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Nest architecture of a bagworm species: Rhythmic pattern in the arrangement of sticks

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Abstract. Nest architecture of a bagworm species, *Clania crameri* was examined. Fortytwo bags (nests) were collected from the host plant, *Clerodendron indicum* and number of sticks used in each bag was counted. Furthermore, length of each stick in each nest was measured (in mm) clockwise one after another serially beginning with the longest stick. The data obtained were subjected to frequency analysis and power spectrum analysis. Results clearly reveal that the larvae of bagworms do not glue together sticks of different size randomly but with a definite pattern.

Keywords. Lepidopterans; *Psychidae*; bagworms; nest architecture; stick arrangement pattern; outlier test.

1. Introduction

Many animal species build nests. Species specific architecture of the nests provide protection to them against natural predators and unfavourable environments (Mayr 1974; Hansell 1984). Nest designs are thus adaptive and nesting behaviour of a given species has been known to be perfected through the process of natural selection (Hansell 1985).

Bagworms are a group of highly specialized Lepidopterans belonging to the family Psychidae and exhibit extreme development of sexual dimorphism. Of around 800 known species in the world (Richards and Davies 1977) it has been estimated that about 40 are available in the Indian territory (Nair 1978; Mathew and Nair 1986). The males are winged whereas females are apterous and remain in larval stage throughout their life (Mathew and Nair 1986). However, larval forms of both the sexes build cases or bags made of silk and other extraneous materials, such as leaves, spines, stems and twigs. What is peculiar about them is that until pupation, larvae move along with their bags. These nests can thus rightly be called as mobile nests. The present study examines the architecture of the nest of the bagworm, *Clania crameri* (Psychidae).

2. Materials and methods

2.1 *Study site*

The study was conducted on the campus of Pandit Ravishankar Shukla University, Raipur (Lat.: 21°14'N; Long: 81°38’E) in the month of August. Plants in the

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campus were examined for bagworm infestation (figure 1) and list of host plants was prepared (table 1).

Figure 1. **(A)** A nest of the bagworm *in situ.* **(B)** A nest showing an active larvae.

Table 1. List of host plants and respective degree of infestation by bagworms.

Host	Family	Type	Intensity*
Thuja orientalis	Coniferaceae	ST	s_1
Clerodendron indicum	Verbenaceae	S	s_3
Hibiscus sp**	Malvaceae	S	s_1
Acaccia nilotica	Mimosaceae	MT	s_2
Cassia tora	Caesalpiniaceae	H	s_1
Rosa sp.**	Rosaceae	C	s_1
Punica granatum	Punicaceae	ST	s_2
Jasminum sambac	Oleaceae	S	s_1
Quiqualis indica	Combretaceae	S	s_1

* Based on visual score assignment system; S_0 = no infestation; s_1 = low infestation characterized by at least one larva or pupa visible on the host plants; s_2 = medium infestation; s_3 = high infestation.
“Species not identified.
ST, small tree; S, shrubs; MT, medium tree; H, herb; C, creepers.

2.2 *Morphometric study*

One patch of a garden which was heavily infested with bagworms was chosen as the site for further study. Fortytwo bags with live larvae were collected from the host plant, *Clerodendron indicum* and subjected to morphometric examination. Data were recorded on weights of nest, stick, larvae, diameter of nest and number of sticks in a nest. The larvae of *C. crameri* invariably use one stick which is disproportionately longer than other. The length and diameter of each stick in each nest was measured clockwise starting from the longest one.

2.3 *Statistical analysis*

The nests built by bagworms were found to be composed of sticks laid longitudinally to form a cylinder with openings at each end. If a cross section is taken holding the nest vertically a circular disc will be obtained with number of sticks lining its periphery and each stick connected to the adjacent neighbours in both the directions (figure 2). The angle between the positions of the longest stick and successive sticks was obtained along an axis passing through the center and was designated as divergence angle (figure 2). The following formula was used to obtain the divergence angle:

$$\sum_{i=1}^{n-1} \phi_i = \omega \times \sum_{i=1}^{n-1} P_i$$

where, $\omega = 360^o/n$, n = number of sticks used in a bag, P_i =clockwise position of stick from the longest one ($P_n = 0$).

