

# Vegetation changes between 1978, 1991 and 2003 in the Nakoudojima island that had been disturbed by feral goats

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## **Abstract**

Changes in vegetation of the Nakoudojima island between 1978, 1991 and 2003 were quantified with aerial photographs. The island was divided into 9200 plots (10 m x 10 m) on the aerial photographs and the plots were categorized into forest, grassland, bare ground or others. Percentages of the grassland increased 66.3% to 69.0% and those of the bare ground increased from 7.0% to 15.5% for 23 years. Some grasslands became bare ground between 1978 and 1991, which resulted in a decrease in the area of the grassland and an increase in the area of the bare ground during this period. On the other hand, some bare ground changed to grasslands between 1991 and 2003, which meant an increase of grasslands. These changes in vegetation would be due mainly to grazing and trampling, and their termination caused by feral goats. Percentages of the forest decreased from 16.2% to 6.0% for 23 years. Many forests changed into grasslands or bare ground even after the eradication of feral goats, which suggests that canopy trees in the forest died by natural disturbances in addition to the lack of seedlings by the grazing of feral goats.

## **Introduction**

Feral goats graze and/or trample vegetation in many oceanic islands, which often causes destruction of vegetation and acceleration of soil erosion (Coblentz, 1978; Coblentz and van Vuren, 1987; Stone and Loope, 1987; Loope et al., 1988; de la Luz et al., 2003). The feral goats were, therefore, eradicated in many islands for native conservation (a review, Campbell and Donlan, 2005). After the eradication, vegetation recovers in some oceanic islands (Hamann, 1975, 1979; Mueller-Dombois and Spatz, 1975; Bullock et al., 2002; Kessler, 2002; Shimizu, 2003a), but it does not in others. One of the reasons why the vegetation did not recover would be shortage of dispersed seeds because of the mortality of reproducing trees.

Vegetation of the Nakoudojima island, one of the Bonin islands in the north-eastern Pacific (27°37'-27°38'N, 142°10'-142°11'E) had been severely disturbed by feral goats and the goats were completely eradicated by 1999. The goats reduced

the vegetation cover of forests and grasslands by grazing and/or trampling, which accelerated erosion of the soil by 1999 (Japan Wildlife Research Center, 1992; Shimizu, 1993). After the eradication, herbaceous species reestablished at some sites in the island (Japan Wildlife Research Center, 2002; Shimizu, 2003b), but there were few saplings and seedlings of tree species except for *Trema orientalis*, *Callicarpa subpubescens* and *Leucaena leucocephala* (Shimizu, 2003b). The above-mentioned changes in vegetation were described only qualitatively by Shimizu (2003b) but not quantitatively. In this study, we quantified areas of forests, grasslands and bare ground, and clarified their spatial distribution in the island with aerial photographs in order to describe how the vegetation of the Nakoudojima island was disturbed and recovered.

## Methods

Three successive sets of aerial photographs in 1978 (1:10000, Japan Geographical Survey Institute), 1991 and 2003 (1:10000, Japan Ministry of the Environment) were used to quantify the spatial and temporal changes of vegetation in the Nakoudojima island. Peripheral areas of the island were not included in this analysis because they were coasts or cliffs without vegetation. The island except for coasts and cliffs was divided into 9200 plots (10 m x 10 m) on the aerial photographs (Fig. 1). The plots were categorized into forest, grassland, bare ground or others based on the largest area in each plot of the aerial photographs. The bare ground meant sites at which surface soil was exposed, and sites at which surface soil was completely lost were categorized into others. The others were mainly consisted of cliffs or rocks.

It is difficult to determine exactly when goats were introduced to the island, but over 60 goats were kept as livestock in the island in 1883 (Ogasawara-Touchoh, 1888). The naturalized goats after World War II increased their numbers and they reached about 500 in 1991 (Japan Wildlife Research Center, 1992). Their eradication was begun in 1997 and completed in 1999 by the Tokyo local government (Japanese Wildlife Research Center, 2002).

