

and thorium when operated in spectrometric mode; however, the same instrument can also be used in integral mode for *in situ* gross gamma radiation counts. These counts were recorded using a grid pattern of 0.5 m × 2.5 m over an area of 2500 sq. m, in the zone of intense alteration. The clusters of higher counts (in micro roentgen/h) were marked as shown in Figure 3. It was observed that higher counts were confined to areas where the basic rock occurs. Also, the highest counts were recorded at the contact of polymictic conglomerate and gritty rock in conjunction with basic rock possibly indicating a weak zone.

Features of brecciation are distinctly observed in N–S trending quartz porphyry dyke lying northeast of the mineralized area suggesting the role of faulting in localizing uranium (Figure 2). This quartz porphyry dyke is emplaced within the polymictic conglomerate. Minor but indistinct signs of brecciation are also seen in the basic dyke exposed to the west of the quartz porphyry dyke.

Radiometric analysis of samples collected from the Sindreth altered rock zone is given in Table 2.

Geochemically, the uranium mineralized rocks are enriched in rare earth elements (REE), Pb and V (Table 3). The correlation coefficients calculated for U₃O₈ versus REE (total), Pb, Ce and V show strong positive correlation of 0.95, 0.97, 0.96 and 0.86 respectively, indicating enrichment of uranium and of these elements as a coeval event, possibly due to hydrothermal solution activity.

U/Th ratios are indicators of mobility and the concentration of uranium in a geological system. A study of these ratios in the area has so far shown that the conglomerate and basic rock acted as hosts for uranium mineralization and these rocks show elevated values compared to average values, whereas rocks such as granite, felsic rocks and phyllites show lower U/Th ratios indicating remobilization of uranium from these rocks.

The volcanogenic-type uranium deposits are known in many parts of the world, viz. Streltsvokye-Antei, Russia; Dornot, Mongolia and McDermitt, USA⁴. In this context, uranium mineralization reported in Neoproterozoic volcano-sedimentary Sindreth Basin appears to be very significant and it has opened up a new geological domain for the uranium exploration in southwestern Rajasthan.

The initial data collected from the Sindreth uranium-mineralized area are encouraging. However, no uranium mineral has been observed so far in the samples. The alpha tracks of mineralized samples reveal dispersed nature of uranium which could result due to the highly oxidized nature of rocks on and near the surface. At depth, below the zone of oxidization, there is probability of finding discrete uranium minerals.

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Seed predators of an old-world tropical deciduous tree (*Terminalia bellirica*: Combretaceae) in wet habitats of the Western Ghats, India

Palatty Allesh Sinu*

Department of Animal Science, School of Biological Science, Central University of Kerala, Padannakad PO, Kasaragod 671 328, India, and Ashoka Trust for Research in Ecology and the Environment, Royal Enclave, Srirampura, Jakkur Post, Bangalore 560 064, India

In this study I assess the diversity of seed predators, intensity of seed predation, germination success and survival of germinated cotyledons of an old-world tropical deciduous tree (*Terminalia bellirica*) in wet habitats of the Western Ghats biodiversity hotspot. Primary arboreal seed predators were Malabar giant squirrel (*Ratufa indica*) in evergreen forests and an unidentified weevil species (Curculionidae: Coleoptera) in wet evergreen forests and coffee agroforests. Kernel predation by weevils was higher in coffee agroforests (43.7%) compared to wet evergreen forests (25%). In both habitats, two terrestrial rodents, the Malabar Spiny Dormouse (*Platacanthomys lasiurus*) and an unidentified rat species (*Rattus* sp.) were the primary seed predators on the ground. Herbivory by ants resulted in low survival of germinated cotyledons in both habitats. Ants consumed a greater amount of germinated cotyledons in coffee agroforests compared to evergreen forests.

Keywords: *Ratufa indica*, seed predation, *Terminalia bellirica*, tropical plants, wet habitats.