The position of the longest stick was considered as the reference point, hence is equal to 0° or 360°. Thus for each stick a divergence angle in degree was computed with reference to the position of the exceptionally longest stick. It was observed that bagworms use sticks of different length in a particular order that

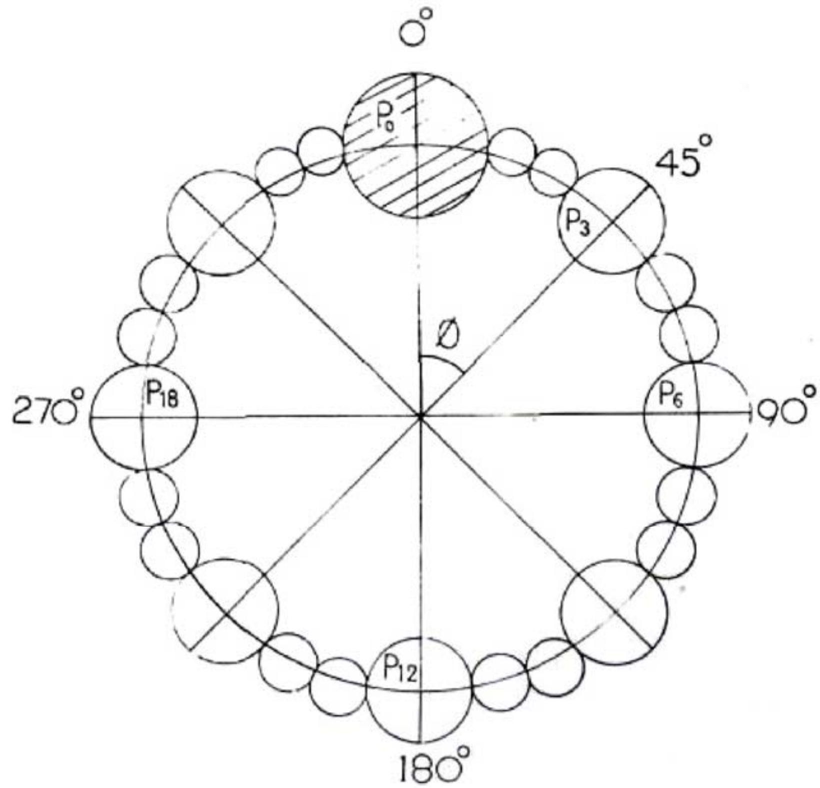

Figure 2. A schematic representation (not scaled) of transverse section of a nest showing stick arrangement pattern in bagworm, *C. crameri.* In this diagram 24 sticks are shown to be glued together in a nest and stick arrangement pattern is shown to be periodic with τ = 45°. The position of the sticks are shown within the circle with a number subscripted to "*P*". For example, the divergence angle for the 3rd stick (P_3) after the longest one (P_0, hatched circle) is of 45°. In this example, relatively longer sticks are used in positions P_3, P_6, P_9, P_{12}, P_{15}, P_{18}, P_{21} and the longest one at P_0.

appeared to repeat several times. Data on stick lengths were subjected to spectral analysis and prominent periods (τ) in repeated arrangement patterns of the sticks for each bag was determined using divergence angle for P_i (De Prins and Malbecq 1983). Thus, "prominent period" corresponds to the prominent amplitude of the validated cycle in the selection of slick size.

The rarity of the longest stick in each nest was examined with the help of the outlier test given by Dixon (Snedecor and Cochran 1994). The test is based on order statistics. The samples were arranged in an increasing order, X_i. being the lowest and X_n the highest value. The best test criterion and levels of α vary with the sample size as well as the degree of extremeness of the observation in a sample (Dixon and Massey 1983). For the present study, with 15 ≥ n ≤ 22 (table 4). The criterion for the exceptionally longest stick is:

$$\frac{X_n - X_{n-2}}{X_n - X_3} \quad \text{at } \alpha \text{ level} = 0{\cdot}20$$

3. Results and discussion

3.1 *Host plants*

Table 1 depicts the name of host plants and their degree of infestation by the bagworms during the period of field study. Nests are shown in figure 1. The *Clerodendron indicum* was found to be the most heavily infested with bagworms.

