The effect of introduced herbivores on vegetation in the Andaman Islands

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Vegetation sampling was carried out in three areas in the Andaman Islands, India to study the impact of introduced elephant and chital. One area (Interview Island) had both, the second area (MGMNP) had chital and the third, Little Andaman, had neither.

Basal areas were similar at all three sites, though they were lower than those at forest sites elsewhere. The number of tree species per unit area at the sapling stage was highest on Interview Island; however at the tree stage, Interview Island had the lowest number of species. There were no differences in the number of trees in each girth class between the sites. Heavy browsing on seedlings was noted at the sites that had introduced herbivores.

The presence of introduced herbivores has led to the local disappearance of a few species and is likely to affect species richness over large parts of the island chain, if not controlled.

The effects of introduced species on islands

THE dynamics of introduced species on islands has aroused a lot of concern worldwide. Species that become established in natural ecosystems, act as agents of change. They have a great impact on the changes that occur in the vegetation patterns of the areas where they occur. In the long term, they may prove more damaging than habitat degradation and fragmentation. IUCN[1] states that this is one of the major threats to native biological diversity, and identifies this problem as one of its major initiatives on a global level. The Union of Concerned Scientists[2] goes even further and identifies invasives as the second largest threat to biodiversity, after habitat destruction: 49% of the species listed as endangered in the United States have the presence of invasives as a cause.

Known causes of extinction for island ecosystems include deforestation, fire and the introduction of weeds. The introduction of grazing animals is also a cause of extinction, and it has a disproportionately large impact on islands. These affect native systems in such pervasive ways that it is difficult to see how native species and ecosystems can be protected without eliminating the introduced species.

Studies of whole islands and enclosures have already demonstrated that ungulate populations affect erosion and fertility, and increase the success of alien plant species[3]. They affect canopy cover and fruit production[4] as well as reproductive success and survivorship[5]. Native ungulates even affect the populations of the smaller mammals due to their impact on food quality[6]. Island plants often lack defences such as thorns and toxic chemicals. Selection for protection against insect herbivory may not help with mammalian herbivores[7]. A reduction in diversity may also increase the possibility of colonization by plant invasives[8]. In many cases, the removal of exotic grazing animals has resulted in the recovery of the local flora[9].

Herbivory by introduced animals brings new problems. Invasives are now attracting increasing attention for the ecosystem damage they cause. Up to 45 bird species may have gone extinct in New Zealand due to introduction of cats and rats. Damage by herbivores has been well documented for several areas. In his classic work, Struhsaker[10] reports that regeneration on logged areas in Uganda is affected severely by rodents, deer and elephant. Elephant damage in heavily logged areas was sometimes so severe that regeneration never occurred in these areas.

The issue in the Andamans

The Andaman Islands are a case in point. Species that have been introduced into these islands, or have gone feral, include dogs, cats and Common Mynahs (*Acridotheres tristis*) introduced from mainland India[11]. Each of them has had a dramatic impact here. Dogs have become predators on sea turtles at a number of sites, and are responsible for their decline. Cats have destroyed populations of indigenous nesting birds elsewhere[12], though this has not been documented for the Andamans. Mynahs may compete with endemics for nesting holes[13], which might be a limiting resource here.

The larger herbivores introduced here included three species of deer and the Asian elephant (*Elephas maximus*). Chital (*Axis axis*) are believed to have been introduced into these islands in the 1930s, along with barking deer (*Muntiacus muntjak*) and hog deer (*Axis porcinus*). Barking deer are still found in small pockets on Middle Andaman, while hog deer have gone extinct locally. Chital have spread to almost all the islands of the Anda-

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man group, having adapted to becoming good swimmers, having begun to swim from island to island. The only islands that do not have populations of chital are Little Andaman and South Sentinel Islands.

Elephants were brought in for forestry operations, and are still being used for these. In the northern part of the Andaman group, on Interview Island, the company carrying out timber extraction operations went bankrupt. Being unable to transport the elephants out of the island, they released about 40 elephants into the wild in 1962. Some elephants later swam over to North Andaman Island. These populations have turned feral, and are known to attack persons they encounter.

What is known already

The only herbivore found in the islands before the introduction of the deer was the Andaman pig (*Sus andamanensis*). The taxonomic status of this – whether it is a valid species, or whether it was introduced at some point from mainland Asia – is not clear. However, midden remains from Andamanese tribals reveal that this species has been on these islands for at least 2000 years.

Forest Department sources have maintained that chital are causing habitat damage. However, the type of damage being caused by them, and the likely consequences on forest structure have not been quantified. A preliminary survey conducted on Sound Island, off Middle Andaman in January showed that seedlings were heavily browsed by chital. The number of saplings seen were also few, an effect that would be expected if seedlings were not allowed to grow.

Sivaganesan and Kumar[14] reported heavy damage to vegetation by elephants on Interview Island, with canes, bamboos and *Pandanus* having shown a major decline. They also found damage to a number of trees that were uprooted or debarked. A preliminary survey by us in January 2001 confirmed that debarking of a large number of trees was occurring.

Methods

Description of study site

The Andaman Islands are bounded by lat 10°30′N to 13°40′N, and long 92°10′E and 93°10′E. The Union Territory which is part of India covers both the Andaman group of islands and the Nicobar group further south.