IN tropical climates, seeds of most wild plants have to undergo a series of events that may affect the natural recruitment¹. This includes pollination, seed dispersal,

*For correspondence. (e-mail: sinu@atree.org)

pre- and post-dispersal seed predation. As an important selective force, seed predation can affect plant community structure, population density, species richness and spatial dynamics of plant recruitment in the tropics¹⁻⁸. Ecosystem processes, such as habitat fragmentation, disturbance and transformation can affect the seed predator fauna, predation rate and eventual recruitment of tropical plants⁸. Plant-animal interactions which occur during pollination, frugivory, seed dispersal and seed predation are critical in determining reproductive success and seedling recruitment of the plant species.

Terminalia bellirica (Gaertner) Roxb. (Combretaceae) is an ecologically and medicinally important deciduous canopy tree species having wide distribution throughout India, but with limited distribution and density in evergreen forests of the Western Ghats. I studied the species-specific natural history and basic ecological studies of *T. bellirica* to understand the arboreal and terrestrial seed predator assemblages and to identify the factors that limit recruitment of the species both at the seed and seedling stage in two habitats, evergreen forests and coffee agroforests. As *Ratufa indica* (Malabar giant squirrel) interacted with the plant frequently for frugivory, its foraging behaviour on *T. bellirica* was studied in detail.

The study was conducted in the Sringeri taluk (12°55'–13°54'N and 75°01'–75°22'E, average 725 m amsl), central Western Ghats, Karnataka. The taluk has a landscape matrix of secondary evergreen forests of two types: Forest Department-managed reserve forests and farmer-managed Soppinabetta forests (see Sinu *et al.*^{9,10} for more details on Soppinabetta forests of Sringeri). Some farmers grow coffee as an agroforestry system under the shade of wild tree species, in modified Soppinabetta forests. Annual rainfall typically ranges between 4,000 and 6,500 mm (ref. 11) but occasionally can exceed the range (2009 rainfall = 7,182 mm; Sringeri Municipality Office). The majority of precipitation happens during the southwest monsoon (June–September). Mean daily maximum temperatures range between 22.8°C and 35.1°C. Mean daily minimum temperatures range between 13.2°C and 19.8°C (ref. 11).

T. bellirica is an uncommon tree (basal area = 0.034 m; P. A. Sinu and G. Kuriakose, unpublished data) in the forests of Sringeri. Focal trees often exceed 40 m in height and 127 cm diameter at breast height. The ripened fruit is a sub-globose brown-coloured drupe. Seed (kernel) of *T. bellirica* is an integral component of traditional folk medicine, which is prepared using the fruits of *T. bellirica*, *Terminalia chebula* and *Phyllanthus emblica*. Seeds of *T. bellirica* are rich in linoleic acid, oil (40%), and protein (35%)¹². The mature fruit has a pale yellow solid kernel (nut) that is well-protected by a hard sclerenchymatous seed coat (nut shell). The outer exocarp (pulp) constitutes 60.9% ($\pm 5.1\%$ SD; $n = 60$ ripened fruits) of the total fruit mass. The seed coat and kernel part weigh

32.7% ($\pm 4.3\%$ SD; $n = 60$ ripened fruits) and 6.4% ($\pm 1.7\%$ SD; $n = 60$ ripened fruits) respectively (P. A. Sinu, unpublished data).

Flowering in focal *T. bellirica* trees occurs during late summer (April–May). However, flowering period varied among years; majority of *T. bellirica* trees flower every 3 or 4 years, but some trees have an irregular phenological cycle (P. A. Sinu, unpublished data). Fruit ripens approximately 7 months (November–December) after flowering. Seed break and germination occur during the summer showers in March–April. Despite medicinal use, commercial or domestic fruit collection does not occur in the study area.

The study spanned the entire fruit-ripening period of 2006–2007 (November 2006 to March 2007). The observations were carried out on ten fruiting *T. bellirica* trees in evergreen forests ($n = 5$) and coffee agroforests ($n = 5$). To determine frugivore and seed predator assemblage, the behaviour of the predators and the impact of predation, diurnal observations were conducted between 0800 and 1200 h as well as 1500 and 1900 h, and nocturnal observations were conducted between 1900 and 2200 h. The nocturnal observations were carried out either using head lamps or night-vision binoculars. Fruit-baited rat traps were used to capture and identify the terrestrial seed predators. Focal trees were watched from an elevated platform or a branch of a nearby tree to record the terrestrial and arboreal nocturnal visitors to the tree. Since *R. indica* was the only arboreal diurnal vertebrate seed predator, its frugivory/seed predatory behaviour was studied in detail. A maximum of 144 h was spent in 18 days to record the behaviour of *R. indica* in fruiting *T. bellirica* trees.

