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RECENT AVIAN POISONINGS SUGGEST A SECONDARY POISONING CRISIS OF BLACK KITES DURING THE 1980S IN TAIWAN

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ABSTRACT.—The Black Kite (*Milvus migrans*) has a limited distribution within Taiwan due to a dramatic population decrease during the late 20th century. Prompted by some poisoning incidents of Black Kites and other farmland birds, we hypothesized that poisoning may be an underreported yet important threat. Thus, we created a citizen-science Facebook group in October 2014 in order to receive more information about possible poisoning incidents. By September 2016, we had received reports of 4753 dead birds in 213 separate poisoning incidents in agricultural areas. The types of fields most often associated with poisoning incidents were direct-seeded rice (*Oryza sativa*), rice that was soon to be harvested, and red beans (*Vigna angularis*). We tested tissues from 29 dead small birds for pesticide residues. Twenty-eight birds contained carbofuran, and one bird contained terbufos, both highly toxic pesticides. Furthermore, of seven dead Black Kites tested from 2010 to 2016, four contained carbofuran, and three contained second-generation anticoagulant rodenticides. After interviewing farmers and reviewing older agricultural literature, we concluded that most of these incidents represented intentional poisonings by farmers attempting to control avian pests and rats (mostly *Bandicota indica* and *Rattus* spp.). We suggest that the Black Kites were likely the victims of inadvertent secondary poisoning incidents. The dramatic decrease of the Black Kite in the 1980s coincided with the rapid increase in the area planted with direct-seeded rice and the widespread use of carbofuran and rodenticides. The recent decreased use of these pesticides due to restrictions has coincided with the recent slow recovery of the Black Kite population. Therefore we initiated public awareness campaigns, and the Taiwanese government has adjusted some pesticide-use policies.

KEY WORDS: *Black Kite*; Milvus migrans; *carbofuran*; *citizen science*; *direct-seeded rice*; *Facebook*; *pesticides*; *rodenticides*; *scavenger*.

ENVENENAMIENTOS RECIENTES DE AVES SUGIEREN UNA CRISIS DE ENVENENAMIENTO SECUNDARIO DE *MILVUS MIGRANS* DURANTE LA DÉCADA DE 1980 EN TAIWÁN

RESUMEN.—*Milvus migrans* presenta un distribución limitada dentro de Taiwán debido a una disminución dramática de su población durante los últimos años del siglo XX. Debido a la ocurrencia de incidentes de

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envenenamiento de *M. migrans* y otras aves que frecuentan tierras de cultivo, planteamos la hipótesis de que el envenenamiento puede ser una amenaza importante pero subvalorada. Por ello, en octubre del 2014 creamos un grupo de ciencia ciudadana en Facebook con el fin de recabar más información sobre posibles incidentes de envenenamiento. Hasta septiembre de 2016 recibimos informes de 4753 aves muertas en 213 incidentes independientes de envenenamiento en áreas agrícolas. Los tipos de campos que fueron asociados con mayor frecuencia con incidentes de envenenamiento fueron campos de arroz (*Oryza sativa*) de siembra directa, campos de arroz recientemente cosechados y campos de frijoles rojos (*Vigna angularis*). Evaluamos los tejidos de 29 aves pequeñas muertas en busca de residuos de pesticidas. Veintiocho aves presentaron carbofuran y una terbufos, ambos pesticidas altamente tóxicos. Además, de siete individuos muertos de *M. migrans* evaluados entre 2010 y 2016, cuatro presentaron carbofuran y tres presentaron rodenticidas anticoagulantes de segunda generación. Después de entrevistar a granjeros y de revisar la literatura agrícola existente, concluimos que la mayoría de estos incidentes representaron envenenamientos intencionales por parte de granjeros intentando controlar aves plaga y ratas (mayormente *Bandicota indica* y *Rattus* spp.). Sugerimos que los individuos de *M. migrans* probablemente fueron víctimas inadvertidas de envenenamiento secundario involuntario. La disminución dramática de la población de esta especie en la década de 1980 coincidió con el incremento acelerado de la superficie cultivada con siembra directa de arroz y el uso extendido de carbofuran y rodenticidas. La reciente disminución del uso de estos pesticidas debido a restricciones ha coincidido con la reciente pero lenta recuperación de la población de *M. migrans*. Por ello, iniciamos campañas públicas de concientización para acompañar los cambios sobre el uso de pesticidas implementados por el gobierno taiwanés.