There are approximately 250 islands covering an area of 6428 km^2. Of this, 5628 km^2 is notified as either Reserved Forest or Protected Forest[15]. The main island group in the Andamans is the Great Andaman, whose main islands are North, Middle and South Andaman, and Baratang. Separate from this group and 50 km to the south is Little Andaman Island. These islands have Malay biogeographical affinities (Figure 1).

Figure 1. Map of Andaman showing the three study areas.

Three study sites were chosen. Interview Island has both elephant and chital; the Mahatma Gandhi Marine National Park (MGMNP) has only chital, and Little Andaman has neither. There is no site with only elephants. Wild pig occurred on Interview Island at low densities, and in Little Andaman, but not in MGMNP; its effects on the results have been ignored.

Interview Island has an area of 104 km^2 situated to the west of Middle Andaman and separated from it by a sea distance of about 10 km. It is bounded by the coordinates of 12°45′N to 13°00′N in lat, and 92°37′E to 92°45′E in long. The island is undulating in nature and is covered with evergreen forest fringed with extensive mangrove areas. In the 1950s and early 1960s, the island was subjected to selective logging, in a patch along its east coast going approximately three km in (about half way across the island) and about 15 km in a north–south direction. The effects of logging on tree composition are a confounding factor, and this was tested for; and will be discussed in detail later on.

MGMNP was declared a protected area in 1983, and covers 281.5 km^2. It lies between 11°15′–11°37′N and 92°30′–92°45′E. The area of the 15 islands and their associated reefs within the park is 56.54 km^2 according to the Forest Department statistics[15]. This was almost identical to the 56.57 km^2 calculated from scanned maps for this study and the figures from the scans are used. The actual land area on these islands above the high tide line is lower, and totals to 28.98 km^2. Table 1 shows the area of each island and reef area in MGMNP. No logging has occurred in this area.

Table 1. Area of each island, and area above the high tide line. The number of habitat types found on each island (out of evergreen, semi-evergreen, deciduous and littoral) is also shown, as well as the number of transects done on the island

Island	Area (Ha)	Island and reef (ha)	No. of habitats	No. of transects
Alexandra	368.89	469.06	3	2
Belle	6.21	34.81	–	–
Boat	282.53	738.73	4	3
Chester	6.90	49.70	2	1
Grub	2.60	44.97	1	1
Hobday	357.02	472.62	3	2
Jolly Buoy	19.64	93.13	1	1
Malay	88.97	195.82	2	1
Pluto	17.15	51.36	–	–
Redskin	453.49	710.75	3	3
Rifleman	2.90	6.76	–	–
Snob	18.48	143.62	2	1
Tarmugli	1186.46	2291.47	4	3
Twins	56.47	200.53	–	–
Others	30.00	152.76		
Total area (ha)	2897.71	5656.09		

The third area, Little Andaman Island, was used as the baseline. It has no feral elephants or deer. It however has wild pig, which might have been a confounding variable – this will be discussed later. It has an area[15] of 731.67 km^2, of which a small part has been logged.

Study animals

The first systematic study on elephants in the islands was a six-week-long survey[14] in 1993. The area usable by the elephants was calculated as 70 km^2. Using transects on dung, an elephant population of 70 animals was estimated. Heavy damage to the vegetation was also reported, with canes, bamboos and *Pandanus* having shown a major decline. Damage to a number of trees was also found, in the form of their being uprooted or debarked.

Chital have adapted themselves extremely well to these islands. They have been observed to swim fairly long distances between islands. To reach Interview Island, a sea gap of about 10 km would have to be crossed. They are forest dwellers here, being found even in dense evergreen forest: a habitat in which they are never observed within their normal range. Since grass is not abundant in evergreen or semi-evergreen forest, they subsist on foliage. In many tree species, all the foliage within reach of the chital – below 1.5 m – has been browsed. Similarly, seedlings are browsed intensively.

While it proved possible to census elephants accurately by counting individuals from observation towers, it did not prove possible to census chital. This is because the animals are extremely shy and are being hunted extensively. Visibility in dense forest is also low, making census difficult. Also, since animals have been seen crossing between islands, censusing populations was unlikely to give an accurate estimate of population densities over time. Thus, only presence and absence data were considered.

Field techniques

Elephant census: If food resources were a limiting factor on Interview Island, this might be reflected in the population trends seen on the island. A population drop would be indicative of food shortages, even though it might be a consequence of other factors such as disease or poaching. The results of the census done on elephants are reported elsewhere[16]. An estimate of 31 animals on Interview Island was arrived at, down from an estimated 70.

Vegetation sampling: Belt transects were laid out on Interview Island in February and March 2001. Transects were enumerated in the MGMNP in May–July 2001, and were done in Little Andaman in February 2002.

Five transects were done on Interview island, two and a half each in logged and unlogged areas. Transects were left unfinished where the terrain did not allow completing them. Eighteen transects were done in the MGMNP. The larger islands had three transects each, the medium-sized ones had two, and the smaller ones had one (Table 1). Four transects were done on Little Andaman Island, one of which was in a logged area. Logistical considerations made taking more transects difficult.

