

The Effects of Forest Fragmentation on Population Structure and Reproductive Output in Populations of *Magnolia obovata*

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Introduction

Forest fragmentation caused by anthropogenic activity is a threat to the continuation of local populations and communities throughout the world, because it causes a decrease in the number of conspecific reproductive individuals, which can result in decreased reproductive output and, eventually, increased risk of extinction. Forest fragmentation also changes environmental conditions via edge effects, which can positively or negatively affect seedling establishment, growth, and reproductive output of trees. Animal-pollinated plant reproductive output can be influenced through changes in local animal assemblages, caused by changes in behavior and flight patterns, in response to fragmentation (Aizen and Feinsinger 1994; Didham 1996). Thus, forest fragmentation can directly and indirectly affect reproductive output; however, few studies have investigated the effect of forest fragmentation on population structure and reproductive output of tree species.

Many studies have examined reproductive output of herbaceous species and shrubs. However, few studies of reproduction in tall tree species have addressed reproductive processes by marking or sampling reproductive twigs, but it is laborious to estimate reproductive output at the individual level. In this study, we addressed whole plant reproductive output, including flowering, fertilization, and seed set.

The study species, *Magnolia obovata*, is ubiquitous in the cool temperate forests of Japan, but at a relatively low density. It is not clear how such sparse tree populations are maintained. This species has a large reproductive organ, which makes it easy to evaluate the reproductive output at the whole plant level throughout the reproductive process.

The aim of this study was to evaluate the effect of forest fragmentation on the population structure and reproductive output of *M. obovata*. We compared tree density, size distribution patterns, reproductive characteristics (flower number, fruit set, and seed number per fruit) at two nearby sites, one conserved and one fragmented, in the southern part of the Abukuma Mountains, Ibaraki Prefecture, central Japan, over a three-year period.

Materials and Methods

Study Site

The study was carried out in the Ogawa Forest Reserve and its surrounding area, in the southern part of the Abukuma Mountains, Ibaraki Prefecture, central Japan (36°56'N, 140°35'E; altitude 610–660 m above sea level). Mean annual air temperature and precipitation at a meteorological station in Ogawa (36°54'N, 140°35'E) during the study period were 10.7°C and 1910 mm, respectively (Moriguchi et al. 2002). The study area is covered by deciduous broadleaf forest, and the dominant woody species in the canopy are *Quercus serrata*, *Fagus japonica*, and *F. crenata* (Nakashizuka et al. 1992; Masaki et al. 1994).

The study site was about 2 km × 3 km, and included lands with various uses, such as conserved natural forest (98 ha), fragmented natural forest (29 ha), secondary forest, coniferous plantations, farmland, and pasture. The study was conducted in the conserved natural forest and the fragmented natural forest (Fig. 1).

The fragmented forest is shaped like a fish bone, and is located about 500 m from the conserved forest (Fig. 1). According to forest management notes and interviews with local people, forest fragmentation was caused by clear cutting of broadleaf forest and planting of coniferous trees in the 1970s. The vegetation of the conserved forest is thought to be similar to that of the fragmented forest. Secondary forests and coniferous plantations surround the conserved and fragmented forests. The secondary forests include several deciduous broadleaf species, such as *Quercus serrata*, and are used for charcoal production by the local people.

