Satellite images indicate vegetation degradation due to invasive herbivores in the Andaman Islands

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Recent studies have documented changes in vegetation cover due to invasive herbivores in the Andaman Islands. In this study we demonstrate that the change is large enough and rapid enough to be detected by remotely sensed data. Using the freely available Normalised Difference Vegetation Index (NDVI) imagery, we examined changes in vegetation cover due to the presence of invasive herbivores in the Andaman Islands. Two time-periods were analysed using different types of imageries. Changes between 1985 and 1995 and also between 2001 and 2005 across four sites with different combinations of introduced chital (spotted deer) and elephants were examined. Results indicate that areas with deer have faster rates of degradation than those without them. The maximum rate of degradation occurred at sites with both elephants and deer, and the minimum where neither of the two animal species occurred. Besides wild pig, all the other herbivores on the islands are invasive, and there is a need to eliminate these invasive herbivores in the islands.

Keywords: Invasive herbivores, remote sensing, satellite imagery, vegetation degradation.

THE Andaman Islands located in the Bay of Bengal, about 1200 km from the east coast of India, extend from the 10°–12°N and 92°–94°E. They form part of an island chain in the Andaman Sea, that starts south of the Mergui peninsula in Burma, and ends north of Aceh, in western Sumatra. More specifically, they are bounded by the Cocos Channel in the north and the Ten Degree Channel in the south.

Numerous studies have shown the degradation of vegetation, for example, a reduction in the number of species or reduction in biomass, by invasive herbivores. Examples of these include degradation of vegetation by feral goats on Aldabra Atoll[1], and the spread of exotic plant species by exotic mammalian herbivores[2].

A recent publication pointed out that introduced herbivores in the Andaman Islands were causing vegetational changes[3]. These included a reduction in the number of tree species as well in tree basal area in regions where chital, also known as spotted deer (*Axis axis*), and elephant (*Elephas maximus*), both introduced, were found. Chital were introduced to the islands in the 1930s as a game animal. In the absence of natural predators and competitors, and being good swimmers, they have spread to every island in the Andaman group of islands, with the exception of Little Andaman. Elephants were brought over from mainland India in the 1880s. In 1962, a timber company on the 106 km^2 Interview Island went bankrupt and released its 40 elephants into the forest. The population was reported as 31 in 2001 (ref. 4), it may have dropped further now (R.A., pers. obs.). It is considered invasive largely because off the vegetation damage done by it.

In this article we establish that the change caused by these herbivores is large enough and occurs over a timeframe that is short enough to be detected by freely available satellite imagery. We also discuss policy issues that need to be addressed urgently to tackle the problems caused by animals that have become invasive.

There are no native herbivores on the island except for wild pig, which is omnivorous. Other herbivores introduced to these islands, including domestic livestock, are not found at any of the sites that were sampled. Since humans cause anthropogenic changes, including forest degradation, areas near human settlements were avoided; the exception being areas with low tribal – Jarawa and Onge – populations. These are foragers, and do not clear land or fell trees. They also occur at very low densities and so are expected to have limited impact. Thus areas in which they are found are considered effectively uninhabited for the purposes of this study.

The earlier study[3] had identified Interview Island as an uninhabited site which has both deer and elephant. Little Andaman has neither, but has a recently settled human population which has caused forest changes, major in some parts, in the last two decades. The west side of Little Andaman is relatively free of logging, encroachment and other human pressures, and has a small population of Onge tribals, and was therefore chosen as a site for this study. The Mahatma Gandhi Marine National Park (MGMNP) has deer populations on its islands. These

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Table 1. Areas and herbivores present at the study sites. For each site, two sets of imageries were used: 1985–1995 and 2001–2005. Each pixel is 1 km^2. The only other herbivore present besides those considered in the study is the endemic Andaman pig. Under 'other factors', possible confounding variables are listed. These are discussed in the text in more detail

Area	Area sampled (km^2)	Herbivores	Other factors
Interview Island	31	Deer, elephant	
Mahatma Gandhi Marine National Park	33	Deer	
Jarawa Reserve	68	Deer	Poaching; small tribal population
Little Andaman	223	–	Small tribal population

islands are uninhabited, except for small settlements on Rutland Island, which has been eliminated from the analysis. Jarawa Reserve has a small population of Jarawa tribals, about 240 spread out over 911 sq. km (ref. 5). It also has deer and their densities appear to be lower here than on Interview Island because of hunting by non-tribals at its periphery. Vegetationally, these areas were all wet evergreen forest. Areas near habitations as well as the coastline have been eliminated from the analysis. The differences in these study areas are summed up in Table 1.