3.2 *Nest morphometry*

Table 2 shows mean ± 1 SE values for each variable based on data obtained for all the 42 nests. The values for coefficient of variation of nest diameter, stick number, length of the longest stick and larval length appear to be low and consistent as compared with those of nest weight, stick weight and larva weight (table 2).

3.3 *Frequency of stick lengths and diameters*

Results of frequency analysis on stick length and stick diameter are summarized in table 3. Bagworms preferred to use sticks between 18–35 mm in length and

Table 2. Summary of morphometry data of all nests ($n = 42$).

Variable (unit)	Mean ± SE	Coefficient of variation
Nest weight (mg)	0·805 ± 0·037	30·00
Nest diameter (mm)	7·431 ± 0·107	9·31
Stick number	18·238 ± 0·285	10·12
Stick weight (mg)/nest	0·366± 0·016	27·73
Stick length (mm)*	41·524 ± 1·031	16·1
Larva weight (mg)	0·395 ± 0·024	40·14
Larva length (mm)	21·640 ± 0.416	12·45

*Of the longest stick.

Table 3. Frequency distribution of the sticks ($N = 766$) retrieved from 42 nests in different length and width classes.

Width (mm)	Length (mm) 9	18	27	36	45	54
0·9	2*	25	19	5	2	2
1·2	19	133	96	23	1	0
1·5	16	155	100	31	1	1
1·8	8	70	51	20	5	1
2·1	0	0	0	0	0	0
2·4	0	0	0	0	0	0
2·7	0	0	0	0	1	0

* Frequency

between 1·2–2·0 mm in diameter more frequently; of the total of 766 sticks, 585 were in this range. The highest number of slicks were used in the range of 18–26 mm length and 1·5–1·7 mm diameter. It was observed that *C. crameri* uses at least one stick which is disproportionately longer than the remaining slicks in the nest. Is it an artifact that emerges as a result of the natural variability in the

Table 4. Nestwise per cent deviation in the size of the longest stick from the shortest stick and the mean. Summary of outlier test.

Nest No.	No. of sticks in each nest	Stick length			% difference in the size of the longest stick from the shortest stick	Mean	Outlier test	
		Shortest stick	Mean	Longest stick			Dixon criterion	α value
01	18	20	30·4	49	145·00	61·18	0·444	< 0·10
02	15	11	22·3	32	190·00	43·49	0·385	> 0·20
03	15	15	25·1	36	140·00	43·42	0·533	< 0·05
04	15	16	25·4	36	125·00	41·73	0·467	< 0·20
05	18	13	25·4	39	200·00	53·54	0·400	< 0·20
06	19	20	28·9	43	115·00	48·78	0·273	> 0·20
07	19	14	26·4	44	214·28	66·66	0·500	< 0·05
08	22	12	26.9	40	233·33	48·69	0·182	> 0.20
09	20	16	24·8	33	106·25	33·06	0·143	> 0·20
10	19	17	24·9	42	147·05	68·67	0·458	< 0·10
11	17	19	25·6	38	100·00	48·43	0·389	< 0·20
12	17	18	27·5	44	144·44	60·00	0·478	< 0·10
13	18	16	26·9	43	168·75	59·85	0·231	> 0·20
14	18	13	26·2	47	261·53	79·38	0·464	< 0·10
15	19	16	23·9	44	175·00	84·10	0·519	< 0·02
16	17	19	24·5	37	94·73	51·02	0·438	< 0·10
17	19	20	26·6	42	110·00	57·89	0·350	< 0·20
18	19	14	23·1	31	121·42	34·19	0·083	> 0·20
19	16	12	19·5	27	125·00	38·46	0·067	> 0·20
20	21	17	26·7	43	115·94	61·04	0·250	> 0·20
21	21	15	27·3	44	193·33	61·17	0·179	> 0·20
22	20	19	26·7	35	84·21	31·08	0·385	< 0·20
23	21	17	29·5	44	158·82	49·15	0·348	< 0·20
24	18	20	28·4	39	95·00	37·32	0·235	> 0·20
25	22	16	24·7	41	156·25	65·99	0·435	< 0·05
26	18	17	29·8	42	147·05	40·93	0·200	> 0·20
27	19	13	21·1	29	123·30	37·44	0·167	> 0·20
28	17	19	28·1	55	189·47	95·72	0·600	< 0·005
29	16	18	25·8	39	116·66	51·16	0·263	> 0·20
30	19	17	28·4	49	188·23	72·53	0·464	< 0·05
31	17	17	24·1	36	111·76	49·37	0·278	> 0·20
32	17	19	31·1	49	157·89	57·55	0·370	> 0·20
33	17	17	31·1	52	205·88	67·20	0·406	< 0·20
34	16	25	33·0	41	64·00	24·24	0·167	> 0·20
35	18	21	27·9	42	100·00	50·53	0·100	> 0·20
36	18	18	30·1	49	172·22	62·79	0·310	> 0·20
37	17	18	25·8	46	155·55	78·29	0·577	< 0·01
38	19	16	24·4	33	106·25	35·24	0·133	> 0·20
39	17	19	24·8	42	121·05	69·35	0·545	< 0·02
40	19	11	28·6	46	318·18	60·83	0·280	> 0·20
41	17	21	27·5	42	100·00	52·72	0·250	> 0·20
42	22	19	34·7	59	210·52	70·02	0·135	> 0·20

