Bird kills at lighted man-made structures: not on nights close to a full moon

A theory which accounts for the congregation of animals at artificial lights predicts a lunar periodicity for the phenomenon. A statistical analysis of dates reported for bird kills in North America reveals this little-recognized periodicity.

F.J. Verheijen

THERE ARE ABUNDANT reports of bird kills at night at lighted obstacles such as lighthouses, tall buildings, ceilometers, radio and television towers. There seems to be a firm belief that meteorological conditions determine the magnitude of kills. The argument is that heavy kills occur when migrants are overtaken by a cold front and forced down by a very low cloud ceiling. Then "a rare combination of deep, low clouds with mist and murk and favoring winds, sets the stage for disaster" (Stoddard, 1962). This author also formulated another widespread belief about bird kills, "So far we cannot see that the phase of the moon has much bearing on the number of birds migrating, or striking the obstruction." The reasoning underlying this belief is that the moon should be visible to birds to affect orientation, and, since this is impossible under the atmospheric conditions conducive to kills, there could be no lunar periodicity in kills. Whereas the belief in the role of the weather in kills is expressed frequently—meteorological data are almost omnipresent in reports about bird kills—the disbelief that the moon could be a factor involved in kills has resulted in the almost complete omission of references to the moon in the relevant literature. Thus the word "moon" is not to be found in a review of 471 publications on bird kills in the last 100 years (Weir, 1976). Taking stock of a century's work we find that students have not yet unraveled the nature of the underlying behavior and the causal stimulus conditions of bird kills at lighted structures. Weir (1976) stated, "In spite of the many references dealing with bird mortality by night at man-made structures, there is a dearth of information on how to prevent kills. Relatively little effort has been devoted to understanding their mechanisms." Avery *et al.* (1976) admitted that "The primary question of what features of lights cause birds to congregate at tall lighted structures under overcast conditions is still unanswered."

Birds are not unique in congregating at artificial lights; insects and fish do so as well. The congregation of insects around light has been experienced as an almost inevitable inconvenience whenever man tried to dispel the nightly darkness from his surroundings. Entomologists have exploited this phenomenon for collecting nocturnal insects (see Southward, 1971). Similarly, it was discovered long ago that several species of fish are attracted by fire, and today fishing methods all over the world employ light to concentrate scattered pelagic fish (see Ben-Yami, 1976). That lunar periodicity influences the effectiveness of light-traps for insects and fish is well known: "It has long been known that light-traps take fewer insects on nights of full moon" (Southward 1971, p. 177),

