Title
Can *Halobates* Dodge Nets? II. By Moonlight?

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Can *Halobates* dodge nets? II: By moonlight?[1]

ABSTRACT

Analyses of surface plankton samples collected at night during the EASTROPAC project suggest that *Halobates* (Heteroptera: Gerridae) may be able to see and avoid nets by the illumination provided by a full moon.

Evidence has been presented (Cheng 1973) that ocean-skaters (*Halobates*) are able to avoid surface plankton nets towed during daylight hours. Preliminary analyses of collection data from 3-day intervals during new moon and full moon suggested that these insects might also be able to dodge nets by moonlight. This would confer some lunar periodicity to the data (as a direct response to the moon rather than an endogenous rhythm). Conventional analyses of data in which periodicities are sought generally involve an implicit assumption that the anticipated rhythm is indeed present. Here, in addition to conventional procedures, we have used an unbiased method of analysis, the "periodogram" (Enright 1965), for testing lunar periodicity and have thereby provided supporting evidence for avoidance of nets by *Halobates* on moonlit nights.

MATERIAL AND PRELIMINARY ANALYSIS

The same group of samples was used in these analyses as in the preceding paper (Cheng 1973), except that only night samples collected between 1800 and 0600 hours were considered. They comprised 2,712 animals, caught in 827 samples taken on 333 days during 16 sequential calendar months.

Data on frequency of samples containing *Halobates* for sets of 3 nights around full moon and around new moon are summarized in Table 1. This breakdown of the data led us to suspect that *Halobates* may have been better able to avoid the net during full moon: the insects were found in 38% of all samples taken around new moon, but in only 24% of samples taken during full-moon nights. A statistical test of the totals in Table 1 supports the interpretation that this difference is significant (χ^2_1 [with continuity correction] = 2.84, $0.10<p<0.05$), but such testing is not entirely appropriate because of the conspicuous heterogeneity in the data. Therefore, further analyses were undertaken, involving periodograms.

THE PERIODOGRAM ANALYSIS

The first procedure underlying calculation of a periodogram requires the grouping of a long, equally spaced time-series of data into sequential, nonoverlapping sets of n members, followed by the averaging of the first, second, . . . , nth members of each set, leading to a set of n average values. On the assumption that a rhythm with a period length of n units is present in the data, this set of average values should provide an estimate of form and amplitude of the periodicity, together with its phase relative to other known cycles with the same period.

The results of this procedure, applied to the nighttime samples and based on the *assumption* of a lunar periodicity, are illustrated in Figs. 1 and 2 for data on frequency of the insects (number of samples in which *Halobates* was taken, divided by total number of samples taken) and on average abundance per night haul. They indicate that *if* there is a lunar periodicity in the data, it involves a pronounced minimum around the time of full moon.

Note, however, that this procedure and these figures involve the *assumption* that a lunar rhythm is present. It is entirely conceivable that, had we made the assumption of a 25-day rhythm in the data (corresponding roughly to the period of solar revolution), an equally striking curve might have resulted; or we might similarly have found evidence for an even more striking apparent rhythm with a period of 33 days—corresponding to no recognizable environmental cycle—had it been sought.

The periodogram is a means of avoiding such ambiguities associated with the use of a single value of assumed period. The

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Table 1. Numbers of night samples collected during 3-day periods around new and full moon each month, and numbers and percentages of samples containing Halobates

New moon period				Full moon period			
Date (1967-68)	No. of samples	No. positive	% positive	Date (1967-68)	No. of samples	No. positive	% positive
8-10 Feb	13	4	30.7	23-25 Feb	14	6	42.8
10-12 Mar	6	5	83.3	25-27 Mar	4	0	0.0
8-10 Apr	-	-	-	23-25 Apr	6	3	50.0
8-10 May	6	4	66.7	22-24 May	4	2	50.0
7-9 Jun	-	-	-	21-23 Jun	5	1	20.0
6-8 Jul	3	1	33.3	20-22 Jul	4	0	0.0
5-7 Aug	6	0	0.0	19-21 Aug	9	1	11.1
3-5 Sep	7	1	14.3	17-19 Sep	6	0	0.0
2-4 Oct	-	-	-	17-19 Oct	-	-	-
1-3 Nov	6	1	16.7	16-18 Nov	9	0	0.0
30 Nov-2 Dec	-	-	-	15-17 Dec	-	-	-
30 Dec-1 Jan	4	0	0.0	14-16 Jan	6	4	66.7
28-30 Jan	3	1	33.3	13-15 Feb	6	0	0.0
27-29 Feb	10	5	50.0	13-15 Mar	4	2	50.0
27-29 Mar	5	4	80.0	12-14 Apr	7	1	14.3
Totals	69	26		Totals	84	20	