## Results

Over twenty plots belonging to the bare ground aggregated in the section B3, C3 and D4 in 1978 in Fig. 2a. Less than ten plots of the bare ground aggregated throughout the island in 1978. In 1991, Over one-hundred plots of the bare ground aggregated in the section A4, B2, B3, B4, C3 and D4 in Fig. 2b. Most of the plots of the bare ground had been those of the grassland in 1978. A part of the plots of the bare ground in 1991 changed into those of the grassland between 1991 and 2003 (Fig. 2c).

There was an area of the forest consisted of over two-hundred plots at D3 and the forest area composed of ca. one-hundred plots in the section B4 in 1978 (Fig. 2a). Forest patches consisted of less than thirty plots scattered in the island in 1978. Between 1978 and 1991, 62.1% of the plots of a forest changed into the grassland

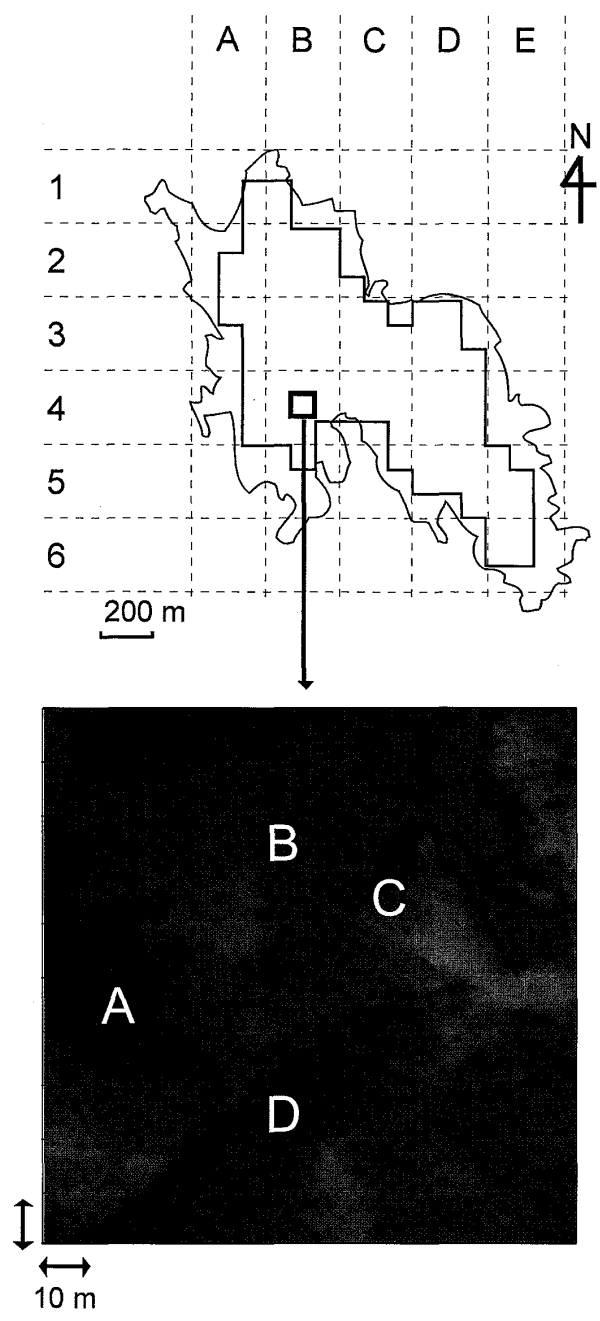
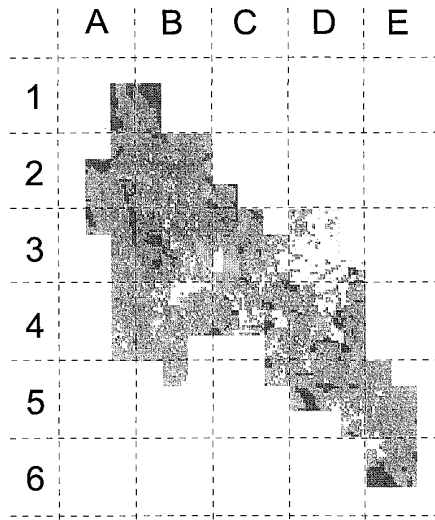
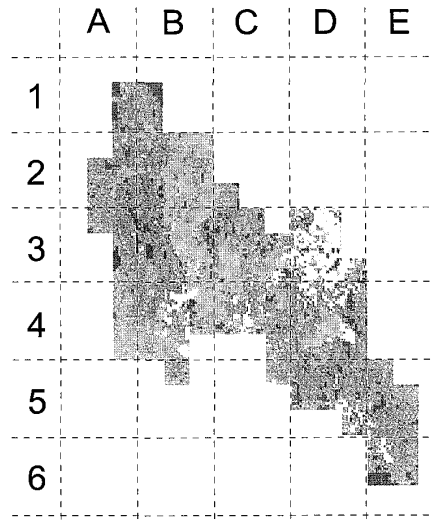


