Restoring the Oceanic Island Ecosystem

Kazuto Kawakami • Isamu Okochi
Editors

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Impact and Management of Invasive Alien Species in the Bonin Islands

Springer

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Preface

Loss of biodiversity on tropical and subtropical oceanic islands is one of the most pressing conservation issues. These oceanic islands are well known for their unique fauna and flora, which evolved over long periods in isolation from external perturbation. However, the majority of these islands in the Pacific were eventually settled by Polynesians and then by Europeans; by about 200 years ago, only a few island groups remained untouched. The Bonin Islands are one of these groups.

The Bonin Island group is one of the most remote in the world. The islands are located 1,000 km south of Japan off the eastern fringe of Eurasia. They were first discovered by the Japanese in 1670, settled by Westerners from Hawaii in 1830, and finally recognized as a Japanese territory in 1862 on condition that previous settlers would be protected and allowed to remain with full rights. Because of this complicated history, the Bonins have two names. The Japanese refer to the archipelago as the Ogasawara Islands, after the name of the feudal lord Ogasawara, who insisted that he discovered these islands. The Western name for the island group is the Bonins, which originally came from the Japanese word *mounin*, meaning "uninhabited."

Before World War II, these islands were developed for crop farming, pasture land, and fuel wood production. During the war, almost all Japanese residents were evacuated from the islands to the mainland and were not allowed back until 1968, when the United States returned the Bonins to Japan. The forests appeared to recover during the postwar years, but researchers found that alien trees had come to dominate the secondary stands, and endemic insects and snails had declined rapidly. Although the researchers visited the islands mainly to seek new evidence of evolution or to search for new species, they found an island ecosystem in crisis. However, national and local government policy at that time was one of "sustainable development" for the local people, a concept based on the illusion that nature can tolerate increased development if it is carefully planned.

The government eventually changed its policy from one of sustainable development to "sustainable life with nature" after accumulating evidence revealed ongoing ecosystem destruction on the islands. Fortunately, this change was made in time to prevent irreversible damage to the island biota. When the new concept was first adopted, the distributions of destructive alien invaders, such as the green anole (*Anolis carolinensis*) and the predatory flatworm (*Platydemus manokwari*), were restricted to the two main inhabited islands. This allowed remaining endemic species to survive on the other islands. For example, the endemic land snail survives on Anijima Island.

Under the new policy, the role of academics changed. What government and residents of the islands need now from researchers is not just evidence of ecosystem destruction, but ways and means for restoration. Moreover, the actions of the government to restore ecosystems through eradication or management of invasive alien species are being accelerated by the fact that the Bonins have candidate status for UNESCO World Heritage Site listing. The expanded restoration programs have been running for about 15 years.

It is noteworthy that ecosystem problems on the Bonin Islands are common to the majority of Pacific islands, which share many members of a suite of problematic invasive alien species,

including cats (*Felis catus*), black rats (*Rattus rattus*), goats (*Capra aegagrus*), pigs (*Sus scrofa domesticus*), cane toads (*Bufo marinus*), European honey bees (*Apis mellifera*), giant African land snails (*Achatina fulica*), predatory flatworms (*Platydemus manokwari*), and plants such as *Leucaena leucocephala*, *Casuarina cunninghamiana* and *Lantana camara*. Research and action investigating these invasive alien species on other islands has been of great assistance to our program, and our experience on the Bonins may be useful elsewhere.

Some invaders of the Bonins, such as bishopwood (*Bischofia javanica*), are currently being investigated, but previously unknown deleterious effects exist, such as the severe declines of endemic insects due to predation by the lizard *Anolis carolinensis*. Anoles are present in Hawaii and the Marianas, where deleterious effects on the insect fauna have not been reported. We are also facing emerging new problems whereby eradication of a dominant alien species may cause population expansion of other alien species previously suppressed by the dominant alien species.

Japanese academics have limited familiarity with oceanic islands because so few are included in the Japanese archipelago, and few workers are engaged in this area of research. Hence, international scientific cooperation among island nations is essential for increasing the conservation knowledge base of Pacific island ecosystems. Research resources available in single countries are insufficient. We have invited researchers from Hawaii, Australia, New Zealand, Spain, and the Galápagos Islands, enabling us to promote our studies and governmental action plans based partially on external advice. We also believe from these discussions that it is important to publish our research in order to share these experiences, which may help conservation on other oceanic island groups. This book was produced for that purpose.

