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The effects of light characteristics on avian mortality at lighthouses

Jason Jones and Charles M. Francis

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The generation of artificial light by human activity can have far-reaching detrimental impacts upon a wide variety of organisms. A great deal of attention has been paid to well-lit buildings, television towers, and communication towers as sources of mortality for nocturnally migrating songbirds. However, despite being among the first human structures known to generate migratory bird kills, little is known about the current impact of lighthouses on birds, or the impact of light design. We examined the impact of a lighthouse on nocturnal avian migrants at Long Point, Lake Erie, Ontario, Canada. From 1960–1989, mean annual kills were 200 birds in spring, and 393 in autumn, with kills of up to 2000 birds in a single night. In 1989, the Long Point lighthouse was automated, with a simultaneous change in beam characteristics – the new beam is narrower and less powerful. This change brought about a drastic reduction in avian mortality at the lighthouse to a mean of only 18.5 birds per year in spring, and 9.6 in autumn from 1990–2002. Our results highlight the effectiveness of simple changes in light signatures in reducing avian light attraction and mortality during migration.

J. Jones (correspondence), Department of Biological Sciences, Dartmouth College, Hanover, New Hampshire, USA, 03755, E-mail: Jason.Jones@Dartmouth.edu. C. M. Francis, National Wildlife Research Centre, Canadian Wildlife Service, Ottawa, Ontario, Canada K1A 0H3, and Department of Biology, Queen's University, Kingston, Ontario, Canada, K7L 3N6.

Photopollution, the generation of detrimental artificial light by human activity, can have profound ecological effects (Verheijen 1985, Witherington 1997). This artificial light is generated primarily by urban centers, although many other structures contribute, such as lighthouses, communication towers, and ceilometers (searchlights used to measure cloud height at airports). One of the most pervasive and negative effects of photopollution is on behaviors controlling orientation, in taxa ranging from insects (Wada et al. 1987) to sea turtles (Witherington 1997) and birds (Kumlien 1888, Evans Ogden 1996). Songbirds that migrate at night are attracted to these sources of light, especially under overcast or foggy weather conditions (Evans Ogden 1996). Birds that are not killed outright by collisions with the light sources can succumb to exhaustion brought upon by prolonged fluttering around a light source or to predation upon individuals in weakened states (Stoddard and Norris 1967, Weir 1976, Evans Ogden 1996). Previous studies have suggested that migrating birds are not equally attracted to all kinds of lights (Cochran and Graber 1958, Herbert 1970, Avery et al. 1976). Strobe lights have been reported to attract fewer birds for shorter periods of time than either slow flashing lights or constant sources (Baldwin 1965). Further information on the attractiveness of different types of lights to birds would be valuable to help develop guidelines to reduce collisions between birds and lighted structures.

A great deal of attention has been paid to well-lit buildings, television towers, and communication towers as sources of nocturnal migration mortality (Evans Ogden 1996, Crawford and Engstrom 2001). However, despite being among the first human-made structures to generate large kills of migratory birds (Barrington 1900, Clarke 1912), comparatively little attention has been paid to the contribution of lighthouses to this problem, especially recently. For example, a 1978 United States Fish and Wildlife Service report (Avery et al. 1978) highlighted 670 references to bird mortality through collisions with human-made structures and only 84 of those references involved lighthouses.

In this paper, we examine the impact on nocturnal avian migrants of a lighthouse at Long Point, Lake Erie, Ontario, Canada. In the past, large kills have been documented at this light, with up to 2000 birds killed in one night (Lewis 1927, Saunders 1930, Baldwin 1965, Bradstreet and Woodford 1970). In 1989, the Long Point lighthouse was automated, with a concomitant change in beam characteristics. Changing the light signature of a lighthouse can have a dramatic effect on its tendency to attract nocturnal migrants. In 1961, the light source of a lighthouse in Dungeness, Kent, UK, was changed from the original revolving beam to a strobe light, and nocturnal kills at this lighthouse stopped almost immediately (Baldwin 1965). Similar changes in light design have occurred, or might be anticipated, at many other lighthouses in North America.

