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Submerged beach ridge lineation and associated sedentary fauna in the innershelf of Gopalpur coast, Orissa, Bay of Bengal

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Detailed echosounding and side-scan sonar surveys coupled with SCUBA-diving operations in the inner-shelf region of Gopalpur, Orissa coast revealed the existence of a submerged NE-SW trending ridge lineation between the isobaths of 25 and 35 m. Morphology of this ridge indicates parallel to sub-parallel pinnacles with variable relief and widths. Very steep scarps in the leeward side of the seabed at many places are attributed to large-scale seabed scouring. Diving operations recovered extensive live sedentary fauna such as sponges, gorgonians, soft and hard corals along with rock encrustations from the ridge features. X-ray diffraction analysis of the rock samples revealed the mineral composition of quartz, feldspars, and low and high magnesium calcite, suggesting the morphological features to be of beach sandstone formation. High-resolution shallow seismic records indicate that the features are from the hard subsurface reflector, probably of Late Pleistocene. The composition of sedentary fauna is discussed and its association over the features is attributed to the availability of porous beach sandstone which favours growth in euphotic zone.

THE continental shelf of Gopalpur coast, Orissa had been earlier studied by several workers in different aspects of relict morphological features related to Late Quaternary sea-level variations, sedimentology and mineralogy^{1–9}. These studies indicated the presence of topographic highs, palaeo channels, relict sediments, etc. and attributed them to the low stand phases of the sea at different water depths of 20–30, 50–60 and 100 m, due to sea-level oscillations during Late Pleistocene–Holocene. Under a collaborative programme between Regional Research Laboratory, Bhubaneswar and Regional Centre of National Institute of Oceanography, Visakhapatnam for collection of marine organisms off Orissa coast under the DOD funded project, Potential drugs from sea, a number of sedentary fauna were collected from submerged rocks off Gopalpur coast during several occasions of underway investigations comprising echo-sounding, side-scan sonar and shallow seis-

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mic profiling to locate the submerged rock outcrops. Though the submerged topographic features were reported by some of the above workers in the innershelf regions of Gopalpur coast, precise lineations with boundaries and echo characteristics of the features are not available so far. In order to delineate the ridge lineation to facilitate the recovery of samples of the sedentary faunal resources, detailed geophysical surveys coupled with SCUBA-diving operations were carried out using GPS. Under this programme, Bapuji *et al.*¹⁰ reported a number of sponges from these locations. This paper presents the morphological features of the lineation off Gopalpur for a stretch of 25 km and the bio-geodistribution of different sedentary faunal groups on these ridges.

The study area covers the innershelf region between Gopalpur in the north and Baruva in the south. Sona class fishing trawler (15 m long and 5 m wide) was used for all survey operations. Echotrack model DF 3200MKII, EG&G Model 260 side-scan sonar, and EG&G seismic profiler (Sparker) and Global Positioning System (GPS) model JLR 4400 were used for bathymetry, seabed image, sub-bottom information and position fixing, respectively. Closely-spaced survey lines with an interval of about 200 m were taken across the shelf from 25 to 35 m isobaths. Constant trawler speed was maintained throughout the survey operations. SCUBA-diving operations were carried out for recovery of sedentary organisms and associated rock encrustations. Underwater video documentation and observations were recorded about different faunal assemblages. X-ray diffraction analysis was done for the rock sample to obtain the mineral composition. Radio carbon dating for the rock sample was done by the Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow. Sediment samples collected at a few locations near ridge were subjected for Ro-tap sieving analysis to obtain the mean grain size of the samples.

High-resolution echograms obtained in the study area helped in demarcating a lineation of pinnacled reef system trending nearly NE-SW in the innershelf between Gopalpur and Baruva (Figure 1). This lineation occurs in general at water depths between 25 and 35 m. Based on the location and nature of the pinnacled reef, the lineation has been divided into two major segments, A and B (Figure 1), separated by a distinct break in continuity of its trend off river Bahuda near Sonapurampet. Segment A (14 km) is subdivided into three sectors, I, II and III, based on the nature and morphological characteristics of pinnacles. Figure 2 *a* shows two widely-spaced and less-prominent pinnacled structures having relief of 1 and 3 m in sector A-I, whereas the echograms of sector A-II depict an enhanced growth in the pinnacle relief to the order of 3–6 m, with a prominent trough in between (Figure 2 *b*). An important observation made in this sector is a sharp increase in the seabed depth by about 4–5 m, enhancing the seaward relief to the tune of about 5 m. A well-defined seaward scarp is noticed in almost all the echo-

grams obtained in this region. Sector A-III is marked by pinnacles of narrow and low relief (Figure 2 *c*).

