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Short communication

Bat fatalities at wind farms in Taiwan

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Abstract. We collected bat carcasses at three wind farms in Taiwan, located along the west coast mostly near the sea and/or in former coastal wetland habitats. We found 43 bat carcasses, mostly of common aerial-hawking species such as *Pipistrellus abramus* and *Scotophilus kuhlii*, but the island endemics *Eptesicus serotinus horikawai* and *Myotis formosus flavus* were also recovered. All bat species affected are believed to remain on the island all year. As far as we know this is the first report of bat fatalities at wind energy facilities in eastern Asia.

Key words: Asia, bat conservation, endemic species, Formosa, wind energy.

Wind power may help to satisfy a growing worldwide demand for energy in general and for electricity in particular. Taiwan is potentially rich in wind power because of the exposed situation and the monsoon, but the country still depends to a large extent on imported fossil fuels. In order to reduce CO_2 production following the Kyoto protocol of 1997, the Taiwan government launched a program for promotion of wind energy, with the goal to increase renewable energy from 5.5% to 10% of the total energy demand between 2004 and 2010 (Yu 2007). Historically, two wind turbines were constructed on the island of Penghu off Taiwan in 1990, and since then the number had increased to 321 turbines in six wind farms in 2014. According to plans it will exceed 1000 in 2030, including farms onshore and offshore (Chou et al. 2013; http://www.twtpo.org.tw/intro.aspx?id=9).

Wind power is usually considered a green form of energy, but impacts on bats have raised increasing concern and observed mortality rates are sometimes so high that the future for some bat populations is in doubt (Kunz et al. 2007; Lehnert et al. 2014). This is true for some migratory bats in northern Europe and North America, but recent evidence suggests that stationary populations in the tropics and subtropics may also suffer considerably. Recent reports from e.g., Mexico (Villegas-Patraca et al. 2012) and Puerto Rico (Rodriguez-Durán and Feliciano-Robles 2015) are quite alarming (Arnett et al. 2016). Bats are attracted to wind turbines (Cryan et al. 2014), perhaps because the turbines attract insects on which the bats feed (Kunz et al. 2007; Rydell et al. 2016). The bats are killed either through direct strikes of the rotors or because of damage to lungs and other organs caused by rapid changes in air pressure near the moving rotor blades (Baerwald et al. 2008). Fatalities may also occur later, following, for example, minor wing fractures or ear damage, but the frequencies of such "cryptic deaths" are unknown (Grodsky et al. 2011).

Taiwan consists of one main island and several small islands in the South China Sea, with a substantial part of the flora and fauna, including more than 30 species of bats, being endemic taxa (Lin et al. 2004; Cheng et al. 2015). Taiwan has been connected to mainland China by land-bridges during the Pleistocene, but it is not clear to what extent bat species are actually shared between the two regions, or whether more localized, endemic lineages predominate (Kuo et al. 2015). Migration of bats between Taiwan and the mainland (126 km) has not been documented.

As wind energy facilities develop in Asia and other parts of the world, dramatically increased numbers of bat fatalities can be expected. Nevertheless, to our knowledge this is the first report on wind farm fatalities of bats

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in eastern Asia, despite extensive wind energy programs in several countries. This is a preliminary report, but the first to indicate that South-East Asian bats are affected by wind farming, just as many bats at higher latitudes.

Materials and methods

The data summarize carcass searches at three wind farms along the west coast of Taiwan made in 2007, 2008, 2010, and 2011 (Fig. 1 and Table 1). The habitats consisted mostly of embankments and wetlands, including former mangrove habitats with canals, oyster- and fish farms, windbreak trees, and some low buildings. The sites were generally quite heterogeneous and usually rich in insects such as mosquitoes and other swarming flies. The turbines surveyed were all of 2.0 MW installed energy and with ca. 60–80 m tower height (total height ca. 100 m) and 75 m rotor diameter. The turbines were installed in 2003 (site A), 2005 (site B), and 2010 (site C), respectively (Fig. 1).

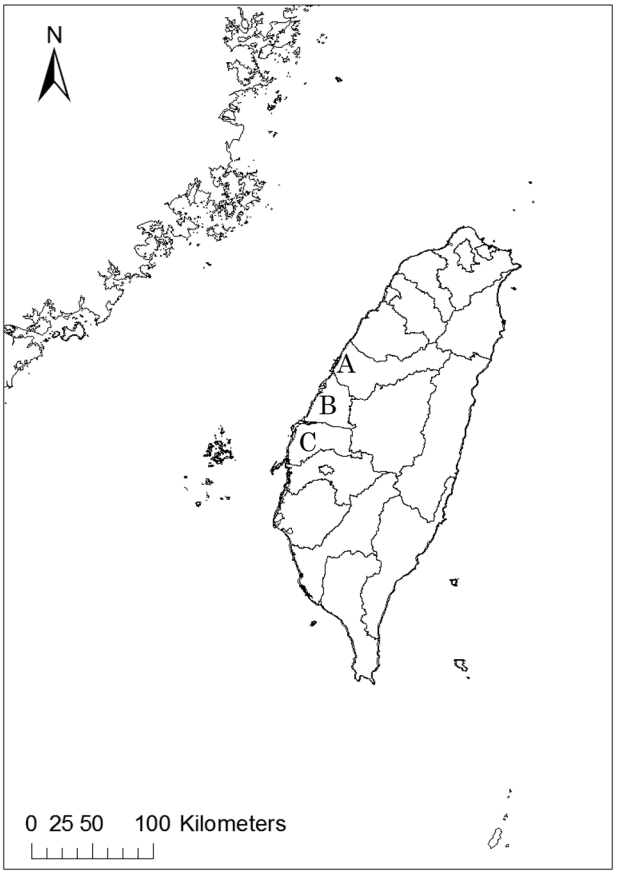

Fig. 1. Map of Taiwan showing the location of the wind farms A, B, and C.