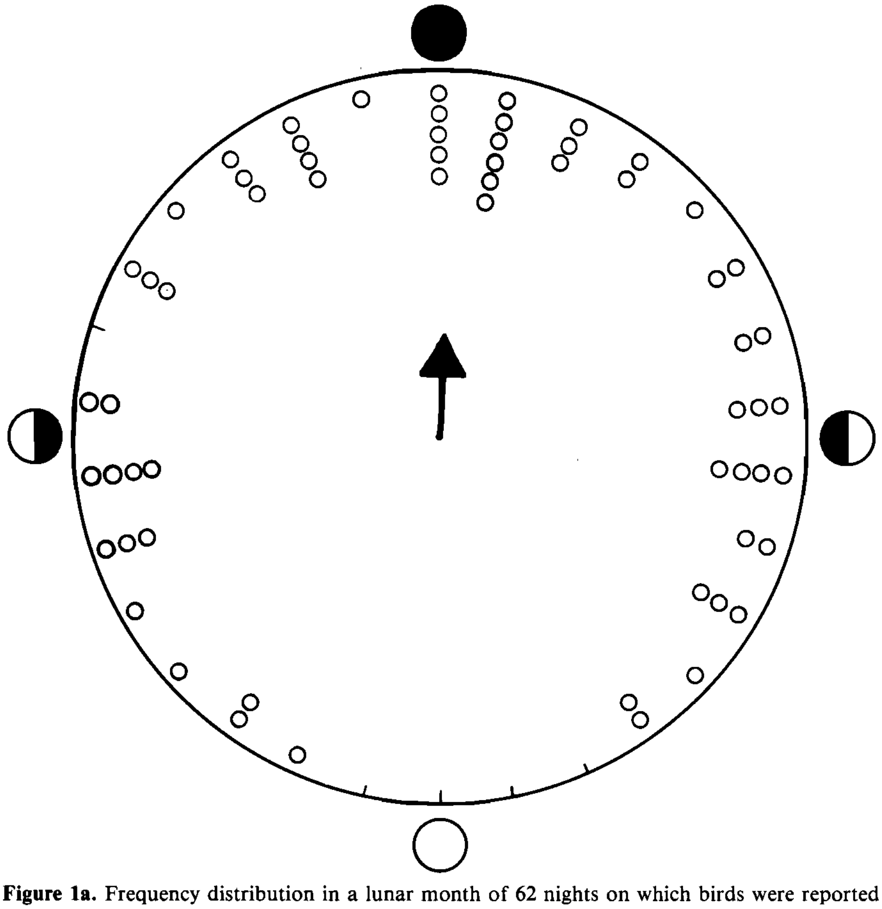

Figure 1a. Frequency distribution in a lunar month of 62 nights on which birds were reported killed in the U.S.A. in the period 1935-1973. Thirty lunar days are assigned to the synodic lunar month. ●,◐,○, and ◑ indicate new moon, first quarter, full moon and last quarter respectively New moon = 0°. The mean vector is shown as an arrow whose length is drawn in proportion to the radius of the circle = 1. n = 62, α = 2°, r = 0.283 ($p < 0.01$).

". the moon is a nuisance because, during the period before, during and after the full moon, fish become reluctant or even stop responding to artificial light" (Ben-Yami, 1976, p. 48).

I HAVE ADVANCED a theory which may account for this effect. It rests mainly on the idea that the optic orientation systems of animals are adapted to the natural angular light distribution (ALD)[1]. The natural ALD is an orientational requirement for survival. The term photopollution denotes the destruction of the natural ALD through the introduction of artificial light. Animals' optic orientation systems may fail to cope with the unnatural directional properties of the light field produced by artificial light. Consequently, the response may be stereotyped and forced, resulting in the aberrant behavior which so often leads to an untoward outcome ("trapping effect": Verheijen, 1958, 1979, 1980a). The reduction of the abnormal directivity—this is the vector by which the directional properties of a light field are specified (Verheijen, 1978)—of the light field around an artificial source as a result of moonlight, whether or not weakened and scattered by clouds, explains the lunar periodicity in the effectiveness of light-traps for insects and fish.

It would be remarkable if bird kills at man-made lights and lighted structures did not show a similar lunar periodicity. It would seem, however, that no statistical analysis of moon-age on dates reported for bird kills has been made in an attempt to discover lunar periodicity. The paradigm which denies the moon a function but allows the weather a function in affecting bird mortalities at lights may have been instrumental in this omission. Recently I analyzed 62 nights on which bird kills were reported in the United States in the period 1935-1973 (Verheijen, 1980a) and 167 nights on which bird kills were reported by Brouwer *et al.* (1929) at a Dutch lighthouse in the period 1924-1928 (Verheijen, 1980b). Both samples were treated as if they were circular distributions in a lunar month; they proved to be non-uniform (Figures 1a, b). The significant mean vector of each distribution points almost exactly towards the new moon (Rayleigh test, Batschelet, 1965). None of the 229 reported nights fell close to the full moon. The two populations of nights from which the two samples were obtained showed identical distribution functions (Smiznov test, Conover, 1971).