[Traducción del equipo editorial]

Many avian predators and scavengers have been suffering from a worldwide poisoning crisis, due to lead, pesticides, or veterinary drugs such as Diclofenac (Margalida 2012, Buechley and Şekercioğlu 2016). For example, in Africa, Europe, and North America, countless primary and secondary pesticide poisonings of raptors have been reported. Many instances resulted from farmers intentionally poisoning predators because they wanted to protect their livestock or game species, but there have been other motives (e.g., to conceal poaching; Allen et al. 1996, Mineau et al. 1999, Berny 2007, Muzinic 2007, Márquez et al. 2013, Walther 2016). However, very few cases to date have been reported from Asia, despite the widespread use of pesticides on this continent (Berny 2007, Costantini 2015).

Two of the most commonly used pesticides are carbofuran and anticoagulant rodenticides (ARs). Carbofuran is one of the most popular chemicals used to poison wildlife all over the world because it is cheap and highly toxic (Ogada and Keesing 2010, Richards 2012, Berny et al. 2015, Ruiz-Suárez et al. 2015). In fact, some early official agricultural articles taught farmers to use a 75% carbofuran powder mixed with rice to reduce pest bird and rat populations in Taiwan (Li 1986, Ho 1994, Zhuang 1994, Chiu 1995).

Similarly, ARs are used worldwide for vertebrate pest control. Despite the fact that ARs are known to cause serious secondary poisoning of predators, they remain in use because of the apparent lack of alternatives (Berny et al. 2010, Rattner et al. 2014). The Taiwanese government gave away hundreds of tons of ARs for agricultural and sanitational reasons each year since the 1970s (Lu 2004, Council of Agriculture 2016) but never investigated the possible threat to nontarget species before this study.

Possibly the most common raptor species in the world, the Black Kite (*Milvus migrans*) is found in most parts of Africa, Eurasia, and Oceania (Orta et al. 2015, BirdLife International 2016a). The Black Kite is adapted to diverse habitats, including human-modified environments (del Hoyo et al. 1994). In Taiwan, the Black Kite is a resident breeding species, usually consuming live animals, typically small vertebrates, but also scavenging dead animals (Severinghaus et al. 2017). As a raptor, the Black Kite is near or at the top of the food chain and may be particularly at risk for pesticide poisoning (e.g., Carson 1962, Newton 1979).

Early naturalists described the Black Kite as widely distributed in the low-altitude plains and hills all across Taiwan (e.g., Swinhoe 1863, La Touche 1898). Similarly, the first systematic bird survey for all of Taiwan was conducted in 1973, and the Black Kite population was categorized as common at that time (Chen and Yen 1973). However, by 1991, ornithologists had realized that the Black Kite had rapidly disappeared during the 1980s, with its estimated population down to only 175 individuals inhabiting only 39% of its previous range (Guo and Lin 1992).

A conservation action plan for the Black Kite, written in 2004, speculated that the main reasons for the kite's decline were habitat loss and illegal hunting (Ding et al. 2004). Other possible factors were inbreeding depression, lack of food, pesticides, pollution, and disturbance by humans; however, these factors could not be evaluated due to insufficient data (Ding et al. 2004). Consequently, the Black Kite was finally classified as an endangered species (EN) on Taiwan's red list by Fang (2005). However, since that time, the population of the Black Kite has slowly recovered, from only 175 individuals in 1991 to 400–500 individuals in 2015 (Y.-H. Sun unpubl. data).

The sudden decline of Black Kites in Taiwan starting in the 1980s was indicative of some serious and rather sudden crisis for the species. We began a Black Kite population and breeding survey in 2011. From 2012 onward, we discovered several poisoned Black Kites, and our preliminary analyses detected either carbofuran or ARs. We also opportunistically uncovered some poisoning incidents of small farmland birds, which suggested to us that Black Kites might also be victims of secondary poisoning. Because no vultures occur in Taiwan, the Black Kite has partly assumed the role of a scavenger, making it more vulnerable to secondary poisoning when eating small animals poisoned by pesticides and ARs.

We hypothesized that primary and secondary poisoning may be an under-reported but important threat for small farmland birds and for the Black Kite. Therefore, we set up an internet community to assist us with the reporting of more poisoning incidents. We analyzed incidents reported since 2014 to determine the most affected regions of Taiwan, the crop/field types which were most often associated with poisoning incidents, and the wild bird species that were affected.