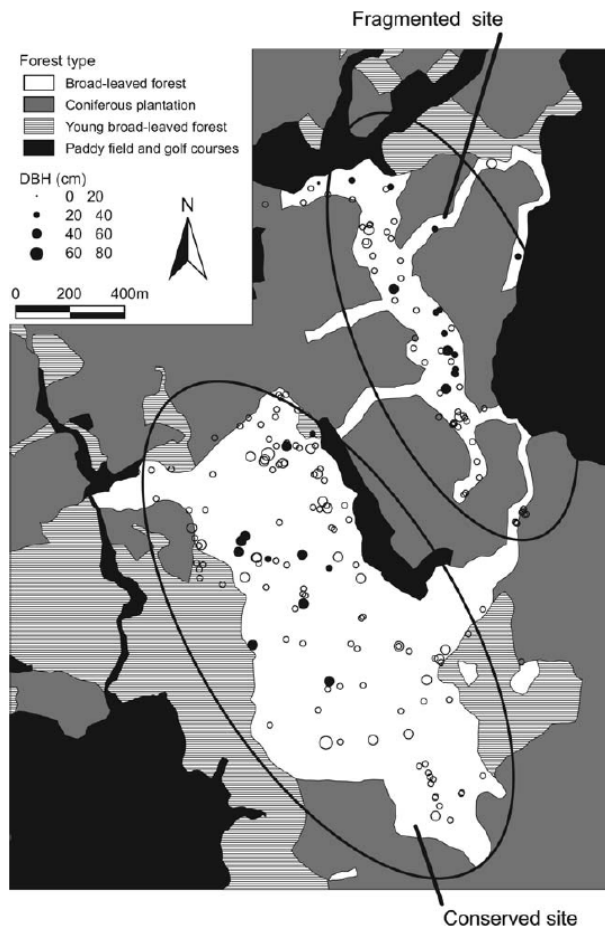


Fig. 1 The sizes and locations of reproductive *Magnolia obovata* trees in the conserved and fragmented forest sites. Filled circles: Adult trees from which fruits were collected (Isagi et al. 2007).

Study Species

The flower of *M. obovata* is one of the largest in the region, protogynous and without nectaries. The main pollinators of the flowers are beetles, bumble bees, and halictid bees (Tanaka and Yahara 1988; Tateno et al. personal observation). Although individual flowers last for 3–4 days, a tree flowers for up to 40 days, from late May to early July, in this study area (Tateno et al. unpublished data). Seeds reach maturity in mid-September at the study site and are dispersed by birds.

Field Study and Sampling

Reproductive *M. obovata* trees were identified and the location of each tree was determined with a portable GPS (eTrex Summit, Garmin, Kansas, USA). We measured diameter at breast height (DBH) of all trees and checked the flowering status of each tree.

Eight individuals (22.1–56.4 cm DBH) per forest type were selected for counting flower number and fruit number from the conserved and the fragmented forests. We accessed the canopy by ladder or climbing ropes, or both, and sketched almost all of the flowers or flower buds on a branch during the flowering period. We checked for fruit set in late September.

We selected fourteen individuals (18.0–56.6 cm DBH) for fruit sampling from the conserved forest and the fragmented forest. Five or more mature fruits were collected from each sampled tree; however, in non-fruiting years, we were unable to collect five fruits per individual. The numbers of ovules and mature seeds in each fruit were counted.

Results and Discussion

The density of trees was 1.3 trees/ha in the conserved forest and 1.9 trees/ha in the fragmented forest. Although there were no differences in size distribution patterns of large trees between the conserved and the fragmented forests, the number of small individuals (<40 cm DBH) was higher in the fragmented forest than in the conserved forest (Fig. 2). These small trees can establish in forest edges and roadsides at the time of clear-cutting of surrounding forests. According to the distribution map of individuals, some patches containing small individuals were located along the forest edge and roadside in the fragmented forest (Fig. 1). The percentage of reproductive trees increased with size, and all trees with DBH greater than 30 cm were reproductive (Fig. 2). These results suggest that, in the near future, the density of reproductive individuals should increase much more in the fragmented forest than in the conserved forest.

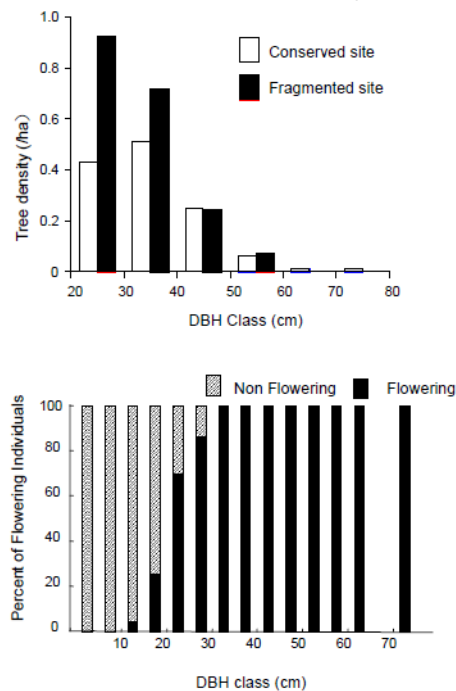


Fig. 2 Size distributions of *Magnolia obovata* trees and the percentage of flowering individuals.