To assess the change in vegetation cover across the four sites, a comparison of Normalized Difference Vegetation Index (NDVI) trends between sites over time was made. NDVI values are based on the principle that chlorophyll strongly absorbs visible light but reflects near-infrared (IR) light. If there is more near-IR reflectance, then the vegetation in that pixel is likely to be dense. NDVI has been used in different kinds of analyses, including monitoring land degradation[6], calculation of biomass and grazing intensity[7], estimation of species richness[8,9], and to assess malaria risk[10].

Satellite imagery has also been increasingly used in the detection and management of invasive species. For example, the imagery has been used to identify healthy stands of hemlock affected by insect pests[11]. NDVI has also been used to map long-term land-use changes partly caused by invasives[12]. NDVI was used to demonstrate that cat removal resulted in an increase in rabbit numbers, thus causing environmental degradation at a World Heritage site[13]. However, satellite imagery has not been used to its full potential: Mack's[14] statement that success with it still remains elusive appears to be valid. This is possibly the first study where it has been used to monitor invasive herbivore impacts directly on vegetation.

In this analysis we use NDVI as a proxy for vegetation health. A recent review[15] discusses the use of NDVI for assessing ecological responses to the environmental change. It has been used to map vegetation since the late 1990s (ref. 16), and also for mapping habitat changes[17].

Methods

For 1986–1995, we used the calibrated vegetation index (CVI) data compiled and mosaicked by the National Institute of Environmental Studies, Japan. These data consisted of multiple cloud-free NDVI images that were processed to obtain the highest NDVI over a short time-period, e.g. 10 days. This compositing is done to remove the impact of clouds or any other atmospheric interference that may reduce the NDVI as read. The individual images were then stitched together to cover the entire region, i.e. mosaicking. The data were radiometrically and geometrically corrected prior to calculation of the normalized vegetation index. So this is not identical to NDVI, as it differs slightly in the processing. The CVI was derived from the Advanced Very High Resolution Radiometer (AVHRR) satellite platform bands 1 and 2.

One kilometre maximum NDVI composited datasets for the period 2000–2005 was obtained via a Goddard Distributed Active Archive Center (DAAC) website[18]. The product is derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) produced by selecting cloud-free values of NDVI from successive daily acquisitions of data and retaining the maximum value, which is assumed to be least affected by clouds, for each pixel location. The compositing period generally is limited to a 10-day or semi-monthly time-interval to minimize temporal variations in the resultant data product.

Although 10-day NDVI images are available, we downloaded and analysed annual maximum value composites. Change in vegetation over time was determined by fitting a regressional slope trend line[19]. The regression of the NDVI values versus year was done for each pixel (block) of 1 km^2. Positive slopes indicate increase in vegetation, whereas negative slopes indicate decrease in vegetation cover. The number of sample grids selected in each site is given in Table 1.

There are numerous sources of error that are possible in this kind of study. Areas near habitation have been avoided to eliminate errors due to logging and encroachments. There are also differences in satellite sensor alignment between different years. We excluded grids along the coast to avoid the influence of changes in coastline due to the sensor alignment problem. The only source of difference that appears to remain is the presence or absence of invasive herbivores such as the chital and elephant.

Results

Figure 1 shows the change in NDVI at the sampled sites for the two datasets, where each pixel shown on the maps