Segment B, covering a length of about 11 km parallel to the coast, comprises prominent multiple-pinnacled reef. These are closely spaced and reveal a dense reef system (Figure 2 *d* and *e*). Sharp increase in the seabed depth to about 13 m is recorded in this segment. Reefal feature has undergone high erosional activity resulting in irregular and sharp, multiple pinnacles which include some shoulder pinnacles on the scarps of the reef system.

Sonographs obtained in the region of sector A-I reveal two sub-parallel ridge lineations separated by well-defined sandy sediment floor of 50–70 m width (Figure 3 *a*). Offsets are recorded all along the general lineation. Sonographs of the sector A-II are denoted by a single lineation with isolated outcrops at some places (Figure 3 *b*). Sonographs of sector A-III show narrow (100–200 m) and insignificant features. The sonographs related to segment B show massive and dense occurrence of outcrops to the extent of 300–400 m. In general, the sonographs of all the regions show sharp edges, knobs, cuttings and deep trenches (2–4 m).

High-resolution shallow seismic records obtained at few locations show the occurrence of acoustically strong, well-stratified uniform bedding up to 29 m depth, wherefrom the seaward dipping morphological feature starts appearing (Figure 4). The top bedding layer again continues seaward from 33 m with a very gentle gradient. From 29 to 33 m, the seabed is occupied by a prominent reflector with a strong acoustic impedance, having a relief of about 3 m shoreward and 5–6 m seaward. Records show that the younger sediment layer on either side overlaps the feature which appears to be cropped up from the pre-existing sub-bottom layer. This feature is buried under a sediment layer of 5–10 m thickness in the region off Bahuda river.

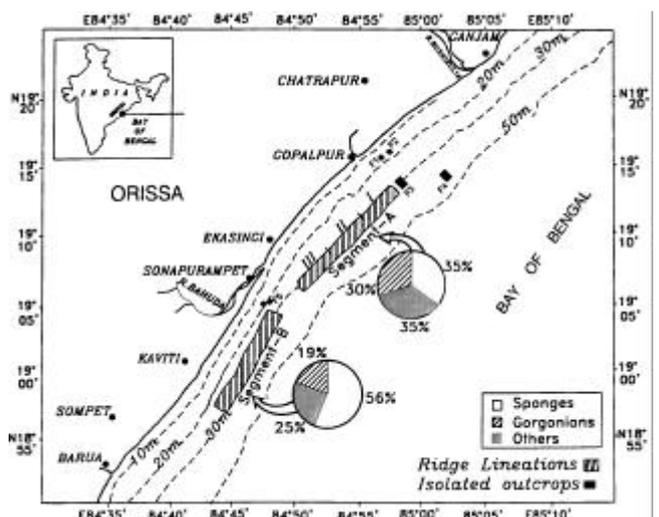


Figure 1. Location map of beach ridge lineations and species composition of sedentary fauna off Gopalpur.

Hard sandstone encrustations were also recovered from the ridge feature by diving operations. Physical observation of the rocks indicated that the rock is compact and hard by the aggregation of coarse clastic detrital sand with carbonate matrix. The residue left out after hydrochloric acid test showed only beach sand grains. X-ray diffraction analysis of the rock sample indicated the presence of quartz and feldspar as major constituents and the low and high magnesium calcite as minor constituents. ¹⁴C radio carbon dates obtained for the rock sample (from 28 m depth, 19°10.94'N, 84°54.94'E) revealed the age of 22210 ± 1130 yr B.P.

The sedentary faunal distribution on the ridges is based on the collection (number of divers), observation and video documentation. The data present a qualitative distribution of sedentary macro-fauna subject to limitations of study due to accessibility of reefal locations like cliffs, steep scarps, trenches (up to 4 m depth) and safety of divers (Figure 5 a, b). The faunal species are presented in three groups, viz. sponges, gorgonians (including sea whips) and others which include soft and hard corals, antipatharians and hydroids. The data are presented in a pie diagram in Figure 1.

