Rapid decline of endemic snails in the Ogasawara Islands, Western Pacific Ocean

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Abstract

The distribution of *Mandarina* spp., endemic land snails (ground-dwelling ecotype species) of the Ogasawara (Bonin) Islands (Japan), was examined from the 1980's to the present in Chichijima and Hahajima islands. In Chichijima Island, *M. mandarina* has been rapidly declining since the 1990's in the northeastern area of the island. On the other hand, *M. chichijimana* has only slightly declined since the 1990's in the southern area of the island. In Hahajima Island since the 1990's, *M. polita* has slightly declined in the central area while *M. ponderosa* has been rapidly declining, and *M. aureola* has shown almost no decline in the southern area of the island. These circumstances offer evidence of the expansion of land snail predators (flatworms). Moreover, Chichijima and Hahajima islands differ in the pace of their respective decline, perhaps because of a predatory flatworm, *Platydemus manokwari*, used previously as a biological control agent abroad for the giant African snail, *Achatina fulica*, which only invaded Chichijima Island in the 1990's.

Key words: *Mandarina* spp.; land snail decline; island biology; *Platydemus manokwari*; Ogasawara (Bonin) Islands

INTRODUCTION

In tropical oceanic islands, it has been found that many endemic land snails have already become extinct as a result of exotic predators such as the predatory snail, *Euglandina rosea* or the predatory flatworm, *Platydemus manokwari* introduced for biological control of the giant African snail, *Achatina fulica*, or through accidental invasion (Muniappan, 1983, 1987, 1990; Clarke et al., 1984; Muniappan et al., 1986; Takeuchi et al., 1991; Hopper and Smith, 1992; IUCN/SSC Mollusc Specialist Group, 1995; Cowie, 2001a, b; Tomiyama, 2002a; Ohbayashi et al., 2005; Sugiura et al., 2006); however, the process by which extinction occurs is relatively unknown.

The Ogasawara (Bonin) Islands are located in the western Pacific Ocean about 1,000 km south of the mainland of Japan. More than 100 species of land molluscs have been recorded on the islands,

of which 94% are endemic (Tomiyama and Kurozumi, 1992; Tomiyama, 1994); however, about 40% of the endemic species are already extinct (Kurozumi, 1988; Tomiyama and Kurozumi, 1992).

The following may be possible reasons for this decline: introduction of exotic snails such as *A. fulica* (Kurozumi, 1988; Tomiyama, 2002a); introduction of the predatory snail *E. rosea* for the control of *A. fulica* in 1965 in Chichijima Island (Takeuchi et al., 1991); predation by predatory flatworms distributed before *P. manokwari* invasion (Kawakatsu et al., 1999; Okochi et al., 2004); invasion of the alien predatory flatworm *P. manokwari* in Chichijima Island in the 1990's (Kawakatsu et al., 1999; Tomiyama, 2002a; Ohbayashi et al., 2005); predation by alien rats (Tomiyama, 2002a); and forest destruction (Tomiyama, 2002a). In Chichijima Island, the most likely cause of the decline of land snails is thought to be the invasion of

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P. manokwari in the 1990's (Kawakatsu et al., 1999; Tomiyama, 2002a; Ohbayashi et al., 2005; Sugiura et al., 2006).

One of the endemic genus *Mandarina* has diversified into taxa occupying many habitats (e.g. arboreal, semi-arboreal, terrestrial, dry, and wet habitats), and shows remarkable diversity in shell and genital morphology (Minato, 1978; Chiba, 1996, 2003); however, *Mandarina* spp. also has suffered serious destruction due to predation by introduced species such as *P. manokwari* (Chiba, 2003). Thus, understanding the process of the decline of *Mandarina* spp. and the impact of *P. manokwari* on *Mandarina* spp. might be useful for the conservation of *Mandarina* spp. in future.

This study was undertaken to clarify the process of extinction of *Mandarina* spp. from the 1980's to the present through distribution research, and how *P. manokwari*, which invaded Chichijima Island in the 1990's, relates to the decline of *Mandarina* spp. by comparing the process of decline in Chichijima and Hahajima islands.

MATERIALS AND METHODS

Study areas. All studies were conducted in Chichijima and Hahajima islands, which are part of the Ogasawara (Bonin) Islands (Fig. 1).