A total of 1,150 ripened fruits ($n = 607$, evergreen forests; $n = 543$, coffee agroforests) were randomly removed from the tree canopy to evaluate the intensity of fruit infestation by weevils. To quantify seed predation at the tree canopy, each fruit was cut open to identify seed predators. A seed was identified as having been preyed upon only if the kernel part was seen being eaten by a weevil larva or if an insect hole existed on the shell and the kernel part was removed. A fruit was identified as infested only if an insect hole was found on the fleshy outer exocarp of the fruit, but the kernel remained intact.

To determine the proportion of seeds consumed by different seed predators, weekly censuses of seeds falling in seed traps (2 m \times 2 m cleared area on ground) that were placed under each focal tree, were done. Six seed traps were randomly installed under each focal tree in both habitats and were regularly monitored until the end of fruit fall. After recording the proportion of seeds consumed by each seed predator species, the seeds were removed from the seed traps. Seeds that were preyed upon displayed characteristic dental marks on the seed coat, which were used to unequivocally establish the identity of the seed predator (Figure 1).



Figure 1. Characteristics of dental marks and predation of each of the predatory agents. *a.* Cross-section showing the habit of the fruit and a late instar weevil larva eating the oil-rich kernel part of a fruit. *b.* A batch of Malabar giant squirrel-predated seed coats showing irregular teeth marks on it. *c.* A batch of Malabar Spiny Dormouse-predated seed coats showing the fine, large orifice on them. *d.* A cache of an unidentified rat species has a pile of consumed seeds. *e.* Equal halves of the seed coats showing the predation by Indian porcupine. *f.* A new emerged seedling of *Terminalia bellirica* that has been consumed by ants.

To assess the rate of seed removal experimentally, five intact fruits were placed at each seed station. Seed stations were randomly placed on the ground within 10 m of each focal tree ($n = 26$, evergreen forests; $n = 16$, coffee agroforests). Stations were monitored for seed predation on a daily basis for the first five days, and then on day 7, 20 and 30. After 30 days, seed stations were visited on a monthly basis until summer rains triggered the germination of the seeds.

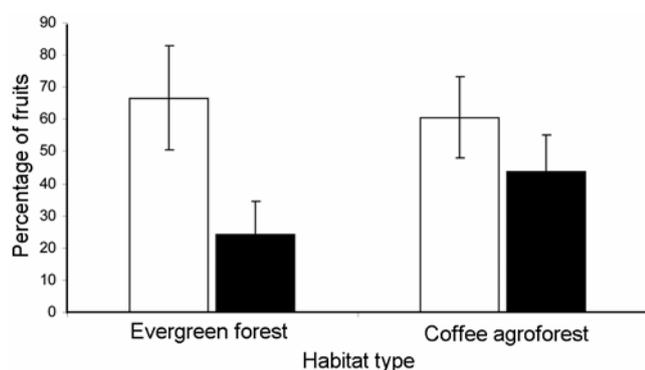
To determine success of germination and the extent of insect predation on germinated cotyledons, two enclo-

tures (0.6 cm^2 gauze) were installed within 10 m radius of each focal tree in both evergreen forests ($n = 5$) and coffee agroforests ($n = 4$). Each enclosure contained five seeds with pulp removed. *T. bellirica* is a pioneer species¹³, therefore, seed enclosures in evergreen forests were placed in canopy gaps adjacent to fruiting trees¹⁴. Beginning late February the enclosures were observed for two months.