Table 1 Age of the moon on 47 nights with bird mortalities reported in North America in the period 1886-1975. Thirty lunar days are assigned to the synodic lunar month. Ages 1, 2, 30 are the darkest phases of the moon, 15 - 17 the brightest, the first and last quarters are ages 8 - 9, and 22 - 23. The dates marked * were used by Verheijen (1980) independently for composing Fig 1a

Date	*Moon-age*	*Weir (1976) page number*	*Weir (1976) reference number*
Sept. 28-29, 1886	1	46	132
Oct. 5-6, 1900	12	74	366
Oct. 20-21, 1935	23	7	295,296
Sept. 9-10, 1948*	5	74	369
Sept. 10-11*	6	55	213
Sept. 17-18, 1950	5	59	247
Oct. 7-8, 1951*	1	52,56,59	185,217,248
Sept. 7-8, 1953	29	76	393
Oct. 5-6	27	40	89
Oct. 6-7	28	40	89
Sept. 8-9, 1954	11	70	330
Oct. 6-7*	9	53	193
Oct. 7-8*	10	39,53	77,193
Sept. 25-26, 1955	9	66	292
Sept 26-27	10	48	156
Sept. 15-16, 1956	10	45,60	125,260
Sept. 17-18	12	79	412
Aug. 30-31,1957	5	44	117
Sept. 29-30	5	50	175
Sept. 30-Oct. 1	6	44	117
Oct. 4-5*	10	53	194
Sept. 16-17, 1958*	3	66,67	299,300
Sept. 22-23, 1959	19	56	219
Oct. 13-14	11	73	357
Sept. 23-24, 1960	2	81	430
Sept. 24-25	3	43,81	108,430
Sept. 25-26	4	81	430
Sept. 26-27	5	81	430
Oct. 3-4	12	44	115
Sept. 12-13, 1961	2	73	358
Sept. 6-7, 1962	7	69	318
Sept. 9-10*	10	54	206
Sept. 25-26	26	38	71
Sept. 18-19, 1963*	30	48	152
Sept. 20-21*	2	46	135
Sept. 21-22	3	72	354
Sept. 7-8, 1964	1	48	154
Sept. 22-23, 1965	26	44	114
Sept. 25-26	30	72	355
Sept. 27-28	2	44	114
Oct. 6-7	11	39	75
Oct. 7-8	12	39	75
Sept. 19-20, 1966	5	44	114
Oct. 10-11, 1967	6	83	447
Sept. 24-25, 1968	2	73	361
May 7-8, 1969	21	30	11
Oct. 14-15, 1975	9	48	155

AFTER THESE ANALYSES I discovered the review of bird kills by Weir (1976). Out of a total of 471 references, this author gives the dates of 47 nights reported for kills in North America between 1886 and 1975. Although 10 of these nights are also found among the 62 nights which I retrieved earlier from the literature, the 47 nights listed by Weir must be considered to be another independent sample of nights with bird kills. No arguments were given for citing these nights in particular. Nevertheless there is no reason to believe that this is not random. The dates and age of the moon on each of these 47 nights are listed in Table 1. Figure 2 shows the frequency distribution of these nights in a lunar month. As in the sample nights shown in Figures 1a and 1b none of the nights falls close to the full moon: obviously no kills were reported on nights with moon-ages 13 up to and including 18 lunar days. The distribution is non-uniform (Batschelet, 1965)[2] and is significantly clustered

[1]/Whether the stimulus should be termed light or radiance is of no concern in this paper because neither the spectral distribution of the stimulus field nor the spectral sensitivity of an organism responding to this field is considered here.

[2]/Rayleigh Test: $p < 0.01$

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around the hypothetical direction of the new moon (Batschelet, 1972)[3]. This distribution differs from the distributions shown in Figures 1a and 1b in that the mean vector points 53° (nearly four and a half days) past the new moon, whereas in the other two distributions, the mean vector points to within a few hours of the new moon. It is not clear whether this 53° deviation of the vector from the new moon towards the first quarter reflects some real aspect of the bird-kill/moon relationship or whether it falls within the normal or expected distribution of mean vectors around the new moon, resulting from the sample size under consideration. We shall not know for certain until a statistical analysis has been made of the many more nights in the literature on which bird kills have been reported.