Distribution of *Mandarina* spp. From 1986 to 2003 (covering spring to winter, with search areas and months differing with the year), we searched under fallen leaves, logs and stones in the daytime, and recorded the sites where live ground-dwelling ecotypes *Mandarina* spp. (*M. mandarina*, *M. chichijimana*, *M. polita*, *M. aureola* and *M. ponderosa*) were detected every 1 to 5 years. Each site was about 1 m² in area. Species of *Mandarina* spp.

were identified according to Chiba (1989, 2003, 2004).

There were 26 research sites in Chichijima Island and 73 sites in Hahajima Island.

Changes in the distribution area of *Mandarina* spp. According to Tomiyama (2002a), the mobility of *Mandarina* spp. is very low, so we assumed that the restoration of extinct populations by re-invasion would not occur during the research years. Therefore, we regarded populations at sites where live snails were confirmed to have been in the same location and not migrants from elsewhere. If a population was not confirmed at a site one year but was discovered at the site in a later year, we assumed that its density had been too low to have been detected in the earlier year. According to these assumptions, we made distribution maps for the years 1986, 1995 and 2003.

Distribution of *Platydemus manokwari*. We searched under stones and logs in the daytime in the years 1995, 1998, 2002, 2003 and 2004 (29 times in total) in Chichijima Island and in the years 1998 and 1999 (5 times in total) in Hahajima Island (covering spring to winter, with search areas and months differing with the year). We also conducted nighttime observations of the forest floor (once in December 1998 and once a month from January to July, 2004 in Chichijima Island and once in January 1999 in Hahajima Island), and recorded the sites where *Platydemus manokwari* was detected.

We also used 20 cm×20 cm mesh bags made of 5 mm nylon mesh as attractant traps into which one live *A. fulca* (shell height: over 40 mm) was put in Chichijima Island. The traps were set on the forest floor near a road (45 sites) from March to May 1998, checked every few weeks, and the sites where *P. manokwari* was detected were recorded.

Fig. 1. Location of the Ogasawara Islands. a: Chichijima Island; b: Hahajima Island.

RESULTS

Distribution of *Mandarina mandarina* (Chichijima Is.)

Mandarina mandarina was distributed over the northern and northeastern areas of Chichijima Island in 1986 (Fig. 2a). In 1995, the first local extinction occurred at one point in the northern area of Chichijima Island (Fig. 2b). After that, extinction advanced rapidly to the year 2003 in Chichijima Island, so that *M. mandarina* now only occurs

Fig. 2. Distributions of *Mandarina mandarina* in Chichijima Island in the years 1986 (a), 1995 (b) and 2003 (c). ●: Live *M. mandarina* was recorded; ○: Live *M. mandarina* was not recorded; ▽: Research was not conducted. Solid lines in the maps indicate surfaced roads and broken lines indicate mountain trails.

Fig. 3. Distributions of *Mandarina chichijimana* in Chichijima Island in the years 1986 (a), 1995 (b) and 2003 (c). ●: Live *M. chichijimana* was recorded; ○: Live *M. chichijimana* was not recorded; ▽: Research was not conducted. Solid lines in the maps indicate surfaced roads and broken lines indicate mountain trails.

in the northeastern area (Fig. 2c).

Distribution of *Mandarina chichijimana* (Chichijima Is.)

In 1986, *Mandarina chichijimana* was distributed over the southern area of Chichijima Island, but there was already no live *M. chichijimana* in the central area of the island (Fig. 3a). In 1995, the first local extinction occurred at one point in the southwestern area of Chichijima Island (Fig. 3b). Subsequently, extinction advanced slightly so that by 2003 in Chichijima Island, the distribution area of *M. chichijimana* was limited to the southeastern and southwestern areas (Fig. 3c). The extinction areas of *M. chichijimana* and *M. mandarina* were sequenced.

Distribution of *Mandarina polita* (Hahajima Is.)

In 1986, *Mandarina polita* was distributed over the northern and central areas of Hahajima Island (Fig. 4a). By 1995, extinctions had occurred at two

points of the central area (Fig. 4b). After that, further extinction advanced in the central area to the year 2003 (Fig. 4c). Moreover, another extinction occurred in the northern area, but it was not clear when it had started (Fig. 4c).

Distribution of *Mandarina aureola* (Hahajima Is.)

Mandarina aureola is an allopatric species whose distribution area is adjacent to the area of *M. polita*. This species was distributed over the southern area and one point of the northern area of Hahajima Island in 1986 (Fig. 5a), and no obvious extinction was observed in either 1995 or 2003 (Fig. 5b, c).