Data from seed traps were pooled for each counting the date for every focal tree before comparing the differences in the levels of seed predation within and between

Table 1. Visit duration, seed predation time and seed consumption of Malabar giant squirrel during forays in the morning and evening hours to fruiting *Terminalia bellirica* trees

	N (Days)	Day pattern	
		Morning	Evening
		18	18
Time spent per tree (min)	Range	44–169	34–209
	Average	70.4 ± 16.6	105.7 ± 21.7
Seed predation time (%)	Range	49–82.4	24.4–91.9
	Average	68.4 ± 5	57 ± 7.3
Seed consumption (Count)	Range	20–111	21–61
	Average	28.3 ± 0.16	37.5 ± 0.05

**Figure 2.** Percentage of fruit infestation (open bars) and kernel predation (closed bars) of *T. bellirica* by weevil predator in trees of wet evergreen forest ($N = 5$) and coffee agroforest ($N = 5$) habitats of Sringeri area of Western Ghats, India. Bars represent ± 1 SD.

habitats. Non-parametric tests were used for statistical analysis. Mann–Whitney U test was used to compare seed predation levels between the two habitats.

Larvae of an unidentified weevil (family Curculionidae; order: Coleoptera) and *R. indica* were the only two arboreal seed predators of *T. bellirica* fruits. In the evergreen forests, weevils infested an average of 69% of the fruits (range 48.1–91%, $N = 5$; Figure 2), but only 25% of infestations led to kernel predation (range 9.2–37.7%, Figures 1 a and 2). In coffee agroforests, weevils infested an average of 59% of the fruits (range 39.2–70.6%, Figure 2), but 43.7% (range 26.4–58.2%) of the infested fruits led to kernel predation. *R. indica* was absent in focal trees of coffee agroforests. In evergreen forests, *R. indica* selectively foraged on ripened fruits to consume nutrient-rich kernels. Seed predation by *R. indica* was characterized by an irregular opening (teeth mark) on each seed that was eaten (Figure 1 b).

The 144 h observation showed that foraging bouts of *R. indica* happened daily between 0830 and 1150 h as well as 1500 and 1830 h. The record of 111 fruits consumed in 2.5 h was the maximum recorded fruit consumption by a squirrel in a single visitation bout. The mean fruit consumption/squirrel/visitation bout was 36.86 (± 19.2 SD; $N = 18$). At a single tree, single visitation

bout of a *R. indica* lasts between 34 and 209 min, (mean 92 min ± 63.67 SD; $N = 18$); however, only an average of 62% ($\pm 20.79\%$ SD) of that time was spent for frugivory. The remaining time was spent to consume foliage and bark peelings of the trees of *T. bellirica* and neighbouring trees of *Mimusops elengi*, *Artocarpus hirsutus* and *Madhuca longifolia*.

Immediately after its arrival at the tree canopy the giant squirrel searched for the ripened fruits of *T. bellirica* and plucked a single ripened fruit using its mouth. By holding the fruit in its front legs, the squirrel bites away the fleshy exocarp from all around the seed coat using its teeth. The average time it took for this exercise was 0.24 min (± 0.02 ; range 0.20–0.29 min, $N = 134$). Once the pulp removal was completed, the squirrel gnawed the thick sclerenchymatous seed coat to consume the kernel part of the seed, which is audible from the ground. Mean time used to open the seed coat was 0.58 min (± 0.04 ; 0.45–1.06 min, $N = 112$) (Table 1). After consuming the kernel, the squirrel dropped the empty seed-coats to the ground and plucked another ripened fruit quickly.

Careful observations through binoculars showed that the squirrel was avoiding non-ripened fruits from plucking. However, if the squirrel sensed insect-infestation in the plucked fruits, the fruits were discarded at the pulp-removal stage itself. An examination of 58 such rejected fruits revealed that the kernel of 60.4% of the fruits was predated by weevils. All such fruits had a hole made by the weevil on the exocarp. Although 12% of the rejected fruits had weevil holes on the exocarp, the kernel part was not damaged. Endosperm was not developed in 19% of the discarded fruits. A small proportion (8%) of the fruits accidentally fell to the ground while handling, but the seeds in such fruits were intact.