METHODS

Collection of Reports of Poisoning Incidents. In October 2013, we found an unusually large number of dead small birds in several red bean (*Vigna angularis*) farms in Pingtung. To gather more information about poisoning incidents, we set up an open citizen-science Facebook group called "Bird Poison Report, Taiwan (BPRT)" (https://www.facebook.com/groups/1490158747925040/) in October 2014. The number of members reached 2592 in September 2015 and 3409 in September 2016. Any person who found dead birds of any species on farmland was able to post photos and additional information to this Facebook group. The additional information that we requested included the date, coordinates, crop type, and species and number of birds. We also asked whether the person had observed anything that suggested poisoned baits were used (e.g., heaps of rice or corn [*Zea mays*], which suggested intentionally placed baits). If an incident was uncertain or the reporter was unable to provide the necessary information, in most cases we visited the site or asked local experienced volunteers for help. We also received reports of incidents from other sources (e.g., another citizen-science Facebook group called "Reptile Road Mortality," which started in 2011) and encouraged reporters to send at least some of the dead birds to us via frozen delivery, a service available throughout Taiwan.

As the reports accumulated, we visited those areas and crops that became associated with many poisoning incidents. We interviewed several local farmers to ask them about their motives, and whether the use of poisoned baits remained a common practice.

Occasionally, dead or incapacitated Black Kites were sent to the Pingtung Wildlife Rescue Center. A veterinary examined them for evidence of trauma and/or neurological changes; the Black Kites that recovered were later released. Kites that died were analyzed for insecticides in 2012 or insecticides and ARs after 2012 (see below).

Evaluation of Poisoning Incident Reports. To avoid the inclusion of reports of birds that may have died from causes other than poisoning, we critically evaluated each report. First, we excluded any report which (1) involved fewer than three dead birds and (2) included no additional evidence of poisoning (such as the presence of baits or unusual behavior of dying birds that suggested poisoning). The presence of poison baits was considered important evidence. Moreover, poisoned birds usually exhibited no trauma, which is usually present in the case of road kills and other accidents.

The threshold of three birds (of the same or different species) was set because we knew from experience that poisoned baits usually attract a larger number of birds, which results in several dead birds found in close proximity. The length of each incident varied from 1 d to approximately 2 wk because, in some cases, reporters or field workers (including us) repeatedly visited the incident site and found additional dead birds in the same location if the poison baits were not removed and no rain washed away the baits.

Table 1. Number of farmland bird (not including Black Kites) poisoning incidents in different counties, and the types of crops associated with them from October 2014 to September 2016.

County	Crop / Field Type							Total
	Seeded Rice	Rice Harvest	Red Bean	Rice Planting	Corn	Others	Unknown	
Tainan	101	20	—	1	7	1	4	134
Pingtung	—	6	24	2	—	2	3	37
Yilan	—	2	—	8	—	1	—	11
Others	—	21	—	—	1	3	6	31
Total	101	49	24	11	8	7	13	213

Poisoned birds can move away and die away from the location of the poisoning, but carbofuran in particular is a very quick-acting poison for birds. For example, Eurasian Tree Sparrows (*Passer montanus*) died within 10 sec of ingesting carbofuran (S.-Y. Hong unpubl. data), and death occurs within few minutes for other bird species (Richards 2012).

Chemical Analyses. Carcasses of Black Kites and other bird species found dead in farmland were analyzed for pesticide residues. For 29 out of the 213 non-kite avian poisoning incidents, we collected or received one or several dead birds. Due to cost constraints, the freshest bird from each incident was chosen for chemical analysis. Chemical analysis was conducted by one of the two officially accredited laboratories (ABM International Lab Inc. or Agricultural Chemicals and Toxic Substances Research Institute) located in Taiwan.

In 2012, 300 g of visceral, bone, and muscle tissue were sampled proportionally from the carcasses of the Black Kites to test the possibility that pesticide concentration might differ among tissue types (Lumeij et al. 2000, Singh et al. 2008). The analytical method followed the Official Guide No. 4, which uses a liquid chromatograph/tandem mass spectrometer (LC/MS/MS) and gas chromatograph/tandem mass spectrometer (GC/MS/MS) that can detect 251 types of pesticide multi-residues (Taiwan Food and Drugs Administration [TFDA] 2011). The limits of quantification (LOQ) ranged from 0.01 to 0.1 μg/g.