Belt transects were used to analyse the vegetation. A starting point and a direction were selected at random. A rope measuring 500 m was laid along the line selected, and plants within 2.5 m of it on either side were enumerated. Each transect was further subdivided into 10 plots of 50 m × 5 m. Only plants with a girth at breast height (gbh) of greater than 5 cm were measured; and the definition of sapling used throughout is plants with a gbh of 5–30 cm. This is in line with other studies[10]. The species and girth of each plant sampled were noted. Where the species was not known, the local name was noted and specimens were collected. In most cases, these could be identified at the herbarium of the Botanical Survey of India in Port Blair.

Selection ratios were calculated as the proportion of use to the proportion of occurrence.

The data for each location were pooled. Analysis was done using the NCSS package[17]. The EstimateS package[18] was also used to generate species–area curves.

Results

The vegetation plots on Interview Island did not have any cane (*Calamus* spp.), bamboo or screwpine (*Pandanus* spp.). Canes and screwpine were only seen on some steep and rocky slopes near the shore. The understorey was missing from most places. In similar topography in other parts of the Andamans, canes are abundant. There is extensive soil erosion. Large trees of *Sterculia campanulata*, *Pterocarpus dalbergoides* and *Manilkara littoralis* were found debarked or otherwise damaged.

The islands comprising the MGMNP had little ground cover, which is atypical for evergreen forest in this region. Seedling densities appeared to be low. In contrast, Little Andaman had a dense ground cover and saplings were abundant.

While debarking by elephants was not an issue in the other areas, it was recorded on Interview Island. Debarking also resulted in the death of trees. Its effects, and possible confounding effects due to logging are considered first.

Effect of logging on Interview Island

Species area curves were plotted for the vegetation, to compare the logged plots with the unlogged plots. These were carried out first for all plants in the sample from Interview Island, and then for the trees (gbh > 30 cm) only (Figures 2 and 3). These distributions are not different from each other using the Kolmogorov–Smirnov 2-sample test; ($D = 0.378$ and 0.377 for all plants and trees respectively, n.s.). However, using the Mann-Whitney U gives significant results ($P = 0.023$ for all plants; $P = 0.04$ for trees). However, the logged plots have many more species than unlogged plots (89 vs 67 spp. per 5000 m^2 for trees; 113 vs 94 spp. per 5000 m^2 for all plants). This would normally be expected, since invasive species and light-demanding deciduous species are expected to occupy the gaps after logging. *Myristica* spp. represent almost 21% of the tree species in the unlogged forest; in

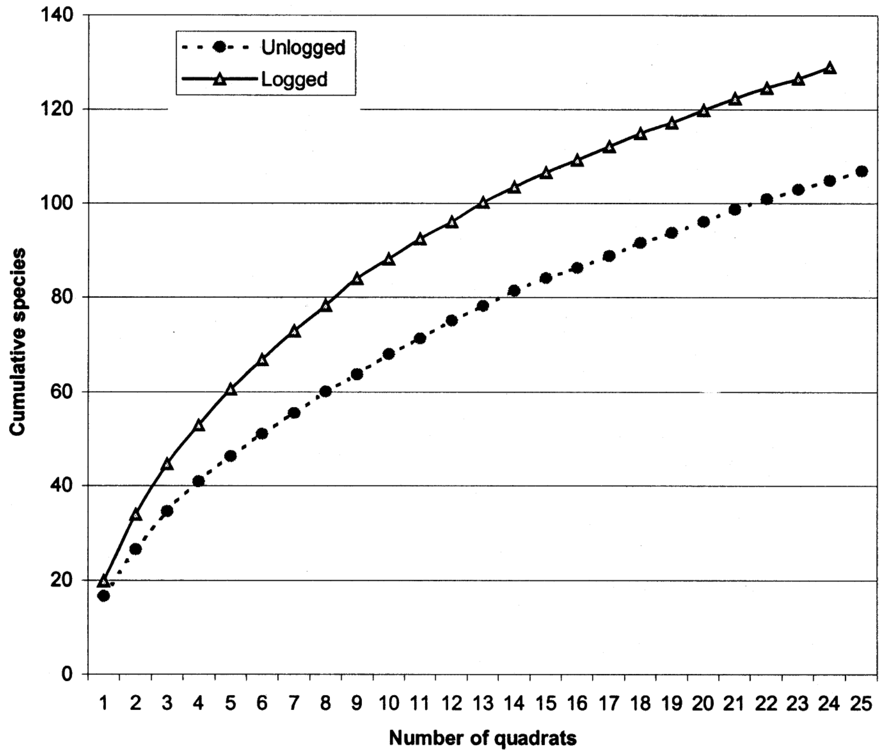

Figure 2. Cumulative species – area curve for all plant species on Interview Island. These were calculated using data from the smaller 50 m × 5 m sub-quadrats. They were randomized and an average taken from 50 runs using the EstimateS program.