The giant squirrel consumed relatively more number of fruits during its visitation bout in the evening than that in the morning (Table 1). The squirrel, however, spent more time to consume the fruit in morning hours (average 2.17 min ± 0.44 ; $N = 225$) than in evening hours (average 1.26 min ± 0.13 ; $N = 412$).

Table 2. Percentage of seed predation and contribution of each of the predatory agents in limiting the recruitment of *T. bellirica* in evergreen forests and coffee agroforests of Sringeri area, Western Ghats, India. The calculation is based on the pooled data from seed traps placed under each of the focal trees. See text for statistical analysis results

	Evergreen forest (<i>N</i> = 5)		Coffee agroforest (<i>N</i> = 5)	
	Average (SD)	Range	Average (SD)	Range
Overall predation	96.3 ± 2.05	94.5–99.1	82.3 ± 3.3	78.03–87.1
Giant squirrel	49.26 ± 4.3	44.15–54.5	–	–
Terrestrial rodents	33.3 ± 21.7	17.3–70.7	54.8 ± 6.04	48.0–64.2
Weevil-predated seeds	27.3 ± 2.5	23.9–29.7	45.3 ± 6.04	35.8–48.5
Aborted fruits	2.94 ± 1.7	0.64–4.41	11.82 ± 4.3	6.0–16.8
Intact fruits	0.75 ± 0.45	0.26–1.21	5.9 ± 1.2	4.1–6.9

Two predatory rodents, the Malabar Spiny Dormouse, *Platacanthomys lasiurus* and an unidentified rat species (*Rattus* sp.) were the predominant terrestrial seed predators of *T. bellirica* in both evergreen forests and coffee agroforests. The dormouse left characteristic circular holes on the seed coat (Figure 1c). The rat left one or two small irregular openings on the seed coat (Figure 1d). The rat often cached fruits in tree holes, buttresses or root mantles of surrounding trees. The caches were only observed in evergreen forests. The Indian porcupine (*Hystrix indica*) is a potential seed predator of *T. bellirica*; but a thorough random search for the predated fruits under the fruiting trees showed that they are rare seed predators of *T. bellirica* in both the habitats. Seeds preyed upon by the porcupine are identified by a seed coat that is split into two equal halves (Figure 1e). Mouse deer (*Moschiola meminna*) and grazing cattle consumed the fleshy exocarp and regurgitated a viable seed in the same location itself (pers. obs.), but do not consume the seeds. Herbivory by ants affected the cotyledons within 48 h of germination (Figure 1f).

Over a seven-week period, 5,543 seeds were counted in 30 seed traps in evergreen forests. Overall, 97% of the fruits were preyed upon by arboreal and terrestrial seed predators. Based on the predation marks on the seed coat it is inferred that *R. indica*, a weevil and the two terrestrial rodents (*P. lasiurus* and *Rattus* sp.) consumed 43%, 26% and 28% of all fruits respectively. Aborted (seeds not developed) and intact fruits with viable seeds accounted for 2.4% and 0.63% of all fallen fruits and seeds respectively (Table 2).

In coffee agroforests, a total of 1,200 seeds were counted from 30 seed traps; 82% of the overall seeds were preyed upon. The two terrestrial rodents and the weevil species consumed 45.5% and 37.0% of all fruits respectively. Fruits with aborted seeds and viable seeds accounted for 12.1% and 5.8% of all fallen fruits and seeds respectively.

Overall seed predation was significantly different between evergreen forests and coffee agroforests (96.3% versus 82.3%, *N* = 10; Mann–Whitney *U*-test, *U* = 0,

P = 0.009). Weevil predation was significantly higher in coffee agroforests (45.3% versus 27.3%, *N* = 10; Mann–Whitney *U*-test, *U* = 0, *P* = 0.007). Terrestrial rodents predated a greater proportion of seeds in coffee agroforests than in evergreen forests (54.8 vs 33.3); however, the difference was not significant (*N* = 10; Mann–Whitney *U*-test, *U* = 5 *P* = 0.11; Figure 3).