Our research projects have been conducted with the cooperation of experts on a variety of taxa that are representative of the fauna and flora of the Bonins. The findings have been reported in scientific journals and have been applied in government restoration projects on Bonin ecosystems.

We selected 22 articles from among the published works to provide an overview of island conservation issues. Some were originally written in Japanese but have been translated into English for this book. We have also some newly written articles on latest issues. We introduce natural and historical backgrounds to Bonin Island ecosystems in Part I. The next two parts are major components of the book, in which we describe negative effects on island ecosystems of several important invasive species (Part II) and methods used to control these species (Part III). Conclusions from these research undertakings are discussed and summarized in Part IV.

I would like to sincerely thank all the researchers and many other people who participated in our projects. This book presents our common dream for restoring a Japanese oceanic island ecosystem, and we hope that this new synthesis will assist others who work toward conservation on their own islands.

Isamu Okochi, Editor

Acknowledgments

The chapters of this book are mainly the outcome of a series of research projects on the conservation and restoration of the Bonin Islands ecosystems since 1995. We would like to express our appreciation to a great number of researchers who participated in these projects. Discussion with them brought us the recent achievements. Although we could show only some of our outcomes in this book, there were many more results. We express our gratitude to Dr. Robert Cowie, Dr. Julie Denslow, Dr. Fred Kraus, Dr. Alan Tye, Dr. Anna Traveset, Dr. Mark Gardner, and Dr. Donald Drake for their participation in our meetings and for discussion on the management of invasive species in the Bonin Islands. We thank Dr. Koichi Goka, Dr. Hiroyoshi Higuchi, Ryuji Nakayama, Dr. Tadakuni Miyazaki, Dr. Yoshikazu Shimizu, and Kiyoshi Okutomi for their critical comments on our research planning. We express our sincerest gratitude to Dr. Noriko Iwai for her editorial assistance, which greatly supported the procedures. She always motivated us, managed our schedules, and patiently awaited the completion of our work. Without her help, we could not have finished this book on time. We are grateful to the staff of the Ogasawara Wildlife Research Society for their field assistance, and to Dr. Kenji Hata, Dr. Simon Lawson, Nodoka Nakamura and Yukiko Aoyama for providing invaluable assistance with the preparation of newly written or translated manuscripts. We are grateful to Yuko Matsumoto at Springer Japan, the publisher of the book, for her technical support. We also would like to thank the Ogasawara General Office (Ministry of Land, Infrastructure, Transport and Tourism), the Ogasawara Experimental Station, the Ogasawara National Park Ranger Office, the Ogasawara Islands Branch Office of the Tokyo Metropolitan Government, and Ogasawara Village for their receptive cooperation and legal support. Our research projects and the publication of this book were supported financially by the Ministry of the Environment of Japan (Global Environment Research Fund “F-051”, Global Environment Research Coordination System Fund).

Contents

Part I
The Bonin Islands

Chapter 1
What's the Bonin Islands?

Kazuto Kawakami

Abstract The Bonin Islands is comprised of oceanic islands located within the subtropical zone of the northwestern Pacific Ocean. Although species richness is low, high endemism is found on the islands due to physical isolation of the unique biota. However, human settlement began in 1830, causing extensive deforestation and the introduction of invasive species. At the height of prosperity, at least 14 islands were colonized and more than 7,000 people lived on them. The islands were under US occupation after World War II until 1968, when they were returned to Japan. Japanese people have since migrated to the islands, and various species have been introduced either intentionally or unintentionally. Insular populations are vulnerable to the devastating effects of introduced predators, competitors, and diseases because they have often evolved in the absence of these biotic factors. The species introduced to the Bonins by humans pose the greatest threat to the current ecosystem.

1.1 Location and Geography

The Bonin Islands are oceanic and arrayed across coordinates 26°33′–27°43′N and 142°05′–142°14′E in the northwestern Pacific Ocean (Fig. 1.1). More than 30 islands and rocks comprise three island groups, the Mukojima, Chichijima, and Hahajima groups. Although broad use of the term "Bonin Islands" sometimes includes the Volcano Islands and three isolated small islands (Nishinoshima, Minamitorishima, and Okinotorishima), we mostly use a narrower terminology here. We refer to the whole islands as the "Ogasawara Islands." Within this book, we include a selection of previously published works, among which island terminology may vary. As the Volcano Islands and the three other small isolated islands are closely related to the Bonins in biogeography and history, we have arbitrarily included information from these islands along with that from the Bonin Islands in the proper sense of the word.