sticks used for building the nest? When the sticks are of varying lengths one among them has to be longer by default but not by design, may be the obvious conclusion. However, the Dixon test (Snedecor and Cochran 1994) clearly reveals that in approximately 50% of the total nests studied (table 4), the longest sticks are outliers. Therefore, it is reasonable to suggest that this phenomenon may have some potential adaptive significance.

3.4 *Periodicity in slick arrangement pattern*

Table 5 illustrates prominent periods obtained for each nest (bag) after subjecting the data on stick length to power spectrum analysis. For example, if prominent period is 45° that means a particular pattern of stick arrangement repeats itself

Table 5. Summary of prominent periods obtained for stick lengths of each nest by spectrum analysis.

Nest No.	τ	Nest No.	τ
01	90·00	22	90·00
02	120·00	23	45·00
03	60·00	24	39·90
04	180·00	25	39·90
05	45·00	26	180·00
06	45·00	27	39·90
07	45·00	28*	—
08	72·00	29	180·00
09	45·00	30	72·00
10	39·90	31	45·00
11	90·00	32	45·00
12	90·00	33	120·00
13	120·00	34	45·00
14	39·90	35	72·00
15	45·00	36	45·00
16	45·00	37	45·00
17	45·00	38	51·30
18	180·00	39	120·00
19	51·30	40	60·00
20	39·90	41	45·00
21	36·00	42	180·00

*Data for this nest were flat, prominent period could not be obtained.

after completion of each divergence angle of 45°. Results indicate that prominent period (τ) was of 45° in at least 14 nests (table 5). Furthermore, prominent periods were obtained for another 4 nests at its second multiple, 90° and for 5 at its fourth multiple, 180°. However, in 30 nests the periodicity of a relatively longer stick being used was found to be between 36°–72°**,** The results clearly show that in an otherwise apparently disordered nest a repeating pattern emerges in the length of the sticks used to build the bag of the larval stage of the worm. However, it is difficult to explain the mechanism that generates the pattern. The present study is also not adequate enough to answer several other questions. Does bagworm glue the longest stick first? Is the observed nesting pattern sex and species specific?

Obviously more intensive studies are required to resolve these and other questions.

However, for the time being it may be construed that the selection of sticks of a particular dimension and their gluing in the nest may not be random; rather the bagworms might have developed some mechanisms to build nests with a definite pattern in response to environmental factors, like direction of wind, rain etc., during their evolution.

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