the Hawk Migration Conference IV. Hawk Migration Association of North America, Rochester, NY U.S.A.

DECANDIDO, R., R.O. BIERREGAARD, M.S. MARTELL, AND K.L. BILDSTEIN. 2006. Evidence of nocturnal migration by Osprey (*Pandion haliaetus*) in North America and western Europe. *Journal of Raptor Research* 40:156–158.

DIEHL, R.H. AND R.P. LARKIN. 2005. Introduction to the WSR-88D (NEXRAD) for ornithological research. Pages 876–888 *in* C.J. Ralph and T.D. Rich [EDS.], Bird conservation implementation and integration in the Americas: Proceedings of the Third International Partners in Flight Conference, Vol. 2. Gen. Tech. Rep. PSW-GTR-191. USDA Forest Service, Pacific Southwest Research Station, Albany, CA U.S.A.

FERGUSON-LEES, J. AND D.A. CHRISTIE. 2001. Raptors of the world. Christopher Helm, London, U.K.

GAUTHREAUX, S.A., JR. 1971. A radar and direct visual study of passerine spring migration in southern Louisiana. *Auk* 88:343–365.

——— AND C.G. BELSER. 1998. Displays of bird movements on the WSR-88D: patterns and quantification. *Weather and Forecasting* 13:453–464.

——— AND ———. 1999. ''Reply'' to displays of bird movements on the WSR-88D: patterns and quantification. *Weather and Forecasting* 14:1041–1042.

———, ———, AND A. FARNSWORTH. 2000. How to use Doppler weather-surveillance radar to study hawk migration. Pages 146–160 *in* K.L. Bildstein and D. Klem, Jr. [EDS.], Hawkwatching in the Americas. Hawk Migration Association of North America, North Wales, PA U.S.A.

GERMI, F. 2005. Raptor migration in east Bali, Indonesia: observations from a bottleneck watch site. *Forktail* 21:93–98.

——— AND D. WALUYO. 2006. Additional information on the autumn migration of raptors in east Bali, Indonesia. *Forktail* 22:71–76.

———, G.S. YOUNG, A. SALIM, W. PANGIMANGEN, AND M. SCHELLEKENS. 2009. Over-ocean raptor migration in a monsoon regime: spring and autumn 2007 on Sangihe, North Sulawesi, Indonesia. *Forktail* 25:104–116.

HEDENSTRÖM, A. 1993. Migration by soaring or flapping flight in birds: the relative importance of energy cost and speed. *Philosophical Transactions of the Royal Society of London B* 342:353–361.

HONG, F.L. 2004. Records of migratory raptors at Fenshan Reservoir. http://raptor.org.tw/ (last accessed 2 March 2009).

KERLINGER, P. 1989. Flight strategies of migrating hawks. The University of Chicago Press, Chicago, IL U.S.A.

LAN, C. 2003. The use of weather radar to study *Accipiter soloensis* migratory behavior at Kenting area. M.S. thesis, Pingtung University of Science and Technoloy, Pingtung, Taiwan. (In Chinese with English summary.)

LIN, W. 1993. Hawk migration survey at Guaninshan in the spring of 1992. Conservation Research Report No. 3, Wild Bird Federation Taiwan, Taipei. (In Chinese.)

LIU, C. 2004. Spring raptor migration survey for the three northernmost townships of Taiwan in 1996. *Raptor Research of Taiwan* 3:25–44. (In Chinese with English summary.)

MEYER, S.K., B. SPAAR, AND B. BRUDERER. 2000. To cross the sea or to follow the coast? Flight directions and behavior of migrating raptors approaching the Mediterranean Sea in autumn. *Behavior* 137:379–399.

MEYBURG, B.-U., P. PATRICK, AND C. MEYBURG. 2003. Migration routes of steppe eagles between Asia and Africa: a study by means of satellite telemetry. *Condor* 105:219–227.

RUSSELL, R.W. 1991. Nocturnal flight by migrant ''diurnal'' raptors. *Journal of Field Ornithology* 62:251–267.

RINEHART, R.E. 1997. Radar for meteorologists, Third Ed. Rinehart Publishing, Grand Forks, ND U.S.A.

SEVERINGHAUS, L.L. 1992. Study on the diurnal birds of prey at the Kenting National Park. Conservation Rept. No. 64. Kenting National Park Headquarters, Pingtung, Taiwan. (In Chinese with English summary.)

SPSS, INC. 1997. SPSS 8.0 for windows. SPSS, Inc., Chicago, IL U.S.A.

SPAAR, R., H. STARK, AND F. LIECHTI. 1998. Migratory flight strategies of Levant Sparrowhawks: time or energy minimization? *Animal Behaviour* 56:1185–1197.

THIOLLAY, J.M. 1994. Family Accipitridae (hawks and eagles). Pages 52–205 *in* J. del Hoyo, A. Elliott, and J. Sargatal [EDS.], Handbook of the birds of the world, Vol. 2. New World vultures to guineafowl. Lynx Edicions, Barcelona, Spain.

TSAI, Y.J. 1996. Study on the populations of staging raptors at Kenting. *Wild Birds* 5:51–55. (In Chinese.)

———, H.H. TANG, AND C.Y. LIN. 2003. Research on population and pass time of autumn migratory hawks in Kenting area (1990–2002). Page 38 *in* Y.C. Hsun, R.C.J. Wang, and D.P. Chamberlin [EDS.], Abstracts of Proceedings of the Third Asian Raptor Research Conservation Symposium. Asian Raptor Research and Conservation Network, Kenting, Pingtung, Taiwan.

WALLINGTON, C.E. 1977. Meteorology for glider pilots, Third Ed. Transatlantic Arts Press, London, U.K.

YOSSI, L. AND Y. YOM-TOV. 1998. Routes of migrating soaring birds. *Ibis* 140:41–52.

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