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Note

Mortality of migrating monarch butterflies from a wind storm on the shore of Lake Michigan, USA

When monarch butterflies (Danaus plexippus) in eastern North America undertake their annual fall migration to wintering sites in central Mexico, they face numerous obstacles, and many do not survive the journey. Large water crossings in particular have long been known to be a source of mortality during migration; before the winter destination of eastern monarchs was known, Beal (1946) reported that he often found monarchs and other insects 'cast up' on the shore of Lake Erie. On one afternoon in September 1943, he collected 57 monarchs 'just above the water line' over 1.5 miles (2.41km) of beach (Beall, 1946). Other evidence that water crossings are risky comes from the monarch's reluctance to cross water during unfavorable winds (Schmidt-Koenig, 1985) and the fact that monarchs tagged along the Atlantic coastline have an extremely low recovery rate at the Mexican overwintering site (Garland & Davis, 2002; Brindza et al., 2008; McCord & Davis, 2010). Large water bodies therefore appear to lead to substantial mortality of migrating monarchs. What is missing, however, from the collective evidence for the effect of water barriers, is first-hand accounts of mortality at such barriers. In this report, we summarize a series of observations submitted to the citizen-science program, Journey North (http://www.learner.org/jnorth/), regarding a mass mortality of migrating monarch butterflies at a location on the shore of Lake Michigan (Fig. 1) following an intense wind storm.

The storm in question was actually three back-to-back low-pressure systems that swept through the Midwest region of the US beginning on October 14, 2011. The national weather service for the Grand Rapids (MI) area described the systems as follows: The first low produced rain and cloud cover resulting in temperatures around normal from the 14th through the 17th. The rain was light with multi-day totals mostly under an inch. Strong winds of 25 to 35mph (blowing westerly) were also felt across the area with winds gusting between 40 and 50 mph from late on the 14th into the 15th. The second low pressure system, which was more intense than the first, came a day later. Temperatures fell to below normal through the 22nd as heavy rain and strong (westerly) winds again lashed the area. Rainfall totals for the storm, mostly on the 19th and 20th, ranged from over an inch to nearly 3 inches across southwest lower Michigan. Winds gusted to between 40 and 50 mph with isolated sites experiencing gusts to near 60 mph. A third system came a day later; thunder and hail were reported at times from the 23rd through the 29th. This was accompanied by light to moderate rainfall. Temperatures were around or below normal through the end of October 2011 (National Climatic Data Center, 2012). The magnitude and duration of these storms can also be seen in a chart of the daily average and maximum wind speeds from the

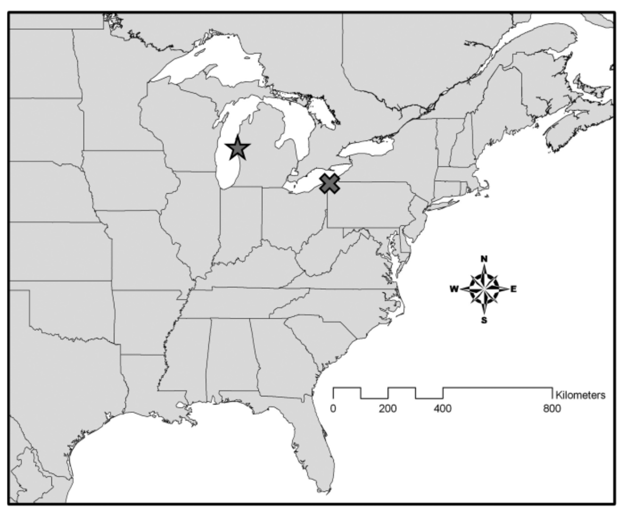

Figure 1. Location of the primary site of monarch butterfly mortality described in this article; a beach in Ludington, MI (star), on the eastern shore of Lake Michigan, USA. Letter X indicates the town of Erie, PA, on the eastern shore of Lake Erie, where additional weather data were obtained for comparison with Ludington.

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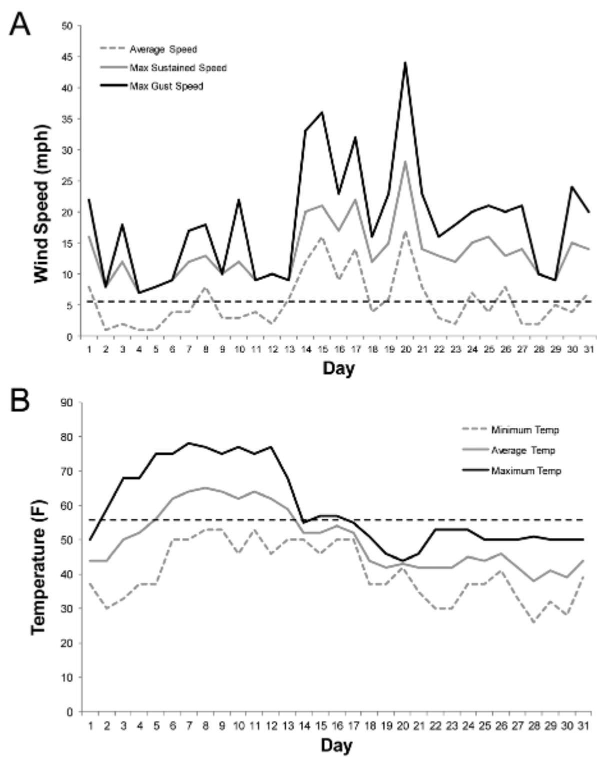

Figure 2. Chart showing daily wind speeds (A) and temperatures (B) for Ludington, MI (the location of the primary monarch report, see Fig. 1) in the month of October, 2011. Dotted line in A indicates the average wind speed for the month of October between the years 2000 and 2010 (6 mph). Dotted line in B indicates flight threshold temperature for monarch butterflies (55°F). Data obtained from Weather Underground (www.wunderground.com).

airport at Ludington, MI (Figure 2A; data courtesy of Weather Underground). In this chart, three distinct periods of exceptionally-high winds (i.e. higher than the 10-year average for this location) can be seen beginning on October 14th.

On October 15th, at the beginning of the storm, one observer (who used a pseudonym in her report and wishes to remain anonymous for this publication) visited a beach in the town of Ludington, MI (Figure 1), and witnessed the event. She subsequently reported to Journey North: "We discovered hundreds and hundreds of dead and dying monarchs on Stearns Beach (a city park beach in Ludington). They are being buried alive in the sand due to gale force winds. The wind was so strong that we could barely walk and yet here were hundreds, if not thousands, of monarchs clinging to anything they could find. We found them holding onto a seagull feather stuck in the sand, small pieces of dry grass, twigs, leaves, almost anything."

On October 18th, this same observer visited the Stearns Beach site again in order to conduct a more complete survey and to take photographs of the monarchs (Figs. 3A-F). On this day she walked approximately 200 meters of Stearns Beach and photographed every monarch she found – living or dead – that was either on the beach itself or up to 15 feet into the beach grass. In total she counted and photographed approximately 100 butterflies, though a few were not monarchs. Based on these images, one of us (Davis) estimated that 45% of the monarchs she saw were females. Also during this survey she noted that many of the dead monarchs were being eaten by various species of beetles (Fig. 3E).

With this anecdotal account it is difficult to estimate the actual number of monarchs killed (or damaged severely enough to incapacitate flight) by this storm, although it is likely in the thousands, if not hundreds of thousands. If we assume that there were 100 dead or dying monarchs per 200m of beach on Lake Michigan (based on the observer's short survey), and there is 2,640 km of coastline on this lake (Wikipedia, 2012), by simple extrapolation we obtain 1,320,000 dead or dying monarchs. If even half of that number is closer to the real figure (660,000) the numbers are still exceptional. Moreover, this estimate is only for Lake Michigan, yet there are five great lakes and all are approximately within the central flyway of the monarch (Howard & Davis, 2009), and, this weather system appeared to encompass parts of Lake Huron, Lake Erie and Lake Ontario. It is also important to point out that Journey North received two additional reports of monarch mortality at other locations (from the same weather event) along the same coastline of Lake Michigan: one at Norton Shores and another at Muskegon, both on October 17. Neither of these was as detailed as the initial report, but they demonstrate that the effect of the storm was widespread on the coast of Lake Michigan.

While this particular storm appeared to be severe, we point out that such storm events are not uncommon during the fall throughout the migration flyways of the monarch. In fact, on further examination of weather data from the Ludington airport from 2001 through 2010 (from weather Underground, www.wunderground.com), we determined that on average, there were 13 days each fall (August through October) with maximum winds over 20 mph at this one location (Table 1). Plus there were nearly 12 days on average with gust speeds over 30 mph. Both of these wind speeds are similar to those from the wind storm of 2011 (Figure 2A), although not all of these days could be considered 'storms'. A true wind storm would be where there were consecutive days with high winds, such

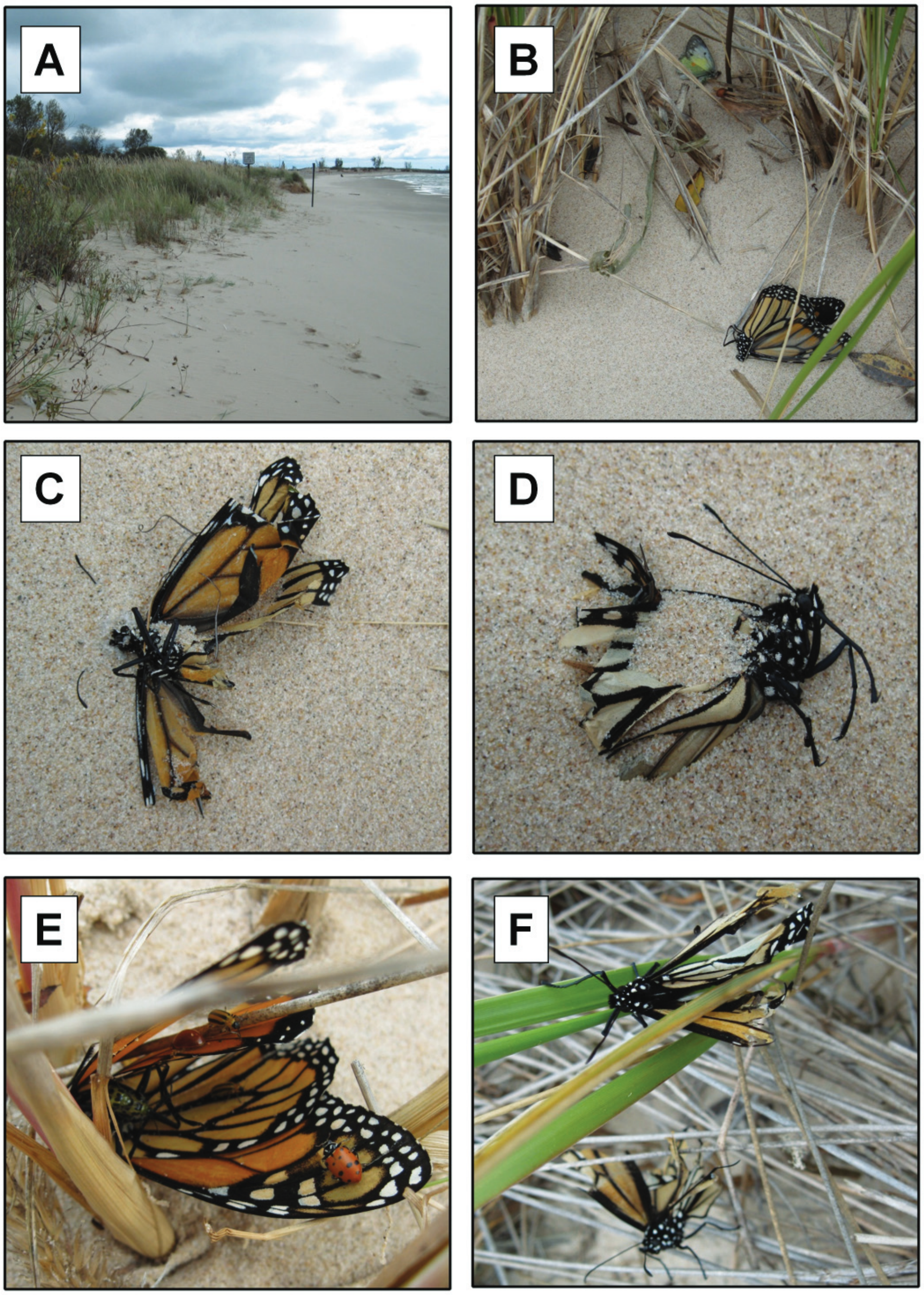

Figure 2. Photographs of (A) Stearns Beach (a city park in Ludington, MI) where monarch mortality was witnessed and (B-F) of monarch bodies, alive and dead, found along the beach. Note the beetles eating the dead monarch in E.

Table 1. Summary of the frequency of days with high winds in the months of August, September and October at Ludington, MI, (the Ludington airport weather station) from 2001 to 2010. Last column indicates the number of times there were 2 or more consecutive days with maximum winds above 20 mph (i.e. a prolonged storm similar to the one in question in this report). Weather data obtained from Weather Underground (www.wunderground.com).

Year	# days w/ max wind above 20 mph	# days w/ max gusts above 30 mph	# storms lasting 2+ consecutive days
2001	17	20	4
2002	14	12	3
2003	9	8	0
2004	14	15	3
2005	12	7	3
2006	9	10	2
2007	23	15	5
2008	8	4	0
2009	14	12	3
2010	11	14	4
Average	13.1	11.7	2.7

as occurred in 2011; at Ludington these occurred about 3 times each fall, on average, in the 10 years examined (Table 1). By comparison, examination of weather data for the same time frame (August-October only, from 2001-2010) at Erie, PA, a town on the eastern shore of Lake Erie (Figure 1) indicated that days with strong winds tend to occur even more frequently at this location each fall (Table 2). Clearly then, severe storms are not uncommon during the fall in the Great Lakes region, and it is very possible that storm-related mortality of migrating monarchs is also not uncommon. In fact, storms may not even be necessary to cause mortality over water crossings. Beall's (1946) early survey of dead monarchs on a beach on Lake Erie made no mention of a storm at all, and he indicated that the monarchs had likely drowned while attempting to cross the water. He further suggested that large water crossings may act as selection events for monarchs because the dead monarchs he collected appeared to be smaller on average than those captured elsewhere during the migration.

Beall's point about selection is well-taken. Whether it is from a major storm or simply from failure to cross large water bodies, a large proportion of monarchs likely die each year during migration. It is also likely that the ones that die are primarily the 'stragglers', or those that fell behind. This may have indeed been the case with the monarchs seen during the storm in October 2011; at a site on the north end of Lake Michigan (Peninsula Point) where migrating monarchs are counted each fall, over 90% of all monarchs pass through before September 15 in most years (Meitner et al., 2004). In addition, by mid-October the leading edge of the fall migration has usually reached 28°N latitude, or southern Texas (Howard & Davis, 2009). Therefore the monarchs seen on Lake Michigan (44°N latitude) during the storm were already approximately 1700km behind the rest of the migratory cohort, and about one month late. And finally, even if they were not killed by the storm, the temperatures in the region fell below the flight threshold for monarchs (13°C or 55°F: Masters et al., 1988) following the storm (Figure 2B), so that all remaining butterflies in this area would ultimately have perished. All evidence therefore suggests that the monarchs witnessed by the observer on Lake Michigan were unlikely to ever complete the migration. Thus, the storm event of 2011 here could be considered an example natural selection acting to fine tune the monarch butterfly migration by weeding out 'suboptimal' individuals. And, if this happens every year, it is easy to see how natural selection would ensure that only the strongest and hardiest individuals would remain in the population.

From a scientific standpoint, it would be interesting in the future to compare certain characteristics of the 'straggler' monarchs to those that survive the journey, much in the way that Beall (1946) did, to find out what factors influence migratory success. While to our knowledge an investigation of this nature has never been done, a recent examination of tagging data did show how monarchs with wing damage and

Table 2. Summary of the frequency of days with high winds in the months of August, September and October at Erie, PA, from 2001 to 2010. Last column indicates the number of times there were 2 or more consecutive days with maximum winds above 20 mph (i.e. a prolonged storm similar to the one in question in this report). Weather data obtained from Weather Underground (www.wunderground.com).

Year	# days w/ max wind above 20 mph	# days w/ max gusts above 30 mph	# storms lasting 2+ consecutive days
2001	18	11	6
2002	8	6	1
2003	14	13	4
2004	13	8	5
2005	21	11	5
2006	34	20	7
2007	22	10	6
2008	22	15	3
2009	22	14	8
2010	28	22	8
Average	20.2	13	5.3

wear can fall behind because of their longer and more frequent stopovers (McCord & Davis, 2012). Moreover, infections with the protozoan parasite, *Ophryocystis elektroscirrha*, can also negatively impact flight ability (Bradley & Altizer, 2005), so that such individuals could fall behind as well. And consistent with Beall's (1946) results, Gibo & McCurdy (1993) showed how monarchs captured late in the migration (which could be considered stragglers) tended to have smaller forewing lengths than those captured during the peak of the migration. Other ideas that could be addressed in the future might be to examine wing shape of stragglers (Altizer & Davis, 2010) to see if it differs from typical migrants, or to compare the genomes of stragglers and successful migrants, which may provide insight into their innate migration programming.

Finally, we point out that identifying any source of annual mortality to monarch butterflies would be prudent, especially given the recent attention to tracking the long-term population status of eastern monarchs (Brower et al., 2012; Davis, 2012). As such, we propose that future efforts should be aimed at surveying areas of coastline for dead monarchs on a regular basis in the fall, much in the way that McKenna et al. (2001) did along roadways in Illinois. This will allow for more precise estimates of annual mortality from storms or otherwise, which, if this report is any indication, may indeed be massive. In any case, this report certainly highlights the risks that all monarchs face when they undertake their long and arduous journey each fall.

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Elizabeth Howard, Journey North, 1321 Bragg Hill Road, Norwich, VT 05055

Andrew K. Davis*, Odum School of Ecology, University of Georgia, Athens GA 30602

*Corresponding author
akdavis@uga.edu