A total of 22 caches were detected for *Rattus* sp. for all five focal fruiting trees in evergreen forests, but no caches were detected in coffee agroforests. Caches were located up to 5.6 m from focal trees (mean 3.2 m). Cache size ranged from 23 seeds to 412 seeds (mean 82.3 ± 21.3 SE). Caches were observed in root mantle (cache size = 356, *n* = 1), leaning/fallen tree trunks (mean cache size = 46.2 ± 7.4 SE; *N* = 13; range 23–115), and tree buttresses (mean cache size 106.9 ± 54.4 SE; *N* = 8; range 41–412).

From the experimental seed stations of evergreen forests, 72% (*n* = 650) of the fruits were removed by different predators during the two-month observation period. From the experimental seed stations of coffee agroforests, 35% (*n* = 400) of fruits were removed during the two-month study period (Figure 4).

An average of 66% (range, 40–100%) of seeds germinated per seed enclosure in evergreen forests. Herbivory by ants affected 43.0% of cotyledons within 48 h of germination, whereas 72.7% of cotyledons were affected by herbivory within a week. In coffee agroforests, an average of 87.5% (range, 71–100%) of seeds germinated/seed station. The ant herbivory of the cotyledons was 25.7% and 83% within 48 h and one week respectively.

The primary objective of the study was to report the diversity and intensity of seed predation in *T. bellirica* in two habitats of the Western Ghats biodiversity hotspot. It was found that loss of seeds to predators is quite high for *T. bellirica* in wet habitats of the Western Ghats, which is comparable to many other tropical and temperate species, globally^{15,16}. Both weevil, arboreal and terrestrial rodents rely on the oil-rich seeds of *T. bellirica* as the fruiting of the species coincided with the relatively lean fruiting

winter months. Seed predation may not have a significant impact on natural recruitment of perennial and annual species having an annual fruiting cycle¹⁷. However, the fruiting phenology of *T. bellirica* is irregular in the wet habitats and happens once every 4 or 5 years. Under this circumstance, the observed seed predation could be a greater loss to *T. bellirica* in wet habitats.

Among focal trees of the evergreen forests, seed predation was extremely high, ranging between 94.5% and 99.1%. Seed predation was relatively low in the focal trees of coffee agroforests. Variation in seed predation between habitats was primarily due to the presence of *R. indica*, the dominant pre-dispersal predatory agent in evergreen forests. *T. bellirica* fruits particularly, became the most preferred food resource of *R. indica* as its fruiting happens during the fruit shortage winter period of the tropics¹⁸. The only other fruit source of *R. indica* during winter period was fruits of *Chilocarpus atroviridis* (a common liana species of evergreen forests of the study area). *R. indica* was absent in all the focal trees of coffee agroforests. The disturbed canopy structure of coffee

agroforests might have limited the distribution of the arboreal *R. indica* in coffee agroforests^{19,20}.

Insects are the major specialist seed predators in the tree canopy^{21,22}. In *T. bellirica*, although fruit infestation by weevils was high, kernel predation was remarkably low. However, the seed loss to weevils was quite high in coffee agroforests.

Although seed dispersal and germination are not our primary focus, the study has shown that the natural germination was not affected in wet habitats. The dispersal too appears to be good as bats frequently visited the fruiting trees during early evening hours (pers. obs.). Although ants can be voracious seed predators^{23,24}, the sclerenchymatous shell (seed coat) of *T. bellirica* seeds might limit ant predation on the intact seed. However, ants were frequently observed eating the remains of seeds preyed upon by rodents from the opened nut shell (pers. obs.).

However, ants consume newly germinated cotyledons (0–5 days old) and potentially limit seedling survival. Although high seed predation results in significant loss of viable seeds of *T. bellirica*, it is important to note that the seeds of *T. bellirica* constitute a major part of the food of *R. indica*, a species endemic to most forested parts of South India²⁵ listed in the Appendix II of CITES²⁶ and Schedule II of the Wildlife Protection Act of India 1972, during relatively low fruiting winter period of the seasonal tropics.