The Bonin Islands are primarily volcanic, dating back to the Tertiary (Kuroda et al. 1981). They are located on the Philippine Sea Plate along its subduction zone at the interface with the Pacific Plate. Each island is relatively small; even the largest island, Chichijima, is only 24 km^2 in area, and the land mass of the whole islands covers just 70 km^2. The climate is subtropical, with monthly mean temperatures on Chichijima ranging from 18 to 28°C and an annual mean temperature of ca. 23°C (Japan Meteorological Agency 2001). Monthly precipitation ranges from 60 to 170 mm, with an annual rainfall of ca. 1,300 mm (Japan Meteorological Agency 2001).

1.2 Fauna and Flora

The biota of oceanic islands is distinct from that of continent because the resident species have never had contact with mainland communities (Carlquist 1974). The ancestors of island species arrived fortuitously after crossing open seas and establishing new populations. Wind dispersal, ocean currents, and bird vectors allowed only a limited number of species to reach the Bonin Islands. The biotas of islands are often species-poor and exist in ecosystem web structures that are simpler than are those in equivalent areas of mainland (Whittaker 1998). This tendency is particularly noticeable on smaller and more remote islands that typically lack indigenous land mammals and amphibians. On the Bonin Islands, no terrestrial vertebrates occur naturally other than the endemic Bonin flying fox *Pteropus pselaphon* and the endemic reptile *Cryptoblepharus nigropunctatus*; no native amphibians or snakes exist (Kuroda 1930; Momiyama 1930). Only 12 resident land bird species and 330 vascular plants are indigenous to the Bonin Islands (Momiyama 1930; Shimizu 2003).

Despite low species richness, the simple food webs of islands promote the evolution of endemism through adaptive radiation in the absence of competitors and/or predators.

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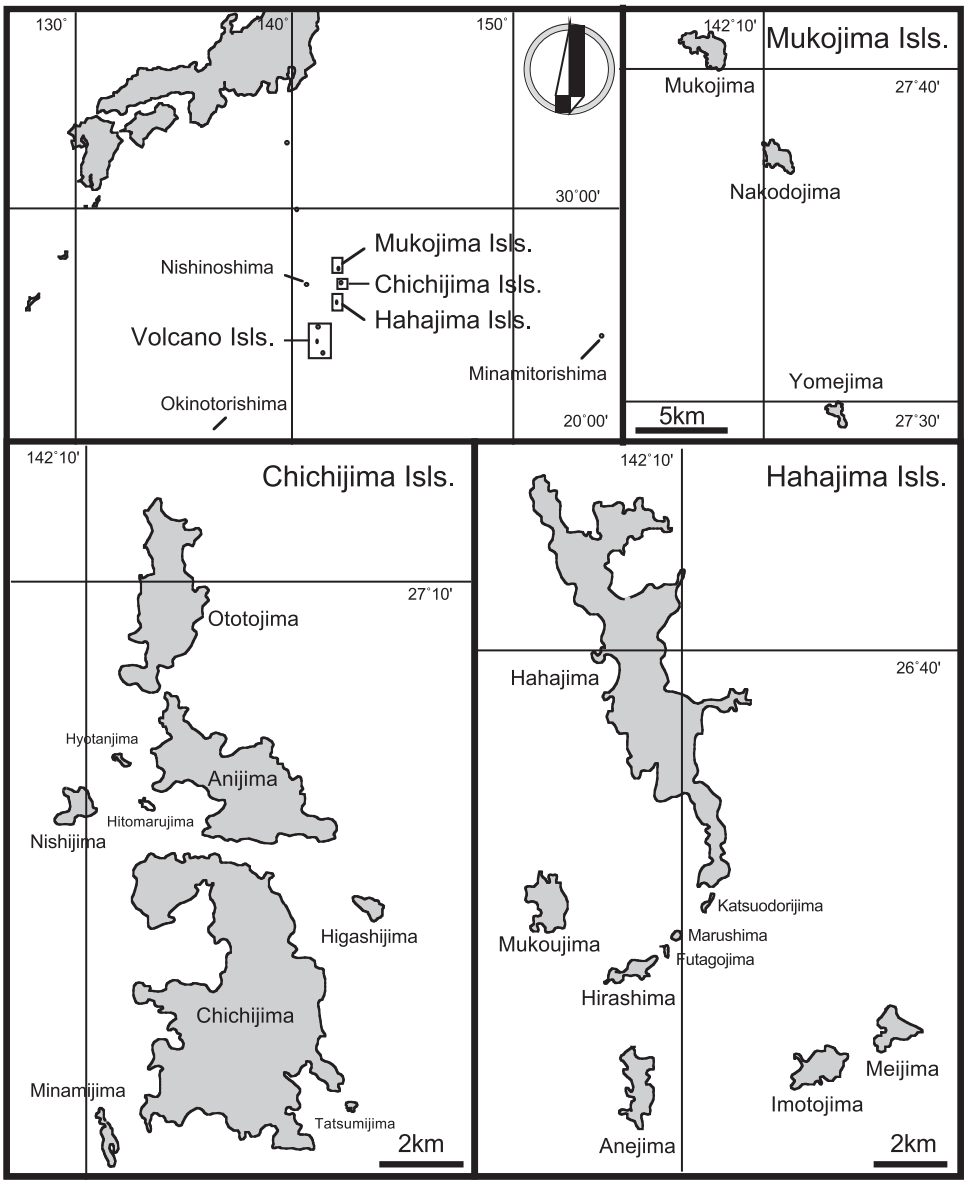