Figure 1 Locations of 10 m x 10 m plots on the Nakoudojima island. The inner area of the solid line was divided into nine-thousand-two-hundred 10 m x 10 m plots. The photograph shows forest (A), grassland (B), bare ground (C) and others(D) .

(a) 1978



(b) 1991



(c) 2003

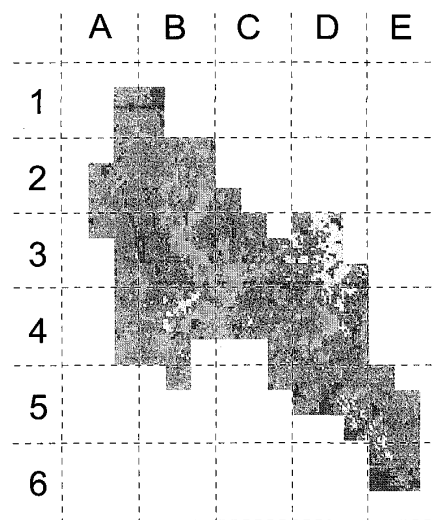


Figure 2 Spatial distribution patterns of forest, grassland, bare ground and others in (a) 1978, (b) 1991, and (c) 2003.

or the bare ground and 59.0% of the plots of the forest into the grassland or the bare ground between 1991 and 2003. As a result, numbers of plots of the forest in the section D3 and B4 in 2003 decreased by 50% of the numbers in 1978. Most forests patches in 1978 disappeared by 2003 (Fig. 2b, c).

Number of the 10 m x 10 m plots belonging to the bare ground was the smallest of those of four categories in the Nakoudojima island in 1978 (Fig. 3). The number drastically increased between 1978 and 1991, and the percentage of the plots of the bare ground against 9200 plots increased from 7.0% to 21.9%. The number of the plots, however, decreased from 1991 to 2003, and its percentage in 2003 was 15.5%. The number of the plots belonging to the grassland decreased from 1978 to 1991, while it increased from 1991 to 2003. Its percentage was 66.3% in 1978 and 58.8% in 1991, while it increased to 69.0% in 2003. The number of the plots belonging to the forest decreased for 23 years. Its percentage was 16.2% in 1978, 11.0% in 1991 and 6.0% in 2003. There were few changes in numbers of the plots belonging to others for 23 years.