The fact that among the 47 nights cited by Weir (1976) for bird kills in a period of nearly a century none appears to fall on one of the six nights close to the full moon may be a surprise to many ornithologists. However, from the comparative point of view, this bird-kill/moon correlation is only an example of the lunar periodicity shown by many species of invertebrates and vertebrates

[3]/V-Test: $n = 47$, $u = 2.70$, $0.005 > p > 0.001$

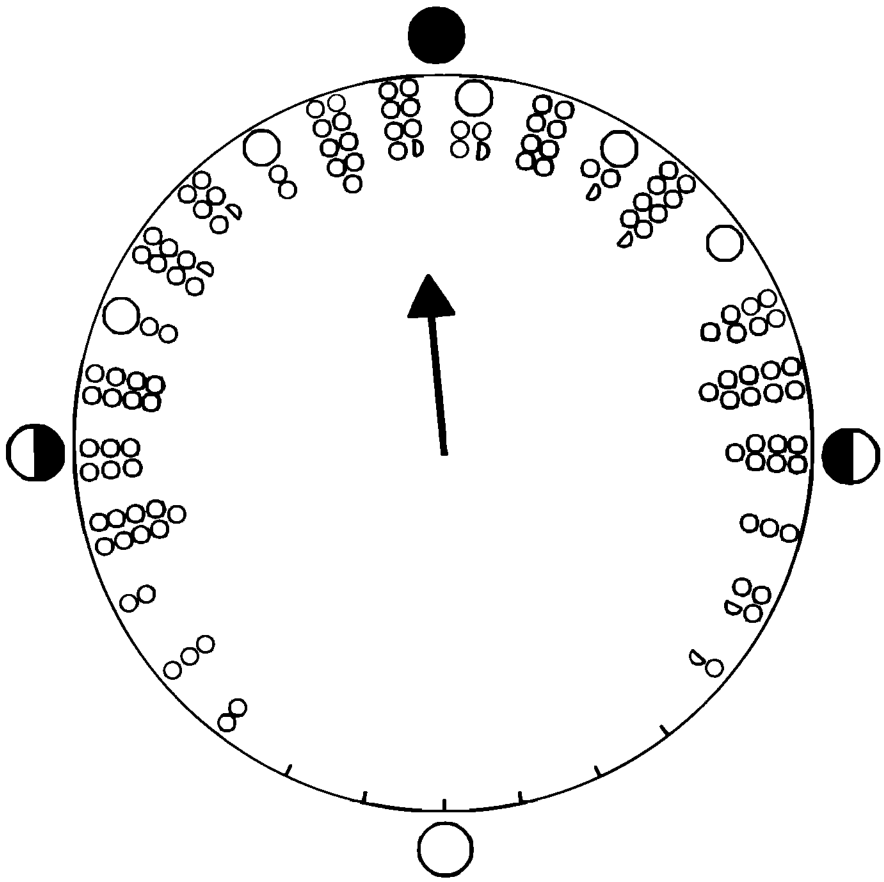

Figure 1b. Frequency distribution in a lunar month of 167 nights on which birds were reported killed at a Dutch lighthouse in the period 1924-1928. Twenty-nine lunar days are assigned to the synodic lunar month. Large circle = 10 nights, small circle = 1 night. Further symbols as in Figure 1a. $n = 167$, $\alpha = 356°$, $r = 0.461$ ($p < 0.01$).