procedure was first proposed for geophysical data by Schuster (1898), and, since the advent of high-speed computers, has become a thoroughly practical procedure, even for long time-series. The essence of the method is an open-minded approach to the data: instead of making a single, a priori assumption about the period length of a postulated rhythm, one makes

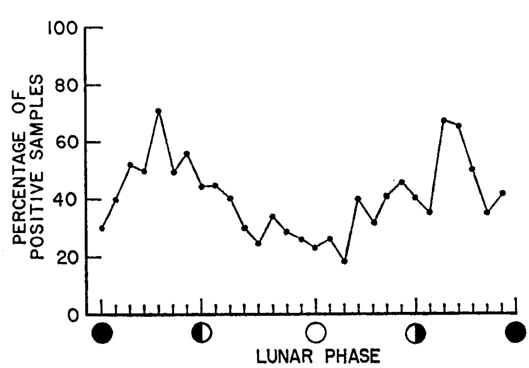

Fig. 1. Percentages of samples containing *Halobates* on each day of the lunar phase (data pooled from 16 months).

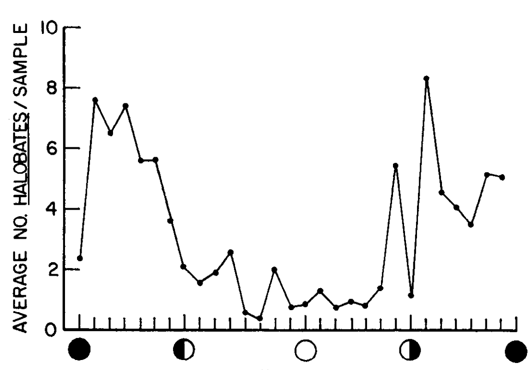

Fig. 2. Average number of *Halobates* taken per total number of samples collected on each day of the lunar phase (data pooled from 16 months).

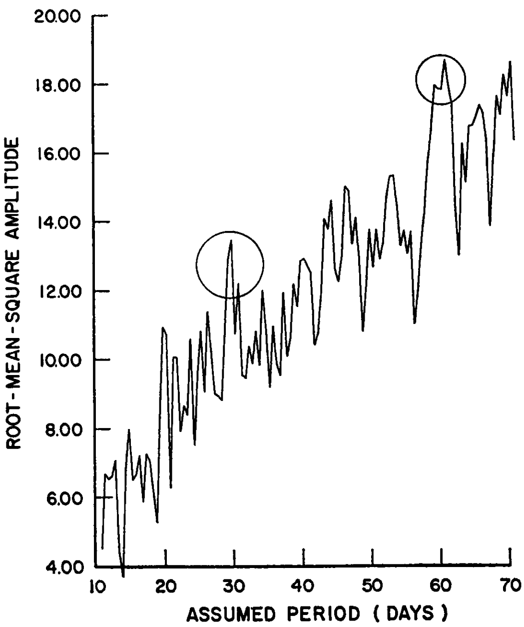

Fig. 3. Periodogram based on percentages of samples containing *Halobates*.

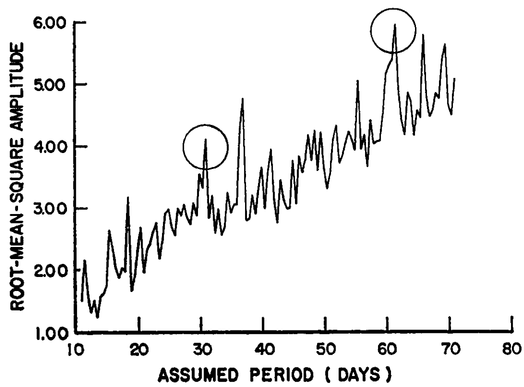

Fig. 4. Periodogram based on average number of *Halobates* taken per sample.

first the assumption, say, of a 10-day rhythm and calculates the resulting set of averages; next, one makes the assumption of an 11-day rhythm; then a 12-day rhythm; etc. Finally, one compares the amplitudes of the resulting large array of "form estimates" (Figs. 1 and 2 represent such form estimates for a ca. 29-day period). The expectation is that, if a real rhythm with a period of x days is present in the data, then the amplitude of the form estimate for assumed period-length x should be greater than that for all other neighboring values of a different assumed period.