This study is a compilation of three independent surveys. For practical reasons the searched areas were usually restricted to the asphalt or gravel immediately below each turbine. The surrounding marshland and bushes were extremely difficult to search and this was usually avoided. In practice we searched an area of 15–30 m radius around the base of each turbine. We report raw numbers, uncorrected for searching efficiencies and predator removals. This is because the experiments that would have been necessary to estimate this have not been carried out in any of the three surveys summarized in this study. Hence the reported numbers are probably gross underestimates of the real fatality rates. The carcasses were identified to species (Cheng et al. 2015) and if possible also to sex and age and then photographed. The photographs and some of the specimens were saved at the Endemic Species Research Institute in Jiji.

Results and discussion

Three wind farms were searched for fatalities. We found 43 carcasses of five species. The dominating species was the Japanese pipistrelle *Pipistrellus abramus*, a common and non-endemic species, accounting for 25 of the 31 specimens that could be identified (81%). Four other species were also recovered as carcasses, namely *Scotophilus kuhlii*, *Nyctalus plancyi velutinus*, *Eptesicus serotinus horikawai* and *Myotis formosus flavus* (Table 1).

Table 1. Number of bat carcasses recovered from each of the three wind farms searched (A–C, as in Fig. 1)

Wind farm	Location	No. of turbines searched	No. of searches per turbine	Time of sampling	Bat species						Total
					Npla	*Eser**	*Pabr*	*Skuh*	*Mfor**	Undet	
A	Taichung	18	3	Jun–Sep 2007	1	1	13			1	16
B	Changhua	42	3	Jun–Sep 2008			2				2
C	Yunlin	37	8	Jun 10–Dec 11			9	3	1	12	25
Total											43

Species acronyms are Npla = *Nyctalus plancyi*, Eser = *Eptesicus serotinus horikawai*, Pabr = *Pipistrellus abramus*, Skuh = *Scotophilus kuhlii*, Mfor = *Myotis formosus flavus*. Asterisk indicates an island endemic (Ruedi et al. 2015; Cheng et al. 2015).

The latter two are island endemics in Taiwan (Cheng et al. 2015).

In Yunlin (C), where the turbines were searched throughout the year, 24 of the 25 carcasses were found in the summer (June–September). The highest fatality count was in September (14 specimens). One single carcass was found in December. The other two sites (A and B) were only searched on three occasions each, all during the summer season (Table 1).

The crucial factor determining the vulnerability of bats at wind turbines is their use of open air space and the tendency to occur at the height of wind turbine rotors (Arnett et al. 2016). In our case, the open air bats include the *Nyctalus*, *Eptesicus*, *Pipistrellus*, and *Scotophilus* spp. but generally not the *Myotis* spp., although there was one exception with an individual *M. formosus flavus* that was killed. This pattern is in good general agreement with the situation elsewhere in the Old World (Rydell et al. 2010; Arnett et al. 2016).

However, *Pipistrellus abramus* dominated among the carcasses, just as other species of the same genus sometimes do in Europe (Rydell et al. 2010). Why pipistrelles in general are more vulnerable at wind turbines than other open-air bats is not clear. Part of the explanation could be that pipistrelles are particularly numerous in habitats with wind turbines, but their foraging behavior and diet, e.g. their tendency to search for prey (small flies) near vegetation and other objects may perhaps also be involved (Verboom and Huitema 1997).

Members of two other genera of open-air bats, namely *Miniopterus* and *Tadarida*, relatively seldom turn up dead under wind turbines, although they are sometimes abundant and often occur in large colonies. This is certainly the case in Taiwan, particularly with respect to *Miniopterus fuliginosus* (Cheng et al. 2015) which is a very common species throughout the island. This observation is also consistent with findings elsewhere in the Old World, e.g., in the Mediterranean area (Eurobats 2015). It seems likely that these long-winged, fast-flying bats spend most of their foraging time in the air high above the wind turbines, away from the zone of immediate risk. This hypothesis remains to be tested, however.

The wind farms of Taiwan were built along the west coast, some of them in wetland habitats which are particularly rich in insects such as small flies, on which many of the aerial-hawking bats, including *Pipistrellus* spp., typically feed (Barlow 1997). With hindsight, this was probably not an optimal location, considering the potential interaction with foraging bats in such habitats. On the other hand, it is not known what effect wind farms in other habitats, e.g., on dry farmland, would have had on bats in Taiwan.

In summary, we substantiate the hypothesis that bats that routinely feed within the zone of wind turbine rotors are at risk in nearly all parts the world and regardless of their roosting and migratory habits. This simple result may have far-reaching consequences and suggests that wind turbines should be mitigated much more consistently than at present in all areas where bats occur. Effective mitigation methods exist for the use in temperate areas (Arnett et al. 2013), but how they should be applied in the tropics and subtropics is less clear and needs immediate attention.

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