Echograms and sonographic data in general, reveal the occurrence of NE-SW ridge (25 km, excluding the break in between) lineation parallel to the shore between the isobaths of 25 and 35 m. This lineation starts at 29–30 m depth at the northern point off Gopalpur and gradually attains 25 m depth at the southern end of the study area (Figure 1). Sharp-edged pinnacles with single/multiple peaks suggest that the submerged ridge system had undergone severe erosional activity. Occurrence of these features at these depths indicates the relict morphological features that were uncovered by modern sediments. Earlier studies carried out over these features attributed them to beach-sand ridges formed during the regressional phase of Late Pleistocene glaciation¹⁻³. Echograms and sonographic data indicate a well-marked lineation consisting of two major segments with a prominent break in between. It is surmised from the echo-characteristics and sonographs that two prominent beach ridges parallel to each other run initially for some length and gradually merge with each other, forming a single lineation (Figure 3 a and b).

It appears from the echo data that the relief of the ridges gradually increased from north to south, the

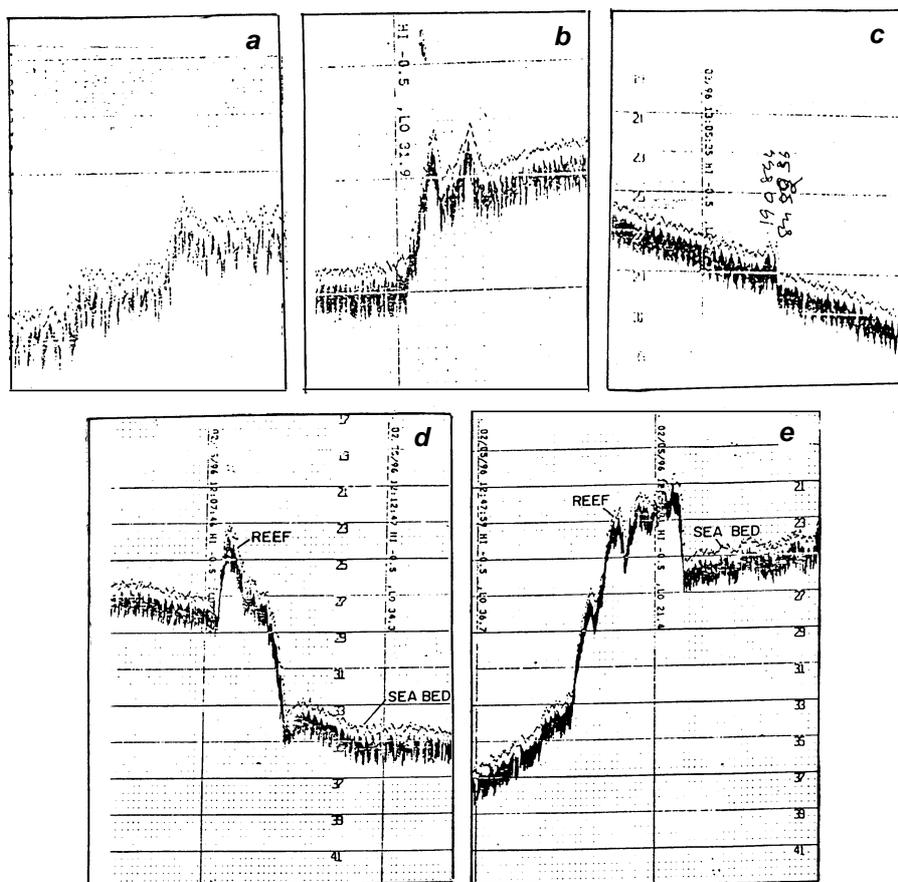


Figure 2. Echograms of pinnaced reef system showing *a*, relief of 1–3 m in sector A-I in segment A.; *b*, relief of 3–6 m in sector A-II in segment A; *c*, relief of < 1 m in sector A-III in segment A; *d* and *e*, multiple-pinnaced reef showing well-defined scarps to the order of 10–13 m in segment B.