Distribution of *Mandarina ponderosa* (Hahajima Is.)

Mandarina ponderosa is a sympatric species whose distribution area overlapped the area of *M. aureola* and *M. polita*. In 1986, this species occurred sporadically over the northern, central and

Fig. 4. Distributions of *Mandarina polita* in Hahajima Island in the years 1986 (a), 1995 (b) and 2003 (c). ●: Live *M. polita* was recorded; ○: Live *M. polita* was not recorded; ▽: Research was not conducted. Solid lines in the maps indicate surfaced roads and broken lines indicate mountain trails.

Fig. 5. Distributions of *Mandarina aureola* in Hahajima Island in the years 1986 (a), 1995 (b) and 2003 (c). ●: Live *M. aureola* was recorded; ○: Live *M. aureola* was not recorded; ▽: Research was not conducted. Solid lines in the maps indicate surfaced roads and broken lines indicate mountain trails.

Fig. 6. Distributions of *Mandarina ponderosa* in Hahajima Island in the years 1986 (a), 1995 (b) and 2003 (c). ●: Live *M. ponderosa* was recorded; ○: Live *M. ponderosa* was not recorded; ▽: Research was not conducted. Solid lines in the maps indicate surfaced roads and broken lines indicate mountain trails.

Fig. 7. Distributions of *Platydemus manokwari* on Chichijima Island in the 1990's (a) and 2000's (b). ●: *P. manokwari* was recorded; ○: *P. manokwari* was not recorded; ★: The point where one of the attractant traps was set. Solid lines in the maps indicate surfaced roads and broken lines indicate mountain trails.

southern areas of Hahajima Island (Fig. 6a), but by 1995, there had been a decline in the central and southern areas (Fig. 6b). Further decline had occurred in the southern area by the year 2003 (Fig. 6c).

Distribution of *Platydemus manokwari*

In Chichijima Island, *Platydemus manokwari* was detected near the town (northwest) and farmland (central) areas, and along the road linking these areas in the 1990's (Fig. 7a). In the present decade, *P. manokwari* has been detected over a wide area of the island (such as the central mountain areas), except for the eastern and southern coastal areas (Fig. 7b).

In nine of the 37 sites where *P. manokwari* was recorded, land snails and *P. manokwari* coexisted, but at the other 28 sites, only *P. manokwari* was recorded, and only one of the 45 traps attracted *P. manokwari* (★ of Fig. 7).

On the other hand, in Hahajima Island, no *P. manokwari* was detected in any area.

DISCUSSION

Until the mid 1980's, before *Platydemus manokwari* invaded Chichijima Island, there were many *Mandarina* spp. populations in Chichijima (and Hahajima) Island(s) (Kurozumi, 1988 and Figs. 2–6). This suggests that the impact of predators such as *Euglandina rosea*, introduced in the 1960's to Chichijima Island (Takeuchi et al., 1991) distributed in limited area, was not so serious in those days (Kurozumi, 1988).

However, around 1986 in Chichijima Island, there was already no *Mandarina* spp. from the northwest coastal area to the south-central area (Figs. 2 and 3). There are many farmlands and roads in these areas which were home to many exotic snails (such as *Achatina fulica* and *Bradybaena similaris*), as well as the predatory snail, *E. rosea* (Kurozumi, 1988; Takeuchi et al., 1991; Tomiyama, 1991, 1994). *E. rosea* is not distributed in Hahajima Island, but except for this point, the conditions on Chichijima Island in the 1980's were similar to those on Hahajima Island at present (Okochi et al., 2004).

In the 1980's, there were several species of predatory flatworms (but not *P. manokwari*) in Chichijima Island (Kawakatsu et al., 1999), so a similar decline caused by alien species and predators may have occurred there, similar to the current situation in Hahajima Island.

In 1995, *M. mandarina* was extinct in one of the northern areas of Chichijima Island (Fig. 2b). There were already *E. rosea* (Kurozumi, 1988) and several predatory flatworms (but not *P. manokwari*) in this area (Kawakatsu et al., 1999), so these predators affected *M. mandarina* in the 1980's, and subsequently in the 1990's, the invasion of *P. manokwari* might have been the final blow for *M. mandarina*. Incidentally, this point is thought to be where *P. manokwari* began its invasion (Fig. 7).