Fig. 1.1 Locations of the Bonin and Ogasawara Islands. The Bonin Islands include Mukojima, Chichijima and Hahajima Islands, whereas the Ogasawara Islands consist of the Bonins, Volcano Islands, and three small remote islands

The proportion of endemism on the Bonin Islands is 40% for all plants and 70% for arboreal species alone (Toyoda 2003); 80% of land birds are endemic species or subspecies (Ornithological Society of Japan 2000). Furthermore, more than 90% of native land snail species are endemic (Kurozumi 1988).

The flora of the Bonin Islands has a close relationship to those of Southeast Asia (e.g. Formosa, the Philippines, and Ryukyu Islands), although it also contains floristic elements found elsewhere, e.g., Japan, Hawaii, and the Polynesian Islands (Kobayashi and Ono 1987). The representative vegetation on Chichijima includes sclerophyllous scrubs dominated by *Distylium lepidotum* and *Rhaphiolepis wrightiana* whereas subtropical wet forests consisting of *Elaeocarpus photiniifolius* and *Schima mertensiana* characterize the vegetation on Hahajima (Okutomi et al. 1983).

1.3 History of Human Disturbances

Prehistoric remains (ca. 800–2000 years old) have been found on Kitaiwoto (Volcano Islands) and Chichijima (Oda 1998). Although the origin of these people is not clear, they may have arrived from the Izu Islands and/or the Marianas (Oda 1998). On many Pacific islands, some or

many bird species survived until (but not through) the first contact with humans during prehistoric times (Olson and James 1982; Steadman 1995; Pimm et al. 2006). Although no direct evidence exists, the original fauna and flora may have been disturbed during this age. Prehistoric residents disappeared prior to the recent human repopulation of the Bonin Islands.

During recent history, the first human colonizers of the islands in 1830 were European and Polynesian. There was whaling in the sea around the islands, which served as whaling stations (Tsuji 1995a). The immigrants exploited forests, established farmlands for crops such as sugarcane, corns, and sweet potatoes (Tsuji 1995a), and introduced domestic animals such as pigs, goats, cows, ducks, chickens, cats, and rats, all of which eventually became feral. The Bonin thrush *Cichlopasser terrestris* has never been recorded since its discovery in 1828, and it likely became extinct during this era of human colonization (Greenway 1967).