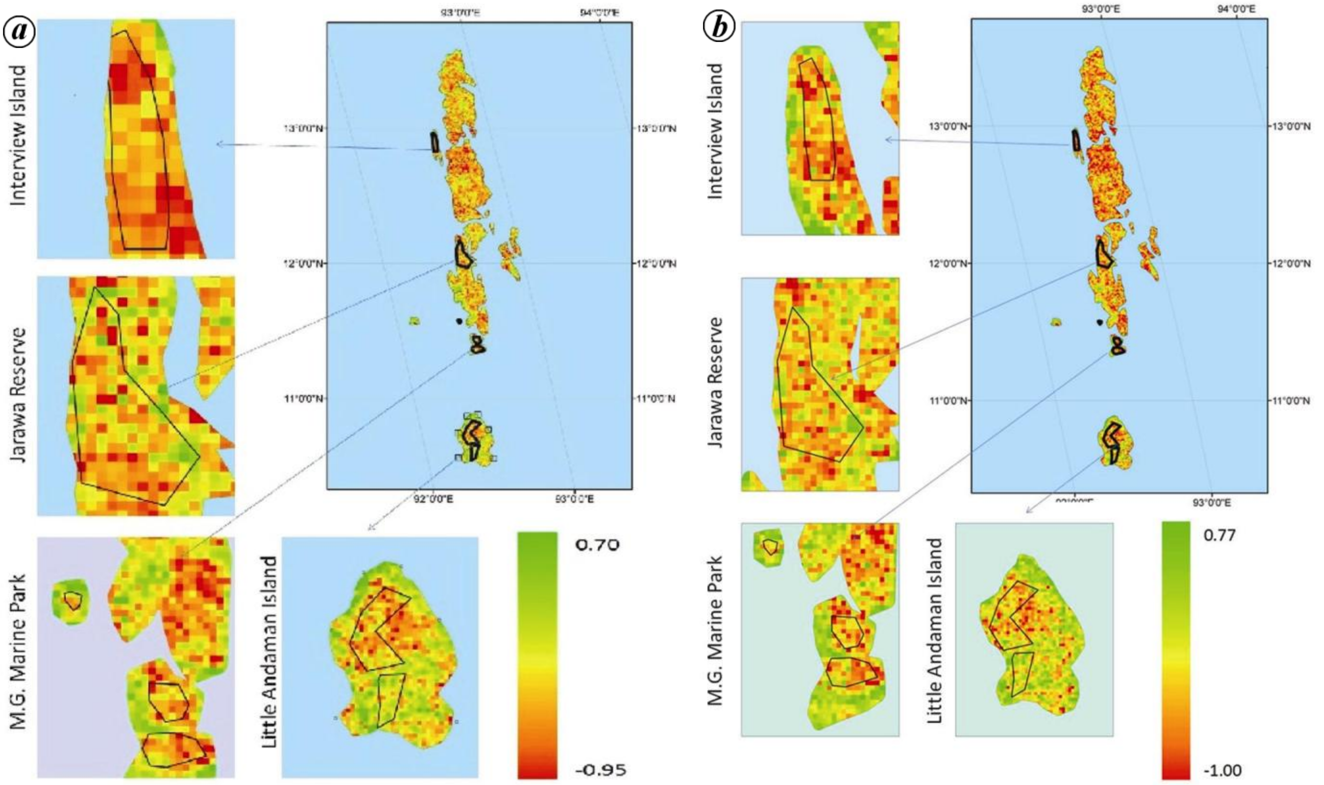

Figure 1. ***a***, Map of CVI trends, from the 1985–1995 AVHRR data. The values represent the per cent slope in NDVI. Here –1 represents 1% decline in the slope per year and + 1 represents 1% increase per year. These values differ from the tables which are 1000 × % change. The larger map shows the location of the sampling sites within the Andaman Islands. ***b***, NDVI trends from the 2001–2005 MODIS data. The values represent the percentage of slope in NDVI. Here –1 represents 1% decline per year and + 1 represents 1% increase per year. These values differ from the tables which are 1000 × % change. The larger map shows the location of the sampling sites within the Andaman Islands.

represents the change in vegetation cover over the time-period indicated. The per cent changes were calculated using a linear regression of NDVI over time. The slope values were then scaled to percentage change. These are the regression slope coefficient. It is apparent that Little Andaman, with no herbivores, has shows least degradation; in contrast, Interview Island, with two herbivores species, shows the maximum degradation. The other two sites, with only chital, are in between.

Box plots were then used to summarize the differences between the four sites. The box plots compare the scaled regression slopes for each pixel in the study area. The slope was calculated by regression of NDVI by year. These are then compared across the study sites using a box and whiskers plot. The results depicted in Figure 2 show the same pattern.

Two statistical tests were used to test this – pairwise Kruskal–Wallis and pairwise ANOVA using Tukey's contrasts for 95% pairwise differences.