A more thorough description of the periodogram procedure, its assumptions and limitations, has been published (Enright 1965). If a lunar periodicity is appreciable in the present data, one should expect a peak of amplitude at a period of 29–30 days, as well as a bilunar peak at 59–60 days. (More explicitly, if one assumes a sinusoidal oscillation with average lunar period, the length of the available time-series means that these peaks should be expected around positions between 27.5 and 31.5 days and between 57 and 61 days: *see* Enright 1965, p. 464). Figure 3 is based on percentage positive samples, Fig. 4 on the average number of *Halobates* per night sample, and Fig. 5 on the natural logarithm of [1.0 + avg No. sample^{-1}].

DISCUSSION

The three periodograms clearly indicate the expected lunar and bilunar peaks. In Fig. 3 there are maxima at 30 and 61 days, in Fig. 4 at 31 and 61.5 days, and in Fig. 5 at 30–31 and 60.5 days. The maxima which stand out most clearly above background are those in Fig. 5; the least clear are those in Fig. 4. Both Figs. 4 and 5 are based on the maximum amount of information in the samples, but the logarithmic trans-

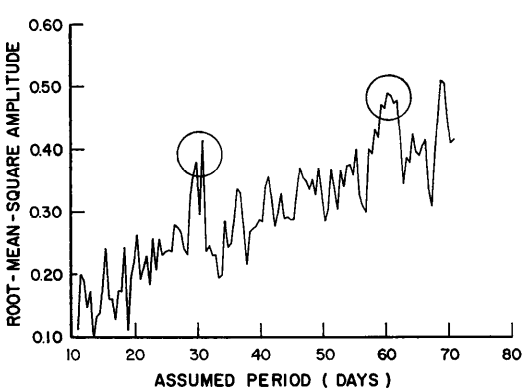

Fig. 5. Periodogram based on the natural logarithm of [1.0 + avg No. of *Halobates* per sample].

formation underlying Fig. 5 reduces the influence on the analysis of those few samples in which very large numbers of insects (up to 190) were caught. The data which led to Fig. 3 (percentage of positive samples) are completely independent of the abundance per sample, and it is encouraging to note that even in this periodogram the lunar and bilunar peaks stand out well in spite of the rather noisy background.

As another precaution, to support the interpretation that we are dealing with a real periodicity, the total data available can be divided into two or more sequential, nonoverlapping subsets, in the expectation that each subset of data should show an amplitude peak near the period value of interest (Enright 1965, p. 440). Such analyses on the first and second halves of the data led to amplitude maxima in the frequency data (corresponding to Fig. 3) at periods of 28 and 32 days (both values being greater than any other amplitude for all periods less than 42 and 38.5 days). For the first and second halves of the abundance data (corresponding to Fig. 4), peak amplitudes occurred at 28.5 and 32 days (both values being greater than any other for periods < 42 and 38.5 days). And for the first and second halves of the log-transformed abundance data (corresponding to Fig. 5), peak amplitudes occurred at 28.5 and 28.5 days (values greater than any other for periods < 47 and 42 days).

None of these analyses (nor, we believe, any other analytical methods available) can provide rigorous and irrefutable evidence for a lunar periodicity in the available data. The animals are obviously patchily distributed in both space and time, which invalidates all conventional statistical methods, and no confidence limits can be attached to the amplitude and period values of the peaks in Figs. 3, 4, and 5. Nevertheless, the internal consistency of the periodogram analyses as well as the biological plausibility of the apparent phase relationship with the moon (Figs. 1 and 2) support our initial hypothesis that *Halobates* may, indeed, be able to see an approaching net by the light of the moon, and on moonlit nights to dodge it more successfully than in darkness.

We are aware that these insects are attracted by light at night and that they may have been more attracted by deck lights on a dark night than on a bright one. However, a number of neuston tows taken recently on the RV *Washington*, using maximum and minimum deck lights on both new and full moon nights, indicated no consistent correlation between numbers of *Halobates* caught and the presence or absence of brilliant deck lights.

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