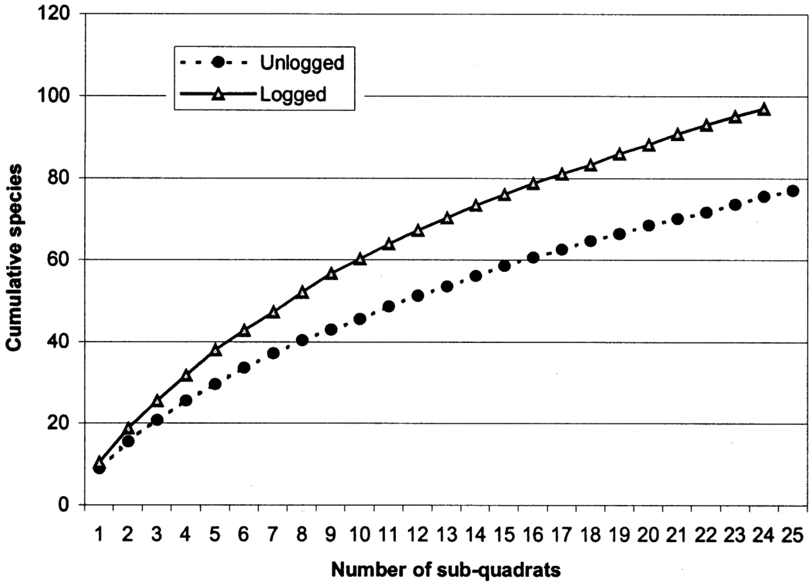

Figure 3. Species – area curve for trees. These were calculated using data from the smaller 50 m × 5 m sub-quadrats. They were randomized and an average taken of 50 runs using the EstimateS program

the logged forest the commonest tree is *Pterygota alata* (15%); here *Myristica* occupies only 9%.

However, the fact that species compositions differ so much, more than 40 years after logging, and the reasons for this need to be understood. One possibility is that different parts of the island have different vegetation. This is unlikely because the sample plots were distributed across the island. Another is that the high density of herbivory has prevented the forest from regaining its original condition. This hypothesis will be tested while considering the effects of chital.

The distribution of basal areas for both the logged and the unlogged areas is extremely similar (Figure 4). This makes another major point of similarity between the logged and the unlogged areas on Interview Island. The actual number of saplings in each girth class was also similar (Figure 5).

Changes in Andaman forests due to logging have been reported[19]. Manipulating the structure to prefer commercially viable species is a management aim[20]. However, since the major physical characteristics of the forest: the species area relations were similar, as were the basal areas and number of stems in each girth class, it was decided to lump the logged and unlogged areas of Interview Island for the purpose of this analysis.

Damage to trees on Interview Island

Twenty-three species that constituted more than 1% each of the total number of species, accounted for 64.5% of all the trees enumerated. Species of *Myristica* spp., *Pterygota alata* and *Dipterocarpus* spp. accounted for 35%. Twenty-two species were found with damage by elephants. In some cases, every tree seen of a particular species was damaged by elephants. A plot of selection ratios (the proportion of use divided by the proportion of occurrence) against the density shows that the less common trees appear to be utilized more heavily (Figure 6).

However, there is no relation between how common a species is and its occurrence in elephant diet. Every species of those found browsed was categorized into common/rare and eaten frequently/not eaten frequently using the means as the cut-offs. There did not appear to be any difference ($\chi^2 = 0.153$, n.s).

Effect on basal area

The basal areas for all three sites are given in Table 2. None of the values obtained are different from each other (One way Analysis of Variance, $F_{2,25} = 0.31$ for saplings; $F_{2,25} = 0.52$ for trees; $F_{2,25} = 0.46$ for all plants sampled; $F_{2,25} = 0.76$ for proportion of basal area in sapling category; all not significant). Little Andaman had the highest basal area, and the lowest proportion in the sapling category.

Effect on diversity

Since the number of transects in each area was different, a simple measure of diversity was chosen. The number of species per sample plot of 50 m × 5 m was taken. The results are plotted in Figure 7. There is a significant difference among the number of species per plot among the

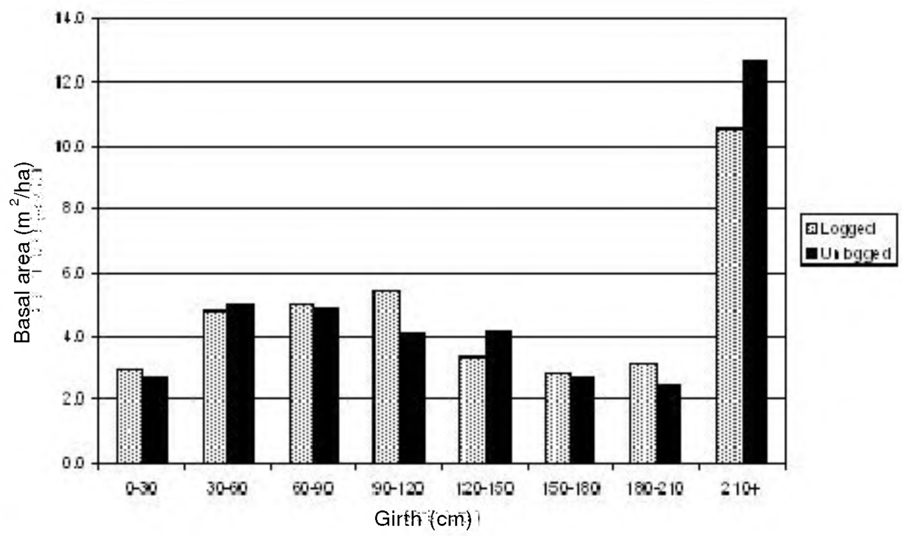

Figure 4. Basal area in different girth classes.

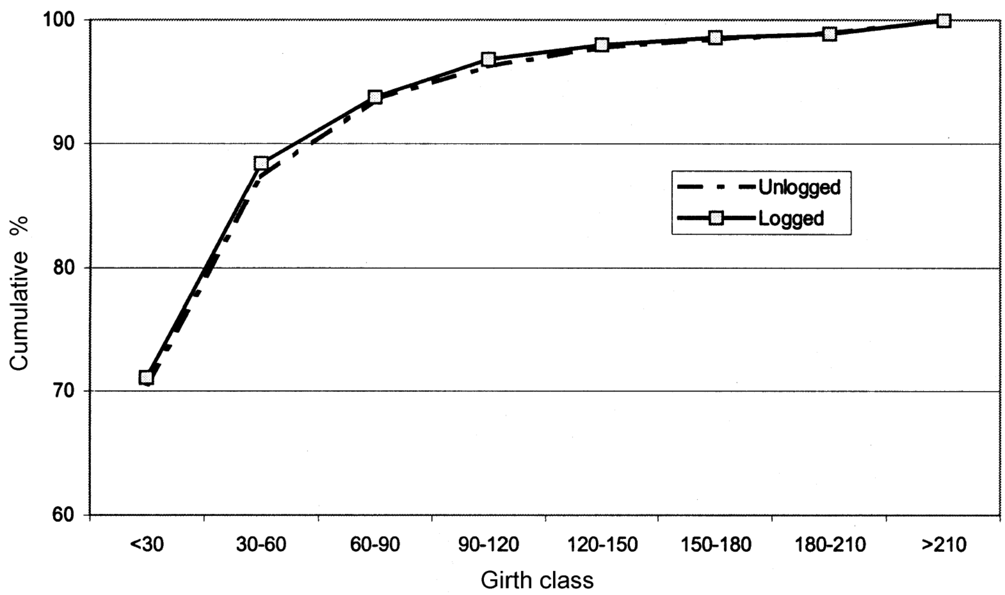

Figure 5. Cumulative frequency in each girth class.

Table 2. Summary statistics for basal area

Basal area (m^2/ha)	Interview (n = 5)	MGMNP (n = 18)	Little Andaman (n = 4)	Mean
Sapling (gbh < 30 cm)	2.59	2.68	2.43	2.61
Tree (gbh > 30 cm)	34.84	33.63	39.46	35.06
All trees	37.43	36.31	41.89	37.67
Proportion of saplings	0.072	0.077	0.064	0.073

three sites ($F_{2,257} = 22.9$, $P < 0.01$). Duncan's multiple comparison test shows that Interview Island is different from the other two ($P < 0.01$), having a greater number of species.

Effect on tree density

There was no significant difference in the density of saplings between each location ($F_{2,27} = 0.61$, n.s.). This is the same for the other girth classes. Considering all trees, the differences are not significant ($F_{2,25} = 2.30$, $P = 0.06$). The same trend holds for all plants ($F_{2,27} = 1.27$).

Figure 8 shows the results for all trees. Little Andaman has the lowest number of trees (gbh > 30 cm) with 470 trees/ha; MGMNP has 481 trees/ha and Interview Island has 585 trees/ha.

There is no difference in basal areas or in tree densities. Interview Island, with elephants, has the highest

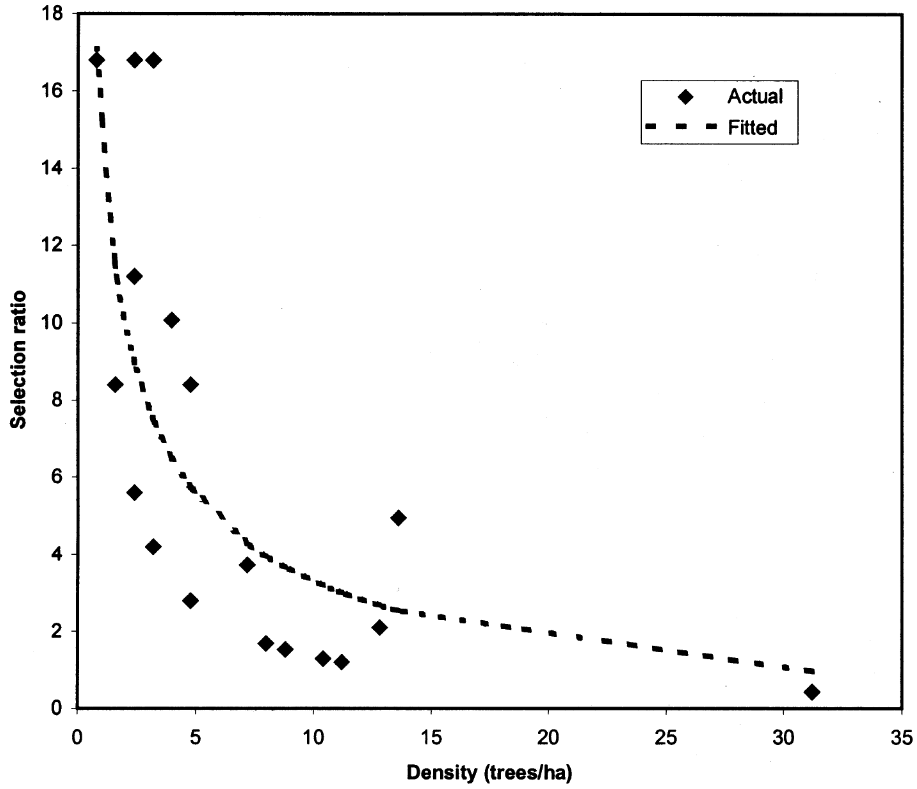

Figure 6. Change in selection ratio with density.

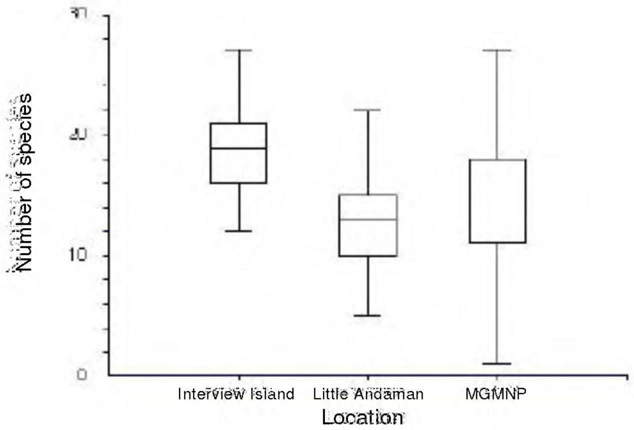

Figure 7. Number of plant species per 250 m^2 plot.

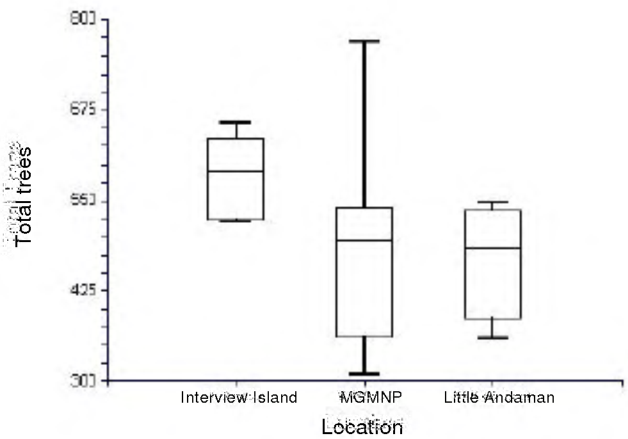

Figure 8. Trees with gbh greater than 30 cm found in each area.

number of species. The number of trees in each girth class is similar between areas, with the exception of the 30–60 cm girth class, of which Interview Island has more than the other two (ANOVA using the logs of the tree counts; Kruskal–Wallis One-Way ANOVA by ranks, $H = 7.60$, $P < 0.05$; however parametric tests indicate that this is only marginally significant with $P = 0.07$). This indicates a process akin to thinning in forestry, occurring where the regeneration in this growth class is enhanced. Also, the difference may partly be due to the large number of *Mussuenda*, a pioneer species, being recorded. To test if there is a change between the number of species found between the sapling and the tree stage, the number of species per plot was recalculated using just data from the trees and ignoring the saplings. Figure 9 shows the outcome, and Interview Island has the least number of tree species per 250 m^2 plot (Kruskal–Wallis ANOVA by ranks, $H = 92.92$, $P < 0.05$). Comparing groups indicated that large trees were significantly lesser on Interview Island. This confirms the possibility that saplings do not tend to survive on Interview Island.

Effect on seedlings

The effect on forest regeneration due to damage of saplings by elephants has been demonstrated. It has been shown that actual damage takes place; the reduction in sapling numbers and diversity also indicates damage by elephants. The issue regarding to what extent regeneration is affected at the seedling level is addressed now.

In the analysis, data on Grub Island from the MGMNP was left out, since the island is extremely small (8 ha) and no chital were recorded there. There is a significantly higher number of seedlings per 25 m^2 sampled on Little Andaman (365.5) than in MGMNP (145.5). The differences between these are highly significant ($t_s = 4.41$, $P < 0.01$). The percentage browses in MGMNP is also much higher (means are 46.8 and 2.6% for MGMNP and Little Andaman respectively; $t_s = 7.76$, $P < 0.01$).

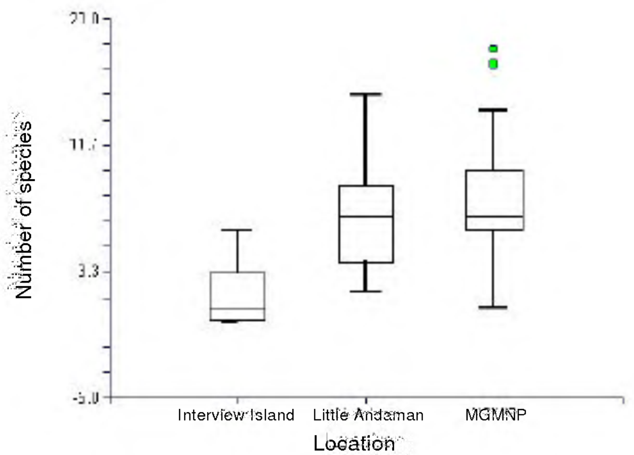

Figure 9. Species of all trees having gbh > 30 cm.

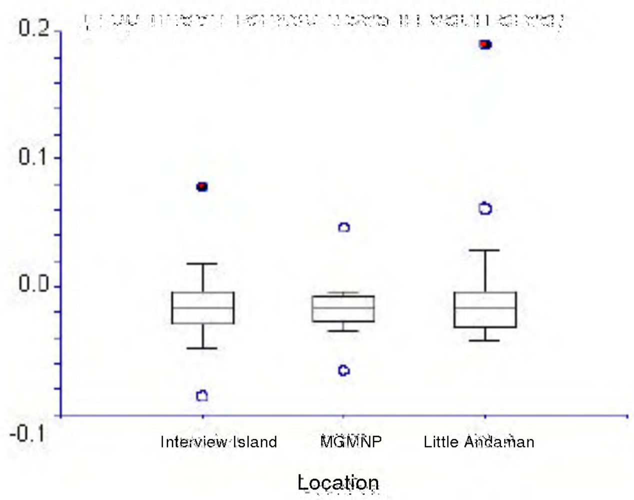

Figure 10. Change in proportion between trees and saplings (top fifteen ranked trees in each area).

Since the stumps left behind by browsed seedlings may deteriorate over time, the total was considered a more reliable estimator of the number of seedlings than the number unbrowsed. Differences between the two areas in total seedlings might be explained due to the different sampling seasons at MGMNP during the start of the monsoon and Little Andaman in the dry season (February). The per cent browsed provides a snapshot check on this and since it shows the same trend, it indicates that season is not a factor. The incidences of browsing seen on Little Andaman are due to pig, which appears to be insignificant compared to deer damage.

The final check is to see whether species compositions of trees are affected due to browsing. If certain species of plants are preferred for browsing, the proportion of trees of that species would decrease.

There were no direct data collected on chital food preferences here. However, observations show that *Pongamia pinnata* and *Lagerstromia hypoleuca*, common in littoral and deciduous forests respectively, are not browsed. The latter was, however, not observed as a sapling in the Interview Island samples. An area that was cleared nearby and then abandoned regenerated predominantly with this species.

For trees comprising the top ten ranks for each area, the difference between the proportion of saplings and the proportion of trees was calculated. The box plot in Figure 10 shows that there appears to be no variation between the three sites. However, what is interesting is that in all cases the mean difference is negative, implying that the commoner trees are under-represented in the sapling stage. In all three cases, about 80% of the commoner species showed a negative trend. No saplings of *Terminalia manii*, *Terminalia procera* and *Planchonia andamanica* were seen on Interview Island; here *Mussuenda macrophylla* was the most common tree recorded as a sapling, almost 7% of all observations. On MGMNP *Caryota mitis*, also heavily browsed, occurred frequently as a sapling but not as a large palm. *Dipterocarpus* saplings were scarce, even though they dominated the canopy.

A comparison between the saplings (less than 30 cm in gbh) and young trees (between 30 and 60 cm in gbh) for all the species that become large trees is instructive. Rank–abundance curves for all three areas indicate that different processes seem to be occurring in different localities (Figure 11). The drops are much steeper for Interview Island indicating that the spread of trees is uneven compared to the other two. This indicates that browsing might be selectively removing some species, and allowing the unpalatable ones to dominate.

There is a possibility that changes in abundance may be related to initial sapling abundance. Comparing the four highest-ranked saplings with the next four indicates that this is not so (Two-way Analysis of Variance $F_{1,18} = 0.81$

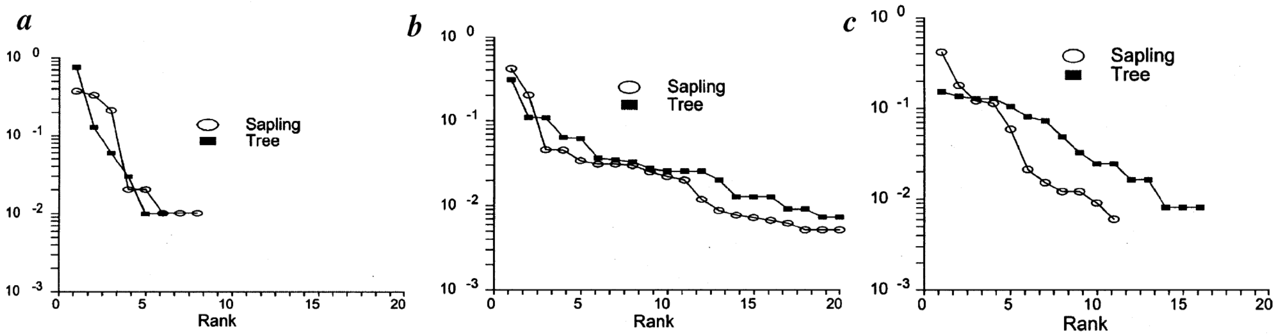

Figure 11. Rank-abundance curve for the three areas. ***a*** Interview Island; ***b***, MGMNP; ***c***, Little Andaman.

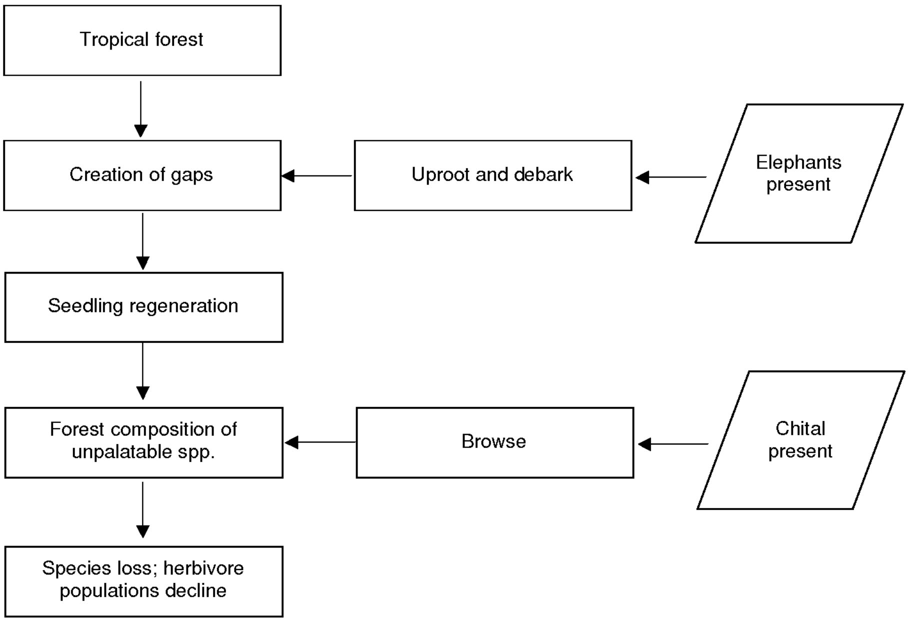

Figure 12. Effect of herbivore action on forest structure.

for rank, $F_{2,18} = 0.86$ for location, n.s.). This suggests that any major changes must occur at the seedling stage.

Discussion and conclusion

Figure 12 summarizes the process that appears to be going on. Trees can be subjected to herbivore-induced processes. Trees that are food items for elephants are debarked or uprooted. These create gaps. Gaps are also created in the other places but due to factors such as windfall or disease, and will be formed at a much slower rate. If the seedlings that colonize the gaps are palatable for chital, these are eaten. The species that would be expected to come up are those that are not eaten by chital. Sapling densities remain the same because seedlings that are browsed would be replaced by other non-palatable ones.

Where there are elephants, saplings that constitute food items would be eaten. The rest would, after attrition due to other factors, become trees.

Forests with herbivores present would change composition to species not browsed by chital. The presence of elephants would accelerate this process by knocking down trees and creating gaps at a more rapid rate.

Elephant food choices appear to have changed. Sivaganesan (unpublished report) noted a number of species that he did not record as being damaged by elephants. These are being browsed now. He had recorded that cane, bamboo and *Pandanus*, all favoured by elephants, were getting scarce. These have disappeared from the transects chosen, and were only seen on steep rocky hill slopes that were inaccessible to elephants. Since the cut-off girths for the trees sampled is not given by him, direct comparisons for other plant species are difficult. The drop in elephant populations, combined with the changes in food, indicate that the population may be facing a food shortage.

The problem seems to be made more acute by the presence of deer, which seriously hamper regeneration of many species. It appears that the sapling densities are lower; however the ones that are not browsed appear to grow faster, and this may explain the similarity in basal areas between the three sites. The effect the deer have on regeneration is shown by the higher number of girths in the 30–60 cm girth class. This effect is the same as the one caused by the thinning of forest, where there is an increase in this girth class.

The similarities in the frequency changes in the top-ranked species are not surprising, given that different species would have different recruitment and mortality curves. Only long-term paired comparisons between browsed and unbrowsed plots would indicate the extent of change that is occurring. We do not, however, have species-level data for seedlings; this is now being gathered by constructing exclosures.

In summary, the forests of the Andamans, which have 14% endemicity in plants, would suffer a species loss in those areas where introduced herbivores such as elephant and chital are present. Some of these are endangered, and additional work needs to be done to establish the endangered species that are found here. It is also likely that plant alien invasives would tend to colonize these areas of reduced diversity. India would then have a responsibility under Section 8 (h) of the Convention on Biodiversity, to institute effective control measures. In the case of elephant, trapping and relocation to mainland India would be appropriate.

There is a conflict between two laws here. The above would make it mandatory to remove elephants. However, according to the Wildlife (Protection) Act, 1972, elephants are protected. In such cases, some law has to take precedence. An amendment allowing the removal of exotics, no matter what their protection status elsewhere, is required. Modifying the Wildlife Act so that ecosystem conservation takes priority over animal rights is also required. These arguments are even stronger in the case of chital, which are not endangered.

For chital, darting and sterilization have been suggested[21]. This however seems impractical given the vast distances between islands, the rainforest habitat and the shyness of the animals. Culling is required. This is problematic under the Wildlife Protection Act, 1972. This case study indicates that the removal of introduced animals, no matter what their protected status elsewhere, has to be permitted in order to protect the ecosystems to which they cause damage.

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