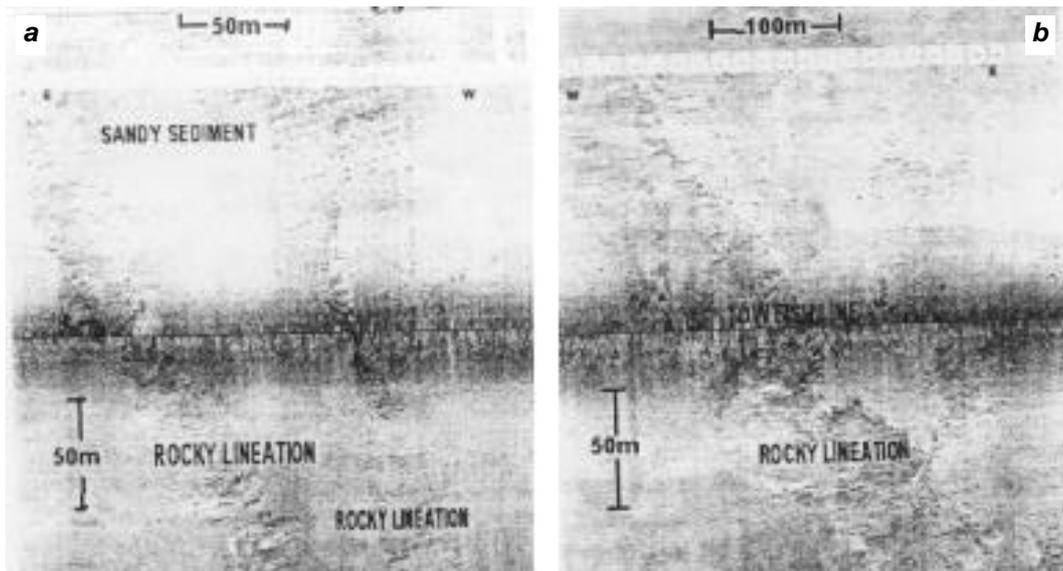


Figure 3. Sonographs of the submerged beach ridge system showing *a*, two parallel to sub-parallel lineations in sector A in segment A; and *b*, single lineation in sector A in segment A.

maximum being noticed in segment B, to the tune of about 13 m (Figure 2 *c*). Echo data show that the lee side seabed had gone down due to some vertical movements (Figure 2 *b* and 2 *c*). However, shallow seismic records show that the reef features had cropped up from the sub-bottom layers, suggesting no indication of vertical movement. A large-scale seabed scouring must have taken place at the foot of the submerged reef, which is evidenced by the occurrence of prominent troughs at the base of the reefs, resulting in the formation of prominent scarps (Figure 2 *b* and *c*). At places, the occurrence of shoulder peaks on the seaward slope of the pinnacled reef envisages the action of large-scale erosion. To develop such kind of scarps, high current activity might have prevailed in this area, which is also supported by long shore displacement of sediments to the order of 1.5 million tons per year along Gopalpur coast². Based on the long-shore energy flux equation, Chandramohan and Nayak¹¹ have estimated a high northerly drift of sediment to the tune of $15\text{--}20 \times 10^5 \text{ m}^3$ per year, which shows continuous sediment transport from the south. Incongruence of inland mineralogy to that of shelf mineralogy reported in the south-east coast of India¹² also suggest continuous sediment transport from the offshore source, which substantiate the northerly drift caused by littoral current. Relatively high current speed of 20–50 cm/s reported in this area¹³, must have played a major role for the development of large-scale scarps. Occurrence of coarse clastic sediment in the study area also suggests that the area had experienced high-energy conditions⁵. Presence of well-preserved ripple marks noticed at some locations in the vicinity of the ridge also indicates the prevalence of high-energy environment in the area. All these evidences suggest the possibility of large-scale seabed scouring,

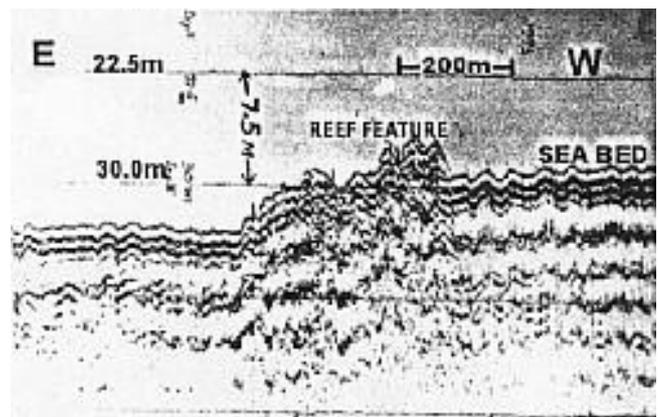


Figure 4. High-resolution shallow seismic record showing the submerged morphological feature over segment B of the lineation.

causing the development of scarps. However, extensive beach erosion during Holocene subaerial conditions is not ruled out.

X-ray diffraction analysis of rock samples recovered from the ridge formation indicates the beach rock/beach sandstone composition of the ridge system. Occurrence of the calcium carbonate matrix in the samples suggests that the lithification of beach sand was done in the sub-aerial conditions, as the calcite precipitation normally takes place in the groundwater regions. Such rock formations in the littoral waters of other parts of this coast are attributed to sea-level low strandlines¹⁴.