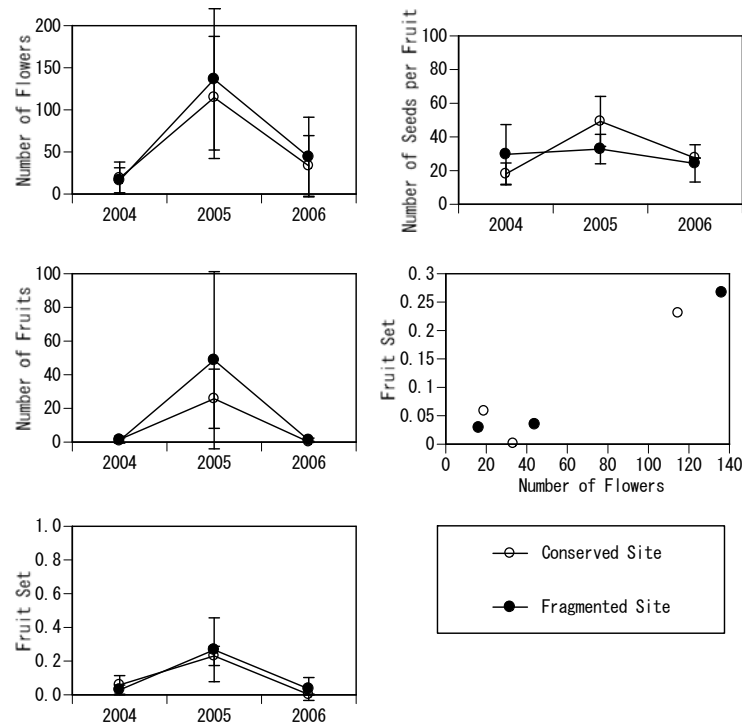


Fig. 3 Interannual changes in reproductive properties of *Magnolia obovata* in the conserved and fragmented forests.

The trees flowered and produced fruit every second year, and were synchronized between the conserved forest and the fragmented forest (Fig. 3). There was a clear positive correlation between flower number and fruit set (Fig. 3), suggesting that increased flower number results in increased fruit set in *M. obovata* of this site. Kikuzawa and Mizui (1990) showed significantly increased fruit set by self-pollination and concluded that populations of *M. obovata* were pollinator-limited in a deciduous broadleaf forest in northern Japan. In contrast to fruit set, seed number per fruit did not show clear inter-annual variation. Seed number per fruit varied widely among fruits. Isagi et al. (2004) found that outcrossing rate and number of pollen donors varied widely among fruits. Pollination is highly variable at the level of fruits and individuals, possibly because of high variability in pollinator behavior. Seed number per fruit may be affected by several other processes, such as seed predation and abortion.

Although the average reproductive output did not differ significantly between the conserved and fragmented forests, the responses of reproductive processes to the local density of reproductive individuals differed between the two sites. Isagi et al. (2007) reported that the fertilization of ovules and outcrossing were more dependent on density of reproductive individuals in the fragmented forest than in the conserved forest. Similarly, fruit set in this study was dependent on density of reproductive individuals in the fragmented forest; however, this relationship was not significant in the conserved forest (Tateno et al. unpublished data). These results suggest that compensatory mechanisms for the low density may operate in the conserved forest more effectively than in the fragmented forest. We speculate that foraging area of pollinators may be wider in the conserved forest because it may be easier for them to forage in the canopy of deciduous trees. In the fragmented forest, the canopy of deciduous trees was interspersed with coniferous plantations, farmland, and pasture, and pollinators may concentrate near trees growing in the congested areas of conspecific trees. A better understanding of pollinator foraging behavior will be

important for predicting the effect of fragmentation on population dynamics of this species.

Forest fragmentation may favor *M. obovata* populations because of the increasing number of safe sites for seedling establishment, growth, and future reproduction. Currently, the reproductive outputs of the two forest sites were not significantly different, but in the future the density of reproductive trees will increase in the fragmented forest, which will weaken pollen limitation and increase reproductive output. However, the fragmented populations may suffer negative genetic effects, such as inbreeding depression, increased susceptibility to diseases and pests, fixation of deleterious alleles, and loss of self-incompatibility alleles. Future studies are required to predict the effects of forest fragmentation, both the ecological and genetic consequences, on *M. obovata* population dynamics.

Acknowledgments

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