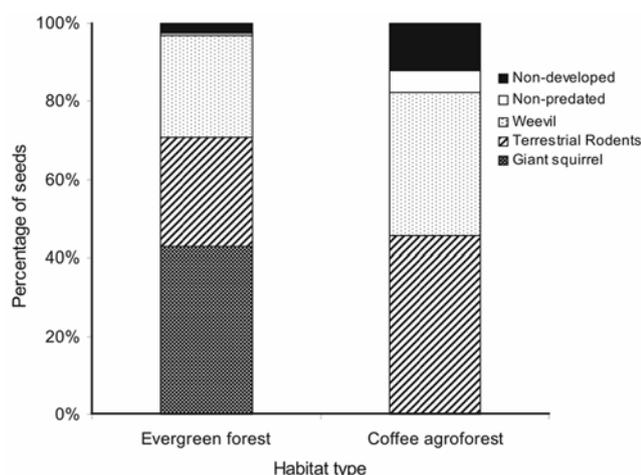


Figure 3. Proportion of intact seeds, undeveloped seeds and consumed seeds by each seed predator in evergreen forest and coffee agroforest habitats of Sringeri area.

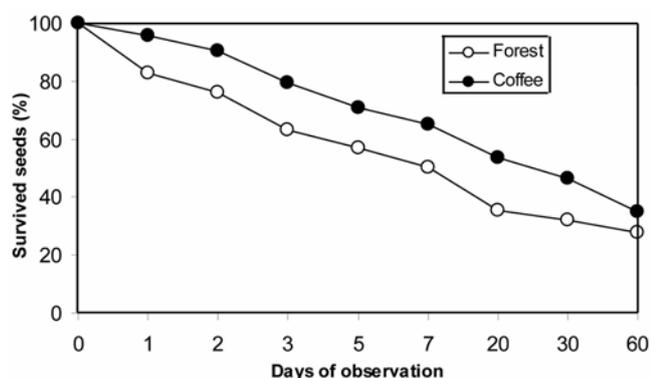


Figure 4. Seed survival (%) in evergreen forests and coffee agroforests of Sringeri area.

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Probing the reliability of DNA barcodes in delineating geographically widespread bird species

B. G. Sasikala¹, P. Anuradha Reddy¹, V. Vasudeva Rao², A. Ramyashree¹ and S. Shivaji^{1,*}

¹Centre for Cellular and Molecular Biology, Uppal Road, Hyderabad 500 007, India

²All-India Network Project on Agricultural Ornithology, A.N.G.R. Agricultural University, Rajendranagar, Hyderabad 500 048, India

Studies on birds have shown the efficiency of cytochrome *c* oxidase subunit I (COI) barcodes to identify and assign more than 95% of the species to their respective families. These studies indicate that small, inconspicuous birds are good candidates as cryptic species or show allopatric divergences, whereas the larger birds which can fly/swim long distances show lesser divergences. Here we attempt to check the efficiency of COI barcodes in delineating species with worldwide distribution. We analyse genetic differences in birds of the family Ardeidae with global distribution to evaluate the possibility of allopatry. COI barcodes and sequences of a variable region of cytochrome *b* gene were compared in seven out of nine widely distributed Ardeidae species and we found deep intra-specific divergences and diagnostic mutations in four species. Whether these sequence divergences are evolutionarily significant needs to be further analysed.

Keywords: Birds, DNA barcodes, cytochrome *c* oxidase subunit I, cytochrome *b*.

A DNA barcode system envisages a library based on the sequence diversity in a standard region of the mitochondrial cytochrome *c* oxidase subunit I (COI) to accurately identify all animal species and to speed up the discovery of new species¹. Extensive studies on birds have shown the efficiency of the barcodes in correctly identifying and assigning more than 95% of the species studied to their respective families^{2–5}. Some of these earlier studies have also shown that a standard threshold of 10 × mean intra-specific variation in the COI sequences can correctly assign individuals in more than 90% of the species. Further, Tavares and Baker⁶ showed that mitochondrial DNA barcodes are extremely effective in identifying closely related sister species in well-studied groups like birds. All sister-pairs were characterized by reciprocally monophyletic lineages and species which comprised of several divergent monophyletic lineages could be flagged as new unrecognized species. Such species could be further

*For correspondence. (e-mail: shivas@ccmb.res.in)