Apparent discontinuity of the lineation off Bahuda river may be attributed to fluvial regime which had not favoured the formation of beach rock ridge, due to continuous flow of water during the sub-aerial exposure of this area. The reported occurrence of buried features

under 5–10 m thick sediments off Bahuda river² suggests that the beach rocks must have developed over the pre-existing rocky formations of the area.

The higher age of radio carbon dates ($22,210 \pm 1130$ yr B.P.) for the beach sandstone indicates that the beach

ridges were not formed during the Holocene transgression period. Radiocarbon dates of the seabed rocks from different parts of eastern Indian shelf at different depths reported by several workers, range from 8000 to 18,390 yr B.P., the maximum being attained at 125 m depth^{15–18}. Worldwide studies also indicate that the sea level retreated maximum between 121 and 130 m depth about 18,000 yr B.P. during Last Glacial Maxima (LGM)^{19,20}. The relatively higher age is attributable to the formations related to regressional phase of last glaciation and needs further confirmation.

Though both the segments in the lineation showed good distribution of species of different groups, dominance of certain groups in some locations is recorded. Relatively rich, soft coral beds are recorded in sector A-I, whereas rich species diversity of gorgonians is noted in sector A-II. Both these locations are characterized by moderate relief with smooth to rugged sea-floor in the troughs.

Sponges are dominant both in diversity and density in segment B at some locations, as given in the Figure 1. The number of species collected from this region showed nearly two-fold increase. This may be due to high relief of the pinnaced reef structure favoured by abiotic factors such as relatively clear water, sunlight, and better water movement on reef tops (22–25 m peak depth). Though the area is considered to be a high-energy environment, the dominance of sponges in segment B indicates the existence of some protected regions, perhaps conspicuous troughs within the segment, which favour the growth of sponges. Presence of hard corals was recorded in the southern edges of this region. At places the lineation/ridge is well-characterized by cliffs and trenches rich with biota. The co-habitat of different faunal groups is revealed in the video documentation (Figure 5 c).

A NE-SW trending beach ridge lineation is delineated in the innershelf between 25 and 35 m water depth with an apparent discontinuity off Bahuda river, which was related to sea-level oscillations. The nature and morphology of this ridge system suggest a large-scale seabed scouring due to high erosional activity caused by high littoral current activity. Radiocarbon dates of the ridge rocks and seismic records indicate that the beach ridge system was formed during the regression phase of last glaciation. Irregular surfaces of highly porous beach sandstone formations seem to have favoured the rich growth of sedentary fauna like sponges, gorgonians, hard and soft corals, etc. under euphotic conditions on this substratum. Preliminary observations show possible extension of the lineation which needs further exploration and recording of biological resources.