From 2013 to 2016, we sampled only 2 g of liver tissue from each dead Black Kite and other small bird species. We analyzed liver samples because several studies (e.g., Goutner et al. 2011, Thomas et al. 2011) stated that sampling the liver is sufficient for reliable pesticide detection. However, one Black Kite found in 2016 was too decayed to obtain a useful liver sample. Therefore, its stomach contents were used instead. Because Eurasian Tree Sparrows' livers weighed <2 g, we used their whole bodies, fully digested for chemical analysis. The analytical method followed the Official Guide No. 5 with LC/MS/MS and GC/MS/MS, which can detect 310 types of pesticide multi-residues (TFDA 2013). The LOQs ranged from 0.005 to 0.01 μg/g.

The Black Kite liver samples were also tested for 13 ARs with LC/MS/MS from 2013 to 2016. Of these 13 ARs, nine were legally registered for agricultural and sanitational use, and four ARs (coumafuryl, coumachlor, pindone, valone) were not legally registered in Taiwan. The nine legally registered ARs were either first-generation ARs (FGARs; namely, chlorophacinone, coumatetralyl, diphacinone, and warfarin) or second-generation ARs (SGARs; namely, brodifacoum, bromadiolone, difenacoum, difethialone, and flocoumafen). The LOQs of ARs ranged 0.005 to 0.01 μg/g.

Results

Poisoning Incidents and Associated Crops/Fields and Species. We received 232 reports of dead birds on farmland (not including cases of Black Kites) via BPRT from October 2014 to September 2016. Of those, 213 met the criteria for analysis (Table 1). A cluster of 93 incidents was reported from December 2014 to January 2015 in Tainan. Tainan had 41 additional incidents, followed by Pingtung and Yilan with 37 and 11 incidents, respectively. The crops/fields most often associated with incidents were direct-seeded rice in Tainan, rice harvest in several counties, and red beans in Pingtung (Table 1, Fig. 1). The most frequent months were January, October, and December (73.4% of the total; Fig. 2).

A total of 4753 dead birds were killed in these 213 incidents (mean $\pm$ SD $= 23.9 \pm 56.1$ birds/incident, range 3–511). Forty-seven species were killed, with Eurasian Tree Sparrows and Red Turtle-Doves (*Streptopelia tranquebarica*) composing 66.4% and

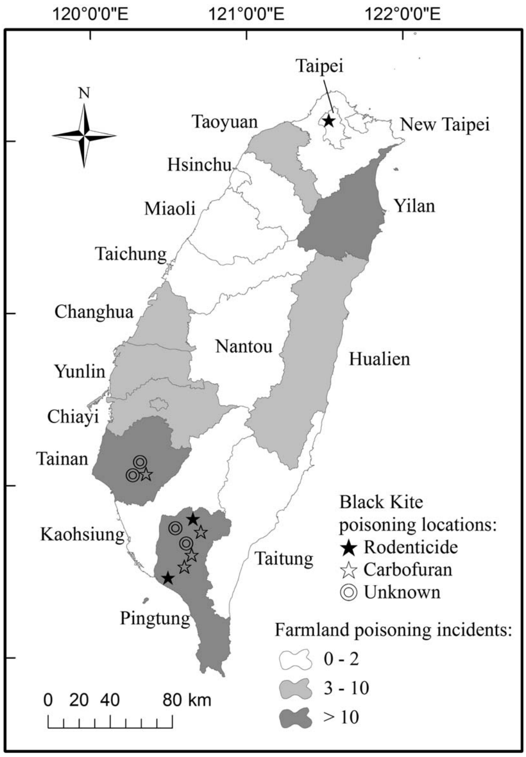

Figure 1. Distribution of avian poisoning incidents within Taiwan. Eleven Black Kites are marked individually for 2010–2016 (Table 3), and the 213 farmland bird poisoning incidents are in different grayscale within county boundaries for 2014–2016 (Table 1). Four Black Kites were released after their successful recovery without being tested, so the reasons for their incapacitation remain unknown.

16.7% of the total, respectively (Table 2, Appendix A).