Here we document and compare the frequency of kills and numbers of birds killed at the Long Point lighthouse before and after the change in light signature, and consider the reasons behind the observed changes in kill frequency. We then use our results to make general recommendations about how to minimize nocturnal migration mortality through light source management.

Methods

The Long Point peninsula is a 35 km long sand spit that extends eastward into Lake Erie from near Port Rowan, Ontario. The lighthouse is situated at the eastern tip of the peninsula (42°33′ N, 80°10′ W), approximately equidistant in a north-south direction from the Ontario and Pennsylvania shores, and has been in place at the tip since 1916. It is 31.1 m high.

During the period of our study, from 1960–2002, there have been several changes to the design of the light (Geoff Fortier pers. comm., David Hussell pers. comm.). Although the flash frequency of the light has not changed in the last 40 years, the intensity and breadth of the beam have. In 1960, the light was a 4-panel bulls eye system rotating once every 32 s (1 flash every 8 s) and was lit by a 1500 W incandescent lamp that was changed to a 400 W mercury vapor lamp in 1962. Prior to 11 October 1989, the optical system in the lighthouse had a conservative range estimate of 32 km. On 11 October 1989, the lighthouse was converted to solar power and a new rotational lantern (PRB-46) was installed. The PRB-46 had two beams with a full rotation every 16 s (1 flash every 8 s). The estimated range of this light was 29 km. On 13 June 1996, the range of the PRB-46 was downgraded from 29 km to 24–26 km. On 24 June 1998, an APRB-252 rotational lantern was installed. This light has 6 beams that rotate every 48 seconds, thus maintaining the flash frequency. The current system has a horizontal width of 8 degrees and a vertical width of 4 degrees. This equates to a beam approximately 28 m wide and 14 m high at a distance of 100 m. The exact dimensions of the beam prior to solarization are unknown but the beam would have been much wider in both dimensions (Bob Nichols pers. comm.). The intensity of the original beam was estimated at close to 100,000 candlepower, the current system is less than half as intense.

From 1960 onwards, Long Point Bird Observatory (LPBO) has been operating a banding and migration monitoring station in both spring and fall at the tip of Long Point (Hussell et al. 1992, Francis and Hussell 1998). As part of the daily operations, staff or volunteers carry out a standardized 1 hr observational count each morning, along a route that runs past the base of the lighthouse. As part of this count, they are asked to check for any dead birds around the lighthouse. In addition, on nights when weather conditions were considered appropriate to attract birds (e.g. foggy conditions or dense cloud cover; Baldwin 1963, Evans Ogden 1996), observations were often made of birds at night, and an extra effort was made to search the base of the lighthouse in the early morning. Lighthouse keepers were on duty every night and would often wake LPBO personnel if there were birds in the beams. Prior to 1973, observers were permitted to climb the lighthouse at night and often captured large numbers of birds fluttering against the windows for banding. Any dead birds were collected and identified, with age and sex recorded when possible. Through most of its history, the base of the lighthouse was surrounded either by a pond of water or exposed sand. However, in summer 1987 a concrete heli-pad (measuring about 1.5 m high and about 10 m in diameter) was installed around the base, substantially reducing the effects of scavengers, and making dead birds easier to find.