On the other hand, one extinct area of *M. chichijimana* population in the southwestern area of Chichijima Island in 1995 (Fig. 3b) was far from the first area invaded by *P. manokwari*, but recently, *P. manokwari* has been recorded in the vicinity (Fig. 7b). Consequently, this extinction is thought to have been caused by *P. manokwari*.

The expansion of extinct areas during the eight years from 1995 to 2003 has been startling (Figs. 2 and 3). *P. manokwari* occurred in those areas (Fig. 7b), so it is believed to be the cause of decline. This sudden expansion might have been caused by artificial transmission by human activities, and the abundant supply of exotic land snails as food sources. So it is likely that *M. chichijimana*, as the endemic species of Chichijima Island, might become extinct some time in the future.

In Hahajima Island, *M. polita* has slightly declined (Fig. 4). This decline was thought to have been caused by predation by flatworms (Kawakatsu et al., 1999) which have increased their population

by preying upon, and winning competition against, exotic land snails such as *A. fulica* (Okochi et al., 2004). The extinction areas were concentrated along surfaced roads from north to south on Hahajima Island and the mountain trail in the central part of the island. According to Numazawa et al. (1988), the exotic land snail *A. fulica* preferred disturbed areas affected by human impact. Furthermore, Okochi et al. (2004) described that predators such as *P. manokwari* can readily be transported by human activities, so disturbance caused by the construction of these roads has led to the invasion of exotic land snails and predators and, as a result, extinction areas might be increasing.

Meanwhile, *M. aureola*, which is distributed in the southern area of Hahajima Island, was thought to be safe from extinction (Fig. 5); however, a surfaced road was constructed in the southern area of Hahajima Island recently, but exotic land snails are still rare there (Okochi et al., 2004), so *M. aureola* is surviving.

M. ponderosa has declined in the central and, especially, southern areas of Hahajima Island (Fig. 6), but the reason for its decline is thought to be different from that of *M. polita*. They are all ground-dwelling ecotypes (Chiba, 2003), so they compete against each other; therefore, extinction may occur if their populations are decreased by environmental deterioration. Except for one northern area where *M. ponderosa* has survived and *M. polita* is extinct, *M. ponderosa* is competitively inferior to *M. polita* and *M. aureola*.

These findings reveal that the respective processes of extinction of *Mandarina* spp. in Chichijima and Hahajima islands are very different (Figs. 2–6), as is the distribution of *P. manokwari* in the two islands (Fig. 7). In other words, the invasion of *P. manokwari* has caused a rapid decline in land snails; if the invasion of *P. manokwari* had not occurred, the decline might have been slow. Indeed, Sugiura et al. (2006) confirmed that *P. manokwari* puts high predation pressure on land snails in Chichijima Island.

The invasion of *P. manokwari* is rapidly bringing about the extinction of *Mandarina* spp. in the oceanic Ogasawara Islands because ecological resistance against the invasion of *P. manokwari* there might be weak. Moreover, the expansion of *P. manokwari* might be very rapid in disturbed areas (Fig. 7). It thus might be very difficult to eradicate

P. manokwari that has already invaded Chichijima Island (Tomiya, 2002b), so it is necessary to take immediate steps to preserve the populations of endemic species, *M. chichijimana*. For this purpose, populations must be isolated from predators, or introduced (or re-introduced) to outlying islands where no *Mandarina* spp. occur (if possible, to islands where land snails were distributed previously).

Moreover, it is necessary to make all possible efforts to prevent *P. manokwari* from invading Hahajima Island as well as uninhabited islands surrounding Chichijima and Hahajima islands. However, since a large amount of materials are moved between Chichijima Island and Hahajima Island, it will be necessary to restrict the transfer of plant seedlings and cars that have soil adhering to them. In addition, efforts should be made to keep uninhabited islands such as Anijima Island isolated.

P. manokwari is vulnerable to low temperature (Kaneda et al., 1992) and seawater (Ohbayashi, unpublished), so to prevent it from invading these uninhabited islands, shoes ought to be sterilized using refrigeration or seawater.

Incidentally, in Hahajima Island, which has currently not been invaded by *P. manokwari*, extinction by alien species and predatory flatworms has occurred in disturbed areas such as road construction sites; however, it is notable that extinction has also occurred at Mt. Chibusa in the central area, where only mountain trails have been constructed (Figs. 4 and 6). So in areas where many endemic land snails still survive, the construction of mountain trails should be reconsidered, and if possible, these areas should be managed to avoid disturbing endemic snail habitats.

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