We also received 11 Black Kites from October 2010 to June 2016 (Table 3). All the kites were found alone, i.e., not found with other dead birds or associated with the 213 farmland bird poisoning incidents mentioned above. Nine out of these 11 Black Kites were juveniles or nestlings, and 10 were found from October to January.

Chemical Analysis. We analyzed samples from 29 farmland birds associated with 29 different incidents. Twelve incidents occurred in direct-seeded rice crops in Tainan, 11 incidents occurred in red bean farms in Pingtung, and one incident occurred in a rice planting in Yilan. In addition, we also tested carcasses from five incidents in four additional counties. Twenty-eight birds contained carbofuran (mean $\pm$ SD = 2.48 $\pm$ 4.59 μg/g, range 0.010–21.640 μg/g), and the remaining bird contained terbufos (0.075 μg/g). Six of the 29 birds also contained one to three more mildly toxic pesticides (Appendix B).

Four Black Kites were released after their successful recovery and the reasons for their weak condition were not determined (Fig. 1). Seven dead kites were found dead and were tested for pesticide and AR residues. Carbofuran was detected in four kites, and one or several SGARs were detected in three kites (Table 3). Three kites were also contaminated with p,p′-DDE and one of these three was contaminated with mirex.

DISCUSSION

Carbofuran was by far the most common pesticide that was detected in the poisoned farmland birds. We also documented that secondary poisoning caused by carbofuran and/or SGARs killed at least seven Black Kites in Taiwan. Based on our results, we believe that secondary poisoning incidents may partly explain the rapid decline of Black Kites in Taiwan during the late 20th century. Of course, it is possible that other pesticides also killed birds, but we did not detect any such mortalities, possibly due to our sampling scheme.

Crop Types, Species Killed, and Reasons for Poisoning Incidents. Most reported poisoning incidents were concentrated in direct-seeded rice in Tainan. The cultivation technique of seeded rice was popularized by the Taiwanese government in the early 1980s across Taiwan, with over 37,000 ha planted (Fig. 3; Xu and Sung 1994). The direct seeding of rice saves labor because rice seedlings do not need to be transplanted; however, the seeds are easily eaten by birds and rats. The standard practice to minimize avian and rat damage to seeds was to use a 75% carbofuran powder or a 90% methomyl powder (also a highly toxic pesticide, banned in 2006) mixed with seeds before sowing (Li 1986, Ho 1994, Zhuang 1994, Chiu 1995). In addition, this method was also frequently recommended in earlier popular agricultural magazines.

However, seeded rice crops had problems with weeds, uneven growth, and a longer growing period (Xu and Sung 1994). When the new eight-row rice transplanter was introduced, direct-seeded rice cultivation was abandoned in most areas in the 1990s (Teng 2003). In recent years, a much smaller area in Tainan was still planted with seeded rice (December to April) because this area is also used to grow water chestnuts (*Trapa natans*; May to Novem-

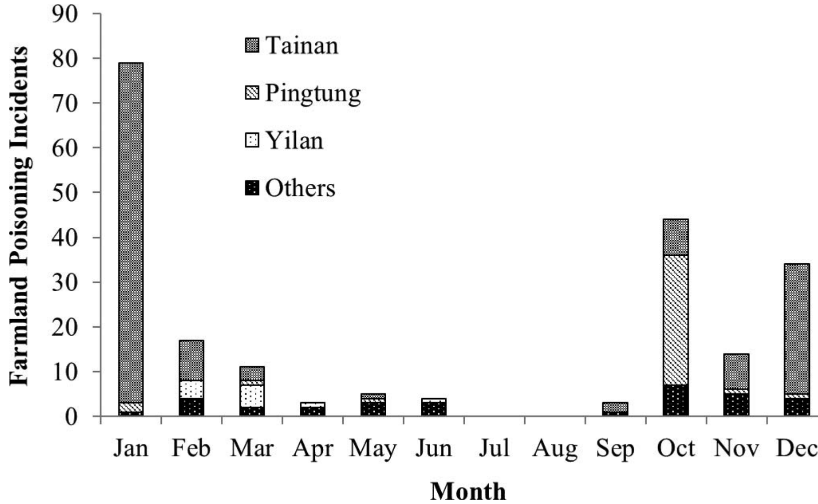

Figure 2. Farmland bird (not including Black Kites) poisoning incidents by month and county (Table 1).

ber; Fig. 3). This area was one of the hotspots of the poisoning incidents reported to BPRT when seeded rice was planted in December and January (Table 1).