Because of inconsistency in the effort devoted to counting or catching birds attracted to the light, but not killed, we restricted our analyses to birds that were killed at the light. We considered both the number of birds killed each year, as well as the number of nights per year with at least one bird killed. We compared spring and autumn results, to determine whether the lighthouse posed a greater threat in one season than in the other. We evaluated the impact of the 1989 change in the lighthouse by comparing mean annual kills up until 1989 (because the change was near the end of the 1989 season), with kills from 1990–2002, testing spring (6 April–10 June) and autumn (13 August–20 October) separately. To determine whether differences in kills might be related to differences in effort, we calculated numbers of days with migration monitoring coverage in each season, excluding spring data from 1965 and 1973 when some of the original records were lost. Although some kills were recorded on days without complete migration monitoring coverage, and checks of the lighthouse may have been missed on some days with coverage, this provides the best available measure of the monitoring effort each year. The number of days of coverage was 2,347 in spring and 3,801 in autumn. To test whether differences in kills may be related to changes in numbers of birds migrating (on days with coverage), we calculated the total numbers of birds counted each season (estimated daily totals), for 64 species of regularly recorded, mainly nocturnal migrants (see Francis and Hussell 1998). All statistical comparisons between seasons, and before and after the 1989 change in the light, were based on Kruskal-Wallis two-sample tests, as implemented through SAS PROC NPAR1WAY (SAS Institute Inc. 1999). Values presented in text are means $\pm$ SE.

Results and Discussion

Over the 41 years of the study, the total number of birds reported killed was 6,259 in spring and 11,899 in autumn, representing 121 species. Most of these species were represented by 1 or 2 individuals, with 10 species accounting for over 50% of mortality (Table 1). The 10 most commonly killed species are not necessarily the most commonly detected species at the Long Point Bird Observatory. For example, the most commonly captured wood-warbler during autumn migration at Long Point is the yellow-rumped warbler *Dendroica coronata* with over 20,000 individuals banded (Jones et al. 2002), however, only 194 have ever been found dead at the lighthouse. Several of the most commonly killed species (e.g. red-eyed vireo *Vireo olivaceus*, bay-breasted warbler *Dendroica castanea*, blackpoll warbler *Dendroica striata*, ovenbird *Seiurus aurocapillus*) have been identified in other studies (e.g. Evans Ogden 1996) as being particularly susceptible to light attraction and mortality. The reasons for this are unclear; one hypothesis states that these species typically make short fast flights through heavy cover and may use 'light patches' as guides during flight (Snyder 1946), hence rendering them susceptible to light attraction. Alternatively, these species may be particularly abundant in North America, or may migrate at lower altitudes or in other ways that make them susceptible to lights.

The number of birds killed at the lighthouse after the 1989 change in the light dramatically dropped in both spring and autumn (Fig. 1). There was substantial variation among years in the number of birds killed (range 0–2423 birds). However, the number of birds killed each year before the change was significantly higher than the number of birds killed each year following the change, in both spring and autumn (Table 2). Similarly, the number of nights with kills each year was significantly higher before than after the change, in both spring and autumn (Table 2). This change was not related to changes in effort, as the mean number of days of coverage for migration monitoring each year remained nearly unchanged (Table 2).

The kill totals are undoubtedly affected by a certain degree of sampling bias. In recent years, less attention has been paid to the region surrounding the lighthouse (because birds were so rarely found) and the number of killed birds has probably been underestimated, although particular attention was paid in 2000, 2001 and 2002 in response to our study. We believe that the zeroes in the data set are real. Similarly, during the

Table 1. The 10 most frequently killed species at the Long Point lighthouse, Lake Erie, Ontario (1960–2002), out of a total reported kill of all species during this period of 6,259 in spring and 11,899 in autumn.

		Spring		Autumn	
English name	Scientific name	n	%	n	%
Swainson's thrush	*Catharus ustulatus*	913	14.6	750	6.3
Common yellowthroat	*Geothlypis trichas*	422	6.7	1,155	9.7
Ovenbird	*Seiurus aurocapillus*	613	9.8	820	6.9
Red-eyed vireo	*Vireo olivaceus*	396	6.3	866	7.3
Blackpoll warbler	*Dendroica striata*	66	1.1	924	7.8
Bay-breasted warbler	*Dendroica castanea*	275	4.4	600	5.0
Magnolia warbler	*Dendroica magnolia*	221	3.5	540	4.5
Veery	*Catharus fuscescens*	426	6.8	163	1.4
Tennessee warbler	*Vermivora peregrina*	147	2.4	344	2.9
Blackburnian warbler	*Dendroica fusca*	154	2.5	263	2.2
TOTALS		3,633	58.0	6,425	54.0