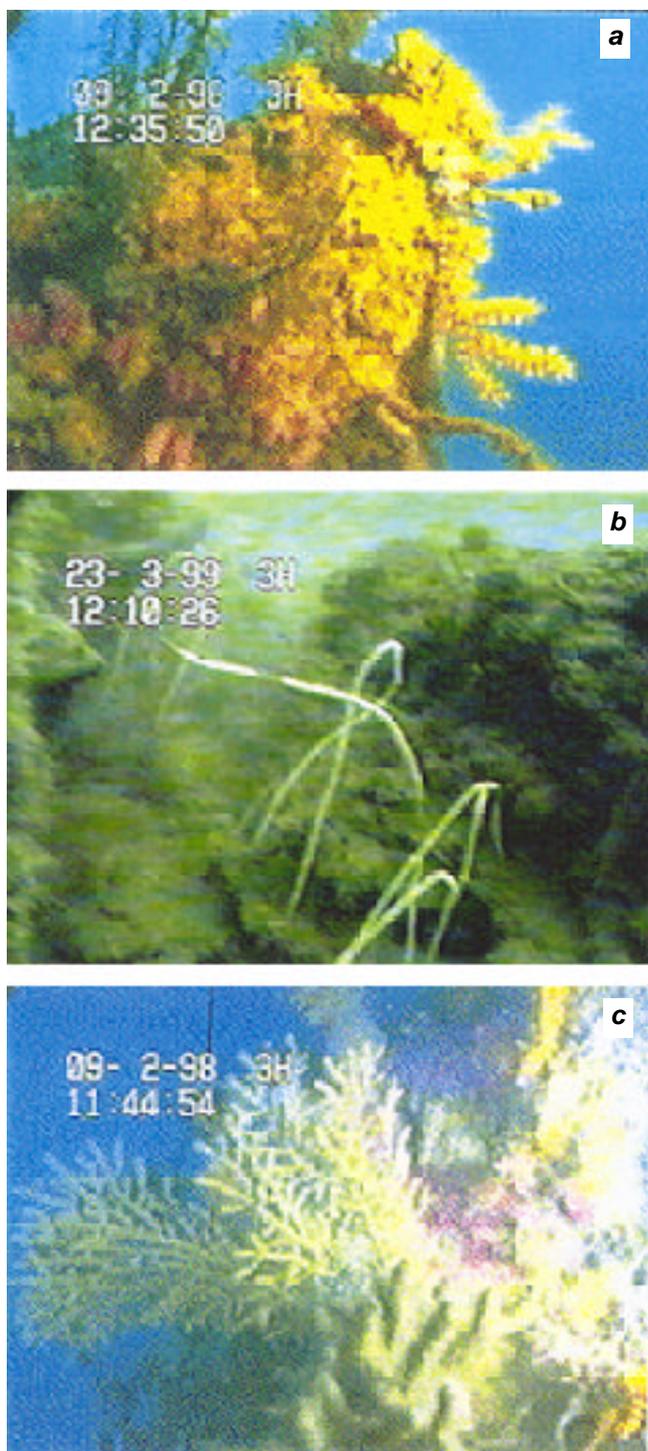


Figure 5. Underwater photographs showing *a*, sedentary fauna over cliffs of the submerged ridge lineation; *b*, deep trenches up to 4 m and growth of seawhips; and *c*, co-habitat of different groups over the ridge lineation.

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Insect visits to some bamboos of the Western Ghats, India

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Bee visits in six tropical woody bamboos (Bambusoideae: Poaceae) – *Bambusa bambos* (native), *Bambusa* sp., *B. vulgaris* (both cultivated), *Ochlandra ebracteata*, *O. scriptoria*, *O. travancorica* (all endemic) were studied. The bees were predominantly of order Hymenoptera and belong to genera *Apis*, *Halictus*, *Trigona*, *Braunsapis* and *Ceratina*. In *Ochlandra* spp and *B. vulgaris* the bees visited the florets only at the male stage. In *B. bambos* and *Bambusa* sp., the florets are wide opened and the male and female organs are exposed together. It is presumed that pollination by bees can occur in such species. Grouping of spikelets based on nature of opening of florets is also discussed.

GRASSES are traditionally considered as wind-pollinated (anemophilous). The peculiar floral features such as reduction of petals into lodicules, absence of nectaries, many flowered inflorescences, large anthers producing abundant uniform pollen grains with smooth exine, thick intine, small germ pore and fewer number of ovules are

factors facilitating anemophily¹. These factors are often interpreted as adaptations for wind pollination to increase efficiency². Knuth³, who studied insect visits to grasses in detail, attributed such visits to the pursuit of food such as pollen or sweet secretions and explicitly stated that all species of grasses are distinctly anemophilous. Some of the later workers^{4–6}, on the contrary, have shown that entomophily does occur at least in a few grass species. In the pioneering study by Soderstrom and Calderon¹ on two South American understory bambusoid grass genera *Olyra* and *Pariana*, insect pollination was suspected.

In woody bamboos, insect visits were reported in a few species such as *Bambusa polymorpha*⁷, *Gigantochloa albociliata*⁸, *Bambusa vulgaris* var. *vittata*⁹, etc. *Apis* and *Trigona* bees were observed removing pollen from *Schizostachyum zollingeri*^{10–12}, *Apis mellifera* and *Allo-dape marginata* from the dichogamous *Ochlandra travancorica*¹³ and *Dendrocalamus strictus*¹⁴ during the male phase, as well as *Trigona biroi* Friese and *Halictus* sp. from *Bambusa vulgaris*¹⁵. In this communication, observations on floral biology and bee visitation during the reproductive phase of six woody bamboo species, viz. *Bambusa bambos* (L.) Voss, *B. vulgaris* Schrad. ex Wendl., *Bambusa* sp. (indetermined), *Ochlandra ebracteata* Raizada & Chatterji, *O. scriptoria* C. E. C. Fischer and *O. travancorica* (Bedd.) Benth., belonging to the tribe *Bambuseae* under the subfamily Bambusoideae of the family Poaceae are presented. Of the six taxa *B. bambos* is native, from India to China, *B. vulgaris* and *Bambusa* sp. are cultivated, while the three *Ochlandra* spp are endemic to the Western Ghats¹⁶.

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