The Ogasawara Islands were confirmed as Japanese territory in 1862, and Japanese people began extensive colonization in 1876. As a result, deforestation and animal introductions were accelerated. Primary forests were destroyed for wood, fuel, and farmland. *Morus boninensis*, an endangered mulberry species, was nearly eradicated for its valuable timber during this period (Shimizu 2003). On the main islands (Hahajima and Chichijima), all areas amenable to cultivation were converted to sugarcane fields until the value of this crop suddenly dropped in 1910 (Kurata 1983). Subsequently, the sugarcane fields were converted to farms producing vegetables and foliage plants for exportation to the Japanese mainland (Funakoshi 1992). At least 14 islands were successively colonized, and the maximum population of the islands reached approximately 7,711 people in 1944 (Tsuji 1995a). Two endemic species (Bonin pigeon *Columba versicolor* and Bonin grosbeak *Chaunoproctus ferreorostris*), and two endemic subspecies (rufous night-heron *Nycticorax caledonicus crassirostris*, and Bonin Islands white-eye *Apalopteron familiare familiare*) all became extinct during this period (Ministry of the Environment 2002). The non-endemic jungle crow *Corvus macrorhynchos* had also disappeared from the islands by 1920 (Momiyama 1930).

One of the strongest impacts of this age was overexploitation of seabirds for feathers, meat, and guano (Tickell 2000). The short-tailed albatross *Phoebastria albatrus*, for example, became locally extinct on the islands (Higuchi 1984). On Minamitorishima, the easternmost island of Japan, Laysan albatross *P. immutabilis* and black-footed albatross *P. nigripes*, whose numbers were described as "exceedingly abundant in former days," were nearly exterminated within only 6 years of the initial colonization in 1896 (Bryan 1903).

World War (WW) II also had a drastic impact on the biota of the islands. The Japanese government forced approximately 6,900 inhabitants to evacuate the Ogasawara Islands in 1944 (Funakoshi 1992), and the farmlands were left unmanaged. Intensive bombing destroyed the forests on at least Chichijima, Hahajima, and Iwoto (Funakoshi 1992). WWII was also the decisive event for many seabird species on Minamitorishima, where the physical topography was entirely altered during wartime (Kuroda 1954). Approximately 5,000 Japanese troops were garrisoned there, and the island was exposed to severe bombardment (Kuroda 1954). Together, exploitation for feathers and WWII caused the local extinction of nine seabird species on Minamitorishima (Bryan 1903; Kuroda 1954; Chiba et al. 2007).

The Ogasawara Islands were under United States occupation from the end of WWII until their return to Japan in 1968 (Kurata 1983). Only a few locals and the US army remained on Chichijima, Iwoto, and Minamitorishima during this post-war period (Kurata 1983; Tsuji 1995b; Okutomi and Iseki 2004). Secondary forests densely covered the cultivated lands and former residential areas, and introduced plants such as *Leucaena leucocephala* and *Bischofia javanica* expanded their distributions (Yoshida and Oka 2000, Shimizu 2003). The green anole *Anolis carolinensis*, an invasive lizard, was also introduced during this time (Hasegawa et al. 1988).

When the Ogasawara Islands were returned to Japan, they were recolonized by both former and new human inhabitants. Only Chichijima and Hahajima were inhabited by civilians, and the other islands were left unpopulated, with the exceptions of Iwoto and Minamitorishima, which were occupied by the Japan Self-Defense Forces, the Japan Meteorological Agency, and the Japan Coast Guard. The current population of Chichijima and Hahajima is approximately 2,400, and transportation from the mainland is by ship once a week (National Institute for Japanese Islands 2004). Since the return of inhabitants, the forests have again been used for residential construction, roadways, parks, and agriculture. Various introduced species have both intentionally and unintentionally accompanied this renewed human activity. The species introduced to the islands by humans pose the greatest threat to the native ecosystem. Typical effects include predation, competition, disease, hybridization, and grazing. Particularly important examples of the introduced species are listed in Table 1.1.

Table 1.1 Distribution of major invasive species and countermeasures against them

	Current distribution	Impact	Ongoing countermeasure	Related chapter
Mammalia				
Goat (*Capra aegagrus*)	CC, OT, ANI (MK, NK, YM, NS, HG, MN, HT, MKU, HR, FT, ANE, IM, MI: eradicated)	Habitat alteration; predation on plants; destruction of seabird nest	Nearly finished to eradicate on ANI eradicating on OT	14
Pig (*Sus scrofa domesticus*)	OT (CC)	Habitat alteration; predation on soil animals	Nearly finished to eradicate on OT	20
Cat (*Felis catus*)	CC