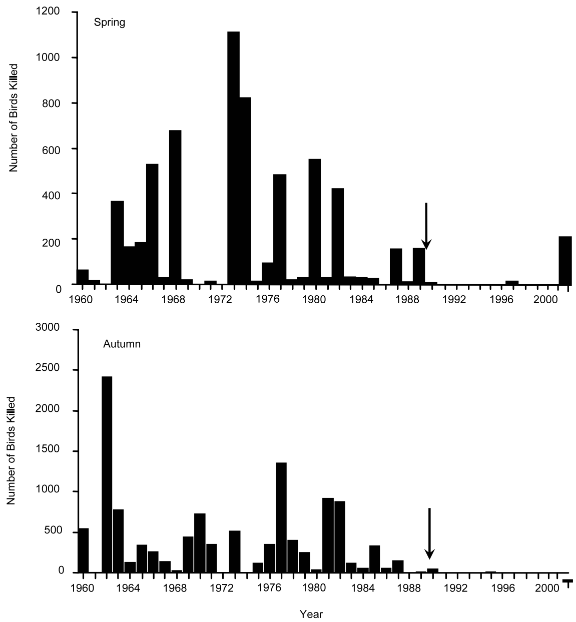

Fig. 1. Number of birds killed each year during spring and autumn migration at a lighthouse at Long Point, Ontario. The arrows indicate the timing of the light signature change.

years of massive kills before the light change and installation of the raised heli-pad, there was no doubt an under-recording of killed birds on at least some nights due to a variety of reasons, including too many birds to process on some nights, greater loss of carcasses due to scavenging by predators such as skunks *Mephitis mephitis* and raccoons *Procyon lotor*, and the possibility of kills on nights without coverage. Although the under-recording bias, as a percentage of total kills, could potentially be larger in recent years, in terms of number of birds it is likely lower, and could not have led to the dramatic changes observed subsequent to the change in the light.

The dramatic decrease observed at Long Point is consistent with the observations at the Dungeness lighthouse, where kills virtually stopped after the light was converted to a strobe (Baldwin 1965). One anomaly that we cannot explain is the relatively large number of birds killed in fall 1990, the first year after the light change (Fig. 1). The Long Point lighthouse was intermittently floodlit during the time period of the study and floodlighting of tall structures has led to declines in avian attraction in some areas (e.g. Dungeness, Baldwin 1965) and increases in others (e.g. the C. N. Tower in Toronto, Evans Ogden 1996). Unfortunately, it is not known if the lighthouse was floodlit in the fall of 1990.

A second anomaly appears in the spring of 2002, with 220 dead birds recorded. One possible explanation was that May 2002 was also unusual from a weather point of view. Temperatures in May in the region were the coldest of the last 34 years and the weather conditions (e.g. wind direction, cloud cover) on the nights of the largest totals created classic kill conditions at the lighthouse (David Hussell pers. comm.).

The mean number of birds killed and the mean number of nights with kills, prior to the change in the light, was apparently much larger in autumn than spring (Table 2), though only the difference in number of kill-nights was statistically significant (number of birds, Kruskal-Wallis two-sample test: $\chi^2 = 3.58$, $P = 0.05$, number of kill nights, Kruskal-Wallis two-sample test: $\chi^2 = 6.23$, $P = 0.01$). The observed differences in the number of nights with kills in spring and autumn is likely due to the more prolonged nature of autumn migration in eastern North America (Preston 1966). This is supported by the small and non-significant difference in the mean number of birds counted each year during spring and autumn migration (Spring: $11{,}882 \pm 902$ birds; Autumn: $13{,}956 \pm 1{,}564$ birds; Kruskal-Wallis two-sample test: $\chi^2 = 0.09$, $P = 0.77$) despite the number of days of coverage being, on average, 50% higher in autumn (Spring: 60 ± 2.8 days, Autumn: 95 ± 4.0 days; Kruskal-Wallis two-sample test: $\chi^2 = 29.83$, $P < 0.0001$).