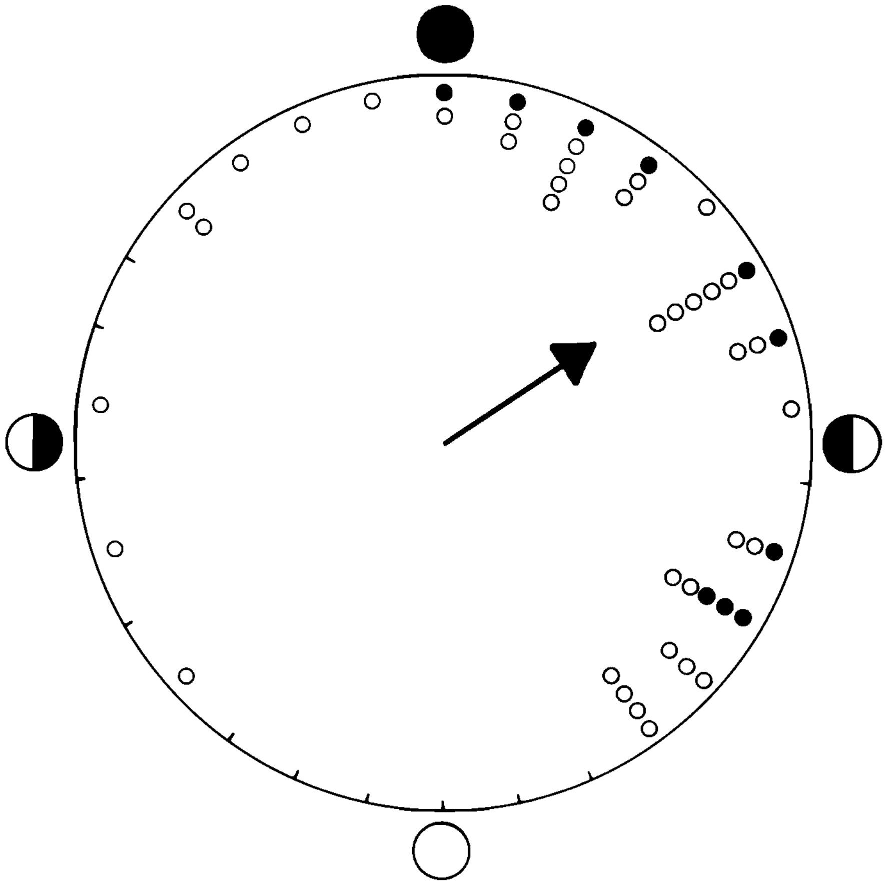

Figure 2. Frequency distribution in a lunar month of 47 nights on which birds were reported killed in North America in the period 1886-1975 as referred by Weir (1976). Thirty lunar days are assigned to the synodic lunar month. Filled circles indicate nights that were used independently among the nights presented in Figure 1a. Further symbols as in Figure 1a. n = 47, α = 53°, r = 0 499 (p < 0.01).

when congregating at artificial light. First, the optic orientation systems—photic and visual cues—of a wide variety of animals show similar adaptations to the directional properties of natural light fields (Verheijen, 1979, 1980a). Secondly, the functioning of these systems may be disturbed by the directional properties shown by an artificial light field Thirdly, moonlight, whether weakened and scattered by clouds or not, can restore the directional properties to a degree which may enable animals to to avoid disorientation from the artificial light source.

The responses shown by animals to the unnatural directional properties of an artificial light field was adequately termed "forced movement" by that man of genius Loeb (1918). His major mistake was that he took this type of response to be universal and natural. Moreover both he and his many opponents failed to recognize that experimental light fields, for instance the indoor light field employed in his famous experiments with caterpillars carried out in a glass tube placed behind a window, were the main causes provoking this forced response (Verheijen, 1958). I argued, moreover, that these shortcomings—the unnatural character of both the stimulus conditions and the response—are also inherent to the phototropism concept of the French psychologist Viaud (1956). Thus the suggestion made by J. Hirsch in his introduction to the 1973 edition of Loeb's famous book, namely that in the controversies around Loeb's concepts a solution would emerge from Viaud's work, does not seem to be convincing. Leaving theory aside it seems advisable to include data about the moon in reports on bird kills at lighted obstacles in addition to the almost omnipresent meteorological data. Elsewhere (Verheijen, 1979) I made a similar recommendation with respect to bird strikes on night-flying aircraft.

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—Laboratory of Comparative Physiology, State University Utrecht, Jan van Galenstraat 40, 3572 LA Utrecht, The Netherlands.