Because the topography of water chestnut farms is similar to that of ponds, the dead birds collected included some species of wetland birds (Table 2), including one threatened species, the Pheasant-tailed Jacana (*Hydrophasianus chirurgus*), which is adapted to floating plants such as the water chestnut; its population is therefore concentrated in Tainan (Severinghaus et al. 2017). We received reports of 13 incidents involving 26 individual Pheasant-tailed Jacanas in Tainan, indicating the serious primary poisoning threat for this threatened species (Appendix A).

We also found poisoning incidents associated with rice harvests and red beans (Table 1). Rice is the most popular crop in the low-altitude plains of Taiwan, with typically two harvests per year. The poisoning incidents during the rice harvest occurred sporadically in several counties of Taiwan, which suggests that some rice farmers attempted to minimize bird damage during harvest by using poison. This method was also described in the

Table 2. Bird families in the three counties with the most poisoning incidents, calculated from the 213 poisoning incidents but excluding the Black Kites. Bird families are ordered according to the total number of dead birds.

	COUNTY				
FAMILY	TAINAN	PINGTUNG	YILAN	OTHERS	TOTAL
Passeridae	972	1529	15	642	3158
Columbidae	690	256	2	98	1046
Anatidae	24	2	55	28	109
Rostratulidae	103	5		0	108
Estrildidae	14	2		83	99
Rallidae	34	7	3	8	52
Sturnidae	3	25		5	33
Jacanidae	26			0	26
Scolopacidae	14	7		0	21
Motacillidae	11		1	7	19
Ardeidae	17			0	17
Others	38		3	24	65
Total	1946	1833	79	895	4753

Table 3. Insecticides and rodenticides in 11 weak or dead Black Kites found in Taiwan, 2010–2016. Concentration (µg/g) of insecticides and rodenticides were determined only for the seven dead individuals. The limit of quantification (LOQ) for each detected insecticide was 0.01 µg/g in 2012. After 2013, LOQ for insecticides and rodenticides was 0.005 µg/g, except for brodifacoum, for which it was 0.01µg/g. The four individuals that recovered following treatment were released without being sampled. A dash (—) indicates that we tested for the presence of the insecticide or rodenticide but no concentration was detected. An empty field indicates that no test was carried out.

							Concentrations of Insecticides (µg/g)			Concentrations of Rodenticides (µg/g)		
No.	County	Year	Month	Age	Recovered	Sample	Carbofuran	p,p'-DDE	Mirex	Brodifacoum	Flocoumafen	Bromadiolone
1	Pingtung	2010	Oct	Juvenile	Yes	Not sampled						
2	Tainan	2012	Jan	Juvenile	Yes	Not sampled						
3	Pingtung	2012	Oct	Juvenile	No	Visceral, bone, muscle[1]	1.29	0.02	—			
4	Pingtung	2012	Oct	Juvenile	No	Visceral, bone, muscle[1]	2.49	0.05	—			
5	Pingtung	2013	Nov	Juvenile	Yes	Not sampled						
6	Pingtung	2013	Nov	Adult	No	Liver	—	—	—	0.033	—	—
7	Pingtung	2014	Oct	Adult	No	Liver	—	—	—	0.148	—	—
8	Tainan	2014	Dec	Juvenile	No	Liver	0.270	—	—	—	—	—
9	Tainan	2015	Jan	Juvenile	Yes	Not sampled						
10	Taipei	2015	Oct	Juvenile	No	Liver	—	0.029	0.005	0.020	0.095	0.009
11	Pingtung	2016	Jun	Nestling	No	Stomach contents	7.539	—	—	—	—	—

[1] A 300-g sample of visceral, bone, and muscle tissue was taken proportionally to their amounts in the carcass.