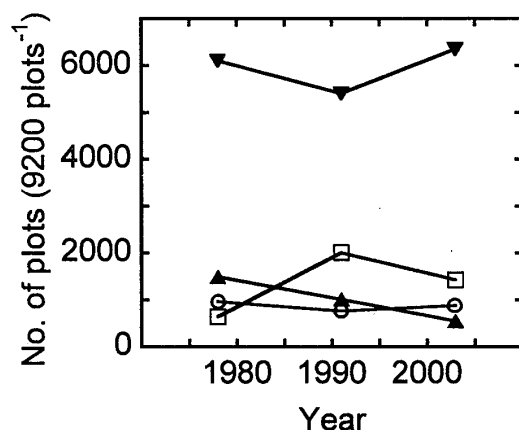


Figure 3 Changes in numbers of the 10 m x 10 m plots of forest, grassland, bare ground and others during the 23 years.

▲ : forest, ▼ : grassland, □ : bare ground, ○ : others

## Discussion

Decreases in the grassland and increases in the bare ground between 1978 and 1991 suggests that large biomass of herbaceous plants were lost by grazing and trampling of feral goats. These results were similar to the tendency observed between 1968 and 1991 in this island (Japan Wildlife Research Center, 1992). On the other hand, increases in the grassland and decreases in the bare ground between 1991 and 2003 suggest that herbaceous plants reestablished in some areas of bare ground after release from grazing and trampling of feral goats by the eradication of the goats, which is consistent with the results of the field experiment conducted in the Nakoudojima island. In the experiment, rapid growth of herbaceous plants were observed at sites from which feral goats were experimentally excluded

(Japan Wildlife Research Center, 2002). The results obtained by this study are also consistent with previous studies in other oceanic islands (Hamann, 1979; Mueller-Dombois and Spatz, 1975; Bullock et al., 2002; Kessler, 2002).

Decreases in the forest between 1978 and 1991 would be caused by mortality of canopy trees due to natural disturbances and by the grazing of seedlings of trees (Shimizu, 1993). There were, indeed, few seedlings on the forest floor in the Nakoudojima islands before the eradication of feral goats (Shimizu, 1993), which was also observed in other oceanic islands (Schofield, 1989).

After the eradication of feral goats, the lack of dispersed seeds due to death of reproducing trees and, thus, the lack of seedlings result in decreases in the forest between 1991 and 2003. In fact, densities of seeds of tree species in the soil of the grassland and bare ground were very low after the eradication of feral goats (Weerasinghe, per. com.). Therefore, it would need long for recovery of forests in the Nakoudojima island after the eradication.

Recovery of vegetation would depend on seed rain. The seed rain would be affected by feral goats in the grassland as well as the forest. The grassland was recovered after the eradication in the Nakoudojima island while the forest was not. The seed rain of the forest would not be sufficient probably because of effects of feral goats and physical disturbances such as typhoons or severe droughts. Therefore, it would need more time for recovery of the forest than that of the grassland.

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## Abstract in Japanese

野生化ヤギによる攪乱を受けた媒島で見られた 23 年間 (1978-2003 年) の植生変化

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小笠原諸島媒島にて、23 年間の植生の変化を航空写真を用いて定量的に評価した。1978 年、1991 年、2003 年の航空写真から森林、草地、裸地の面積の変化を調べた。この間、媒島の植生は、野生化ヤギによる食害と踏圧およびヤギ排除によるそれらからの開放を経験した。草地が島全体に占める割合は、23 年間で 66.3% から 69.0% に、裸地が占める割合は 7.0% から 15.5% に増加した。1978 年から 1991 年にかけて、草地の一部が裸地に変化した。その結果、草地の面積は減少し、裸地の面積は増加した。1991 年から 2003 年にかけて、裸地の一部が草地に変化した。その結果、草地の面積は増加し、裸地の面積は減少した。以上の結果は、草地と裸地の変化は、ヤギによる食害、踏圧とそれらからの開放によって引き起こされたことを示唆する。一方で、森林が占める割合は、16.2% から 6.0% に 23 年間で減少した。これは、森林が、野生化ヤギの有無にかかわらず、草地や裸地に変化したことを意味する。以上は、森林の減少は、ヤギの食害による実生の定着の欠如に加え、種子供給源である林冠木の枯死によることを示唆する。