The linear functions in Figures 3 reflect these trends for the two datasets. These are Tukey pairwise 95% confidence intervals for the difference in the mean. NDVI change for all the pixels in the sample are for location A versus the mean NDVI change for pixels in Location B. The slope values are a comparison of each island with itself in a time series.

The results using the MODIS data are more clearcut than the results using the AVHRR data, since the within-site variation is much lower. Interview Island had a significantly higher rate of degradation than both Jarawa Reserve and Little Andaman.

Table 2 shows the results of a Kruskal–Wallis test for the two datasets. Little Andaman has a significantly lower rate of degradation than both Interview Island and Jarawa Reserve for the 1985–1995 data. For the 2001–2005 dataset, Interview Island degraded faster than the Jarawa Reserve–MGMNP cluster, which in turn degraded faster than Little Andaman, and all but one of these comparisons show significant differences.

If a regional or global change is responsible for the decline over a period of time, then it should be similar for all areas. It is possible that localized impacts operate differently across sites, and we cannot rule this out totally. However, we assume here that there is no difference in localized impacts between the site with elephants and the sites that do not have them. Thus in a declining period, the areas with elephants declined faster than those without elephants. Our analyses do not prove that

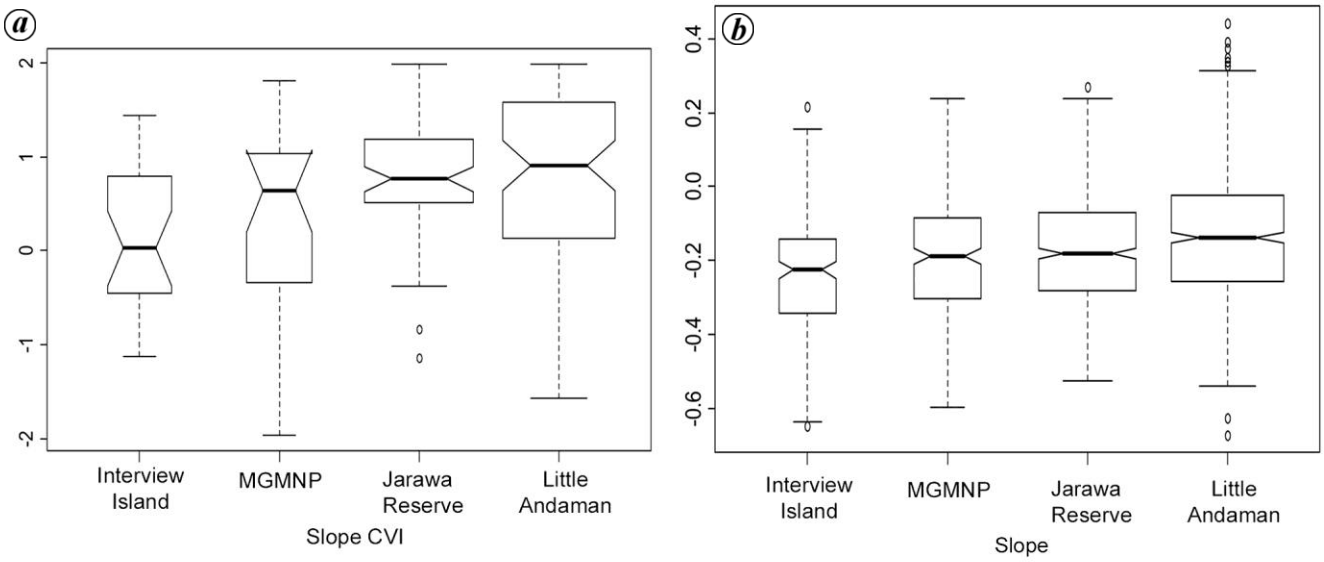

Figure 2. ***a***, Box plot of the slopes obtained for each pixel for the CVI values between 1985 and 1995. The box plots compare the scaled regression slopes for each pixel in the study area. The slope was calculated by regression of NDVI by year. Thus Interview Island has 31 linear regression slope values, MGMNP has 33 regressions, Jarawa Reserve has 68 regressions, and Little Andaman has 223 regressions. These are then compared across the study sites using a box and whiskers plot. ***b***, Box plot of the slopes are obtained for each pixel for NDVI values between 2001 and 2005. The slope was calculated by regression of NDVI by year. Thus Interview Island has 31 linear regression slope values, MGMNP has 33 regressions, Jarawa Reserve has 68 regressions, and Little Andaman has 223 regressions. These are then compared across the study sites using a box and whiskers plot.

elephants are the only cause for the decline, but rather we can reject the claim that there is worse decline in areas with elephants than those without them.

An interesting point is that the slopes for the 1985–1995 data are mainly positive, whereas they are mainly negative for the 2001–2005 data. This might reflect differences in rainfall over these periods. An analysis of the difference in monthly rainfall between three periods, for the AVHRR data, for the MODIS data, and for the non-imaged years in between, is presented in Figure 4. The MODIS years had significantly higher rainfall per month than either the non-imaged years or the AVHRR years. Higher rainfall should lead to increased greening, e.g. increasing NDVI during the MODIS time-period[20]. We still cannot rule out cyclones, high winds or other factors. However, it should be noted here that the absolute values of the slopes are not as important as the differences between the slopes across sites.

Discussion

The vegetation changes in Little Andaman and Interview Island have already been documented[3]. The present study further strengthens the findings of previous field surveys. Interview Island has a high deer population as well as a feral elephant population[4]. The two deer-only places have a lower rate of degradation since tree damage by elephants does not occur.

Plant transects on Interview Island suggest the causes of this degradation[3]. The regeneration in logged areas here consists almost entirely of *Lagerstromia hypoleucos*, one of two common species not browsed by chital (the other being *Pongamia pinnata*, a coastal species on the island).

The answer to this degradation seems to be a combination of chital and elephants. Elephants have damaged the vegetation badly in recent years, and have created a situation where forest regeneration rates are higher than normal. Elephant damage is seen in the form of trees that have been knocked down, or damaged because their bark has been stripped, details are given elsewhere[4]. The chital prevent regeneration by browsing on the seedlings. Besides direct observation on this, there is an abundance of stumps of browsed seedlings that can be seen. To assess the exact quantum of browsing damage would require exclosure studies, which are being undertaken now[17].

The degradation observed over relatively short time-span is worrying, and indicates that the problem of invasives in the Andaman Islands needs to be urgently tackled. Other invasives on the islands that have not been studied but need attention include feral dogs and cats. Unfortunately, very few other studies on invasive species in general have been done in this part of the world[3,4].

The internationally accepted scientific principle for dealing with invasive species is clear. In brief, if it is introduced and causes economic and environmental damage, remove it. An earlier study[3] makes it clear that regeneration is seriously affected by chital, and a case can be made for its removal.

The issue under consideration would be how cost-effective is this removal likely to be? The data indicate that vegetation is decreasing in the sites where chital are

Table 2. Kruskal–Wallis multiple comparison tests between pairs of sites, with critical differences calculated at the $P < 0.05$ level. The variable being tested is the slope of the NDVI for each pixel between sites

Comparison	Observed difference	Critical difference	P
For 1985–1995 data			
Interview Island–MGMNP	3.78	42.58	n.s.
Interview Island–Jarawa	12	36.89	n.s.
Interview Island–Little Andaman	35.57	35.4	<0.5
MGMNP–Jarawa Reserve	15.78	36.11	n.s.
MGMNP–Little Andaman	39.35	34.59	<0.5
Jarawa Reserve–Little Andaman	23.57	27.29	n.s.
For 2001–2005 data			
Interview Island–MGMNP	121.79	125.68	n.s
Interview Island–Jarawa Reserve	163.6	111.1 < 0.5	< 0.5
Interview Island–Little Andaman	280.14	107.61	< 0.5
MGMNP–Jarawa Reserve	41.81	98.78	n.s.
MGMNP–Little Andaman	158.35	94.84	< 0.5
Jarawa Reserve–Little Andaman	116.54	74.44	< 0.5

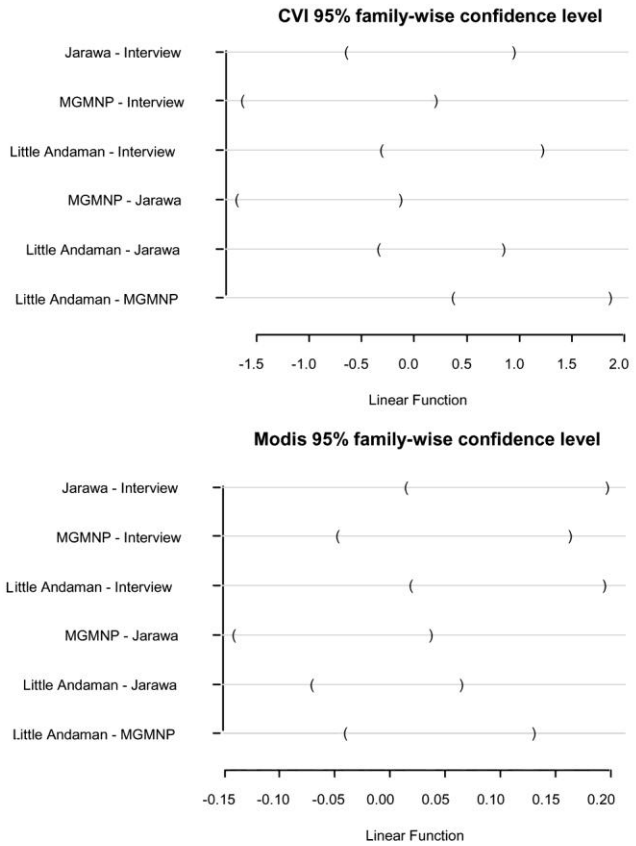

Figure 3. Tukey pairwise 95% confidence intervals for the difference in the mean NDVI change for all the pixels in the sample are for location A versus the mean NDVI change for pixels in Location B. Little Andaman had a mean NDVI change 0.11 higher than Interview Island. The confidence interval for the mean difference did not overlap 0. Hence we reject the hypothesis that there is no mean difference between the two. The slope values are a comparison of each island with itself in a time series.

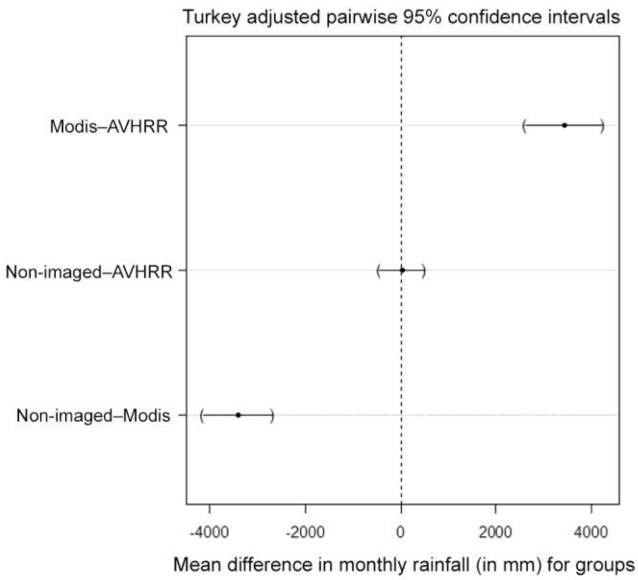

Figure 4. Mean difference in monthly rainfall for Port Blair for the non-imaged years, the AVHRR years (1985–1995), and the MODIS years (2001–2005). The Tukey adjusted 95% confidence intervals for the pairwise differences are also shown.

found, and their removal is therefore likely to stop this deterioration. There are no other herbivores in competition in these areas, and thus multispecies invasions are not a problem. If a policy change allowing hunting to take place is made, then the removals would actually generate revenue for the Andaman & Nicobar Administration.

The issue of removal of elephants is more problematic. Culling would not be possible because of popular sentiment. Periodic translocation of the younger animals to areas in mainland India, or overseas appears to be a solution.

It is worth pointing out that India is one of the very few countries in the world that does not have an invasive species policy, and such a policy is urgently required. A research programme on the impacts of invasives, and the economic and environmental costs of having them, is urgently needed. In respect to these particular cases, studies are required as to the extent of regeneration that occurs when deer are eliminated, for instance, with exclosure experiments. A start in this direction has already been made (Mahesh Sankaran, pers. commun.).

A point that has been raised repeatedly is that no reliable population estimates are available for deer. It is difficult to census herbivores in evergreen forest, which is the dominant vegetation in these areas. However, one does not need census figures to validate the decision to eliminate invasive herbivores. It is enough to show that degradation is happening, and we have shown a quick method for establishing this.

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