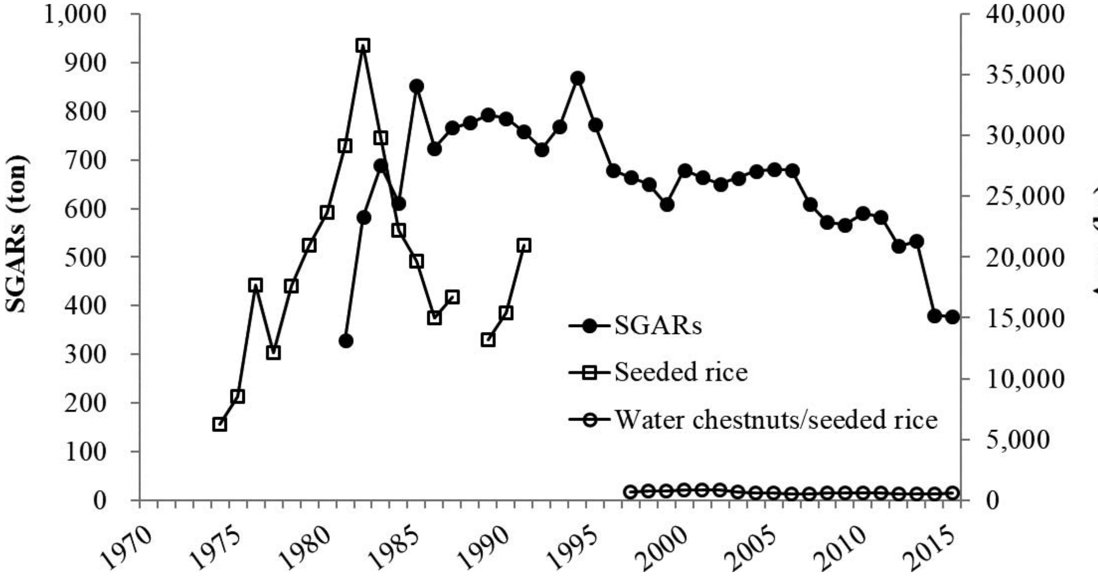

Figure 3. The quantity (in tons) of second-generation anticoagulant rodenticides (SGARs) that the Taiwanese government provided free to farmers each year (Council of Agriculture 2016); the area (in hectares) planted with direct-seeded rice each year from the 1974 to 1993 in Taiwan (Xu and Sung 1994); and the area planted with water chestnut (planted in turn with direct-seeded rice) from 1997 to 2015 in Taiwan (Council of Agriculture 2016). No data were available for seeded rice after 1993 or water chestnut prior to 1997.

crop-protection literature, which targets primarily the Eurasian Tree Sparrow (e.g., Hwang 1974, Lin 2003). In a few sites in Yilan and southern Pingtung, poisoning incidents were reported for rice planting, which is the early period after the transplantation of rice seedlings. In these particular sites, some Anatidae species, usually the Eastern Spot-billed Duck (*Anas zonorhyncha*), entered rice farms and damaged the seedlings, which caused farmers to spread poisoned baits (Lin 2003).

Red beans (October to December) are often alternated with rice (January to September) and are usually seeded in October in Pingtung. Some farmers told us that they mixed carbofuran and grains of rice to poison birds so that the red bean seeds would not be eaten. Corn crops are treated similarly. Carbofuran poisoning is also used to control avian pests in Africa, Asia, and North and South America (Ruelle 1983, Flickinger et al. 1986, Fujisaka et al. 1989, Bruggers et al. 1998, Vyas et al. 2002, Ogada 2014).

In addition to mixing carbofuran (powder or liquid) with grains, some farmers also sprinkled granulated formulations of highly and acutely toxic insecticides, such as phorate, terbufos, and carbofuran, on the ground surface and in front of rat holes. When rats pass by, the granules adhere to their feet and are then eaten inadvertently. These three toxic granulated insecticides are all easily consumed by ground-foraging birds and have resulted in avian mortalities (Balcomb 1983, Dietrich et al. 1995, Elliott et al. 1997, Mineau et al. 1999). Although in some farmers' opinions this method is less efficient at killing birds, we nonetheless detected terbufos in one of our bird samples (Appendix B).

Black Kite Poisoning Incidents and Population History. Four Black Kite carcasses contained carbofuran, and the times and locations coincided with the poisoning incidents that were reported in Tainan (December to January) and Pingtung (October). Most (9 of 11) identified and suspected poisoning cases were juveniles, which suggests that young birds face a greater danger than adults; this may be due to their different foraging areas or strategies, e.g., juveniles lack territories and wander across a larger area (Smart et al. 2010), or they are more dependent on scavenging.

We detected SGAR residues in three dead kites (Table 3). ARs are chronic poisons, and death usually occurs within 3–7 d if a lethal dose is absorbed (Newton et al. 1990, Rattner et al. 2014). According to published risk analyses, the newer SGARs are much more hazardous to both target and nontarget species compared to the older first generation ARs (Erickson and Urban 2004). Although the SGARs' lethal concentrations differ among compounds and species, significant likelihood of hemorrhaging occurred at lower levels than previously thought (e.g., 0.1 μg/g brodifacoum in the liver; Thomas et al. 2011). The concentration for one kite that exhibited stomach bleeding was 0.033 μg/g brodifacoum (S.-Y. Hong unpubl. data).

Given the widespread usage of carbofuran and SGARs, we suggest that Black Kites were inadvertently poisoned by Taiwanese farmers who wanted to control pest birds and rats. The promotion of direct-seeded rice and the anti-rodent campaign by the government (Fig. 3) were therefore possible contributors to the decline of the Black Kite in the late 20th century. Shortly after 2000, the area of seeded rice decreased to a very small and confined area in Tainan. The amount of SGARs provided by the government also decreased after 2005. These decreases may have aided the recent slow but steady increase of the Black Kite's population from only 175 individuals in 1991 to 400–500 individuals in 2015 (Y.-H. Sun unpubl. data).

Similar kite declines have occurred elsewhere. For example, Black Kites were extirpated by agricultural pesticide poisoning in Israel in the 1950s (del Hoyo et al. 1994), and Red Kites (*Milvus milvus*) declined by 20–50% in several European countries during the 1970–1990s due to poisoning (Smart et al. 2010, BirdLife International 2016b).

Citizen Science and Government Policies. Prior to our study, poisoning of farmland birds was occasionally reported in Taiwanese newspapers or community websites during recent years, but such reports did not receive much public attention. With the help of our citizen-science Facebook group, we were able to (1) make the public and the government more aware of the overall situation of intentional poisoning of farmland birds and (2) gather substantially more data on poisoning incidents than we could have without it. Although the survey effort was not constant and systematic, some incident hotspots nevertheless emerged. Naturally, poisoning incidents in open crops and near busy roads were more easily noticed by passersby. Incidents in other areas, such as in orchards in the hills, were likely underreported.

Photos of poisoned birds on Facebook usually aroused public concern. The images revealed the importance of the issue and helped prompt the government to become involved. However, the images also generated a negative view of certain crops by the public, and angered farmers usually protested the adverse publicity. Some bird-friendly control methods were popularized by agricultural authorities, e.g., the use of seed drills to bury red bean seeds into the soil (Firake et al. 2016). Jacana-friendly farming was also promoted by the Tainan Jacana Ecological Education Park.

Six types of carbofuran products (concentrations of 85, 75, 44, 40.64, 37.5, and 3%) have been sold in Taiwan since the mid-1970s but the two highest-concentration products were banned in 1999 due to their high toxicity. The Council of Agriculture in Taiwan announced that the remaining three higher-concentration carbofurans were banned from 1 January 2017 onward, but the 3% granulated carbofuran remained legal. The nationwide anti-rodent campaign was cancelled in 2015, but local authorities can still provide SGARs to farmers if considered necessary. The amount of SGARs procured by the government decreased considerably from 2014 (Fig. 3).

In this study, we focused on intentional poisonings whose purpose was to reduce pest bird damage. Our method of data collection may have missed some pesticides that cause chronic or sublethal toxicity exposure via unintentional poisoning. For example, one of the 29 farmland birds also contained chlorpyrifos (Appendix B), which is associated with some health risks even though birds may not die immediately (Mullie and Keith 1993, Solomon et al. 2001). Birds weakened by sublethal pesticide exposure may then be more likely to starve, be killed by a predator, or be involved in an accident (Berny 2007, Rattner et al. 2014). Thus, we recommend further research on the risks of such sublethal or chronic exposure.

Researcher and conservationist Chen-Chung Shen spent decades recording and protecting the remaining Black Kite populations starting in 1991. His work and part of our study were documented in the feature-length movie "Fly, Kite Fly" (directed by Chieh-Te Liang, released in 2015). This was one of the key factors that brought this issue to a wider public attention. We encourage researchers in other countries to also use citizen science to both report about and raise awareness of bird poisoning incidents. Such studies may also become a starting point to eventually influence government policy.

Supplemental Material

The species and number of individuals of the 4753 dead birds reported to BPRT (Appendix A) and the results for the 29 dead birds tested for pesticide residues (Appendix B) are available online.

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