There are two other possible explanations for the changes in the number of birds killed in the 1990s. The first is that migrant populations in general have declined. However, mean seasonal totals of well-monitored migrants more than doubled, from 9700 ± 600 per season in 1961–1989 to $20{,}500 \pm 1200$ in 1990–2002. These numbers are influenced both by changes in sampling and in bird populations, but more sophisti-

Table 2. Number of birds killed, number of nights with kills and number of coverage days both before and after the 1989 change in the lighthouse at the tip of Long Point, Ontario. Values are annual means ± SE of untransformed variables, with Kruskal-Wallis χ^2 statistics and associated P-values.

	Before	After	χ^2	P
Spring				
Number of birds killed	200.6 ± 52.6	18.5 ± 16.8	3.58	<0.0001
Number of nights with kills	3.7 ± 0.6	0.9 ± 0.4	3.05	0.001
Number of coverage days	61.1 ± 3.9	58.1 ± 2.0	0.65	0.42
Autumn				
Number of birds killed	392.5 ± 92.7	9.6 ± 5.3	4.24	<0.0001
Number of nights with kills	7.7 ± 1.4	2.0 ± 0.7	3.26	0.0006
Number of coverage days	91.6 ± 6.3	95.3 ± 0.9	1.86	0.17

cated analyses, taking into account variation in coverage and other factors, indicate that the numbers of most species that migrate through Long Point have increased over the last 37 years (Francis and Hussell 1998).

The second is that there has been a change in weather conditions that has affected the conditions under which birds are attracted to lights. Weather data from Long Point were only available for some of the years covered by this study. However, an analysis of weather variables from the NOAA station at Erie, Pennsylvania, about 20 km south of Long Point, showed few differences in average weather in each season (temperature, wind speed and direction, cloud cover, horizontal visibility) between 1961–1989 and 1990–2000 (C. M. Francis unpubl. data). There was a significant difference ($P < 0.05$) in cloud cover, but the difference was a decline of 4% in the number of completely overcast days and a corresponding increase in the number of completely clear days. Even if cloudiness does affect bird kills (Evans Ogden 1996), such a small difference could not explain the dramatic drop in kills observed after 1989.

There appear to be two ways in which light signatures can be altered to minimize the impact of tall, lighted structures on nocturnal migration. The first option is to alter the intensity and nature of the beam itself. Light attraction is positively related to light intensity (Verheijen 1985), as exemplified by the changes observed at the Long Point light. Given advances in radio, radar and satellite navigation technology, lighthouses do not play the important safety role they once did; efforts should be made to encourage the downgrading of lighthouse lamp intensities. The second option is to change from a fixed or rotating beam system to a flashing or intermittent light system (e.g. Dungeness, Baldwin 1965). Fixed and rotating beams tend to attract more birds than do flashing or strobe lights, although slow-flashing lights still attract birds (Munro 1924, Tufts 1928, Baldwin 1965). The interruption of the light appears to allow the birds to disperse from the beam (Baldwin 1965, Avery et al. 1976). The adoption of a strobe light system in which there is a complete break between flashes does not compromise mariner or aviator safety and flashing or strobe light systems satisfy current governmental regulations on obstruction lighting (Transport Canada 2000).

It is difficult to estimate precisely the numerical impact of light attraction on migrating birds. Part of the difficulty lies in the inconsistency with which bird kills are recorded and reported. The last comprehensive examination of this problem was undertaken over 20 years ago (Avery et al. 1978). Banks (1979) estimated that collisions with tall, lighted structures were responsible for approximately 1.25 million bird casualties annually. This estimate was based on annual totals from only 3 television towers and given the documented negative effects of other tall structures (e.g. lit buildings), the annual total is likely much higher. Despite the fact that research clearly demonstrates how lighting changes can reduce avian mortality (e.g. this study, citations in Evans Ogden 1996) and that many companies are making serious efforts to affect the necessary change, the application of known effective measures lags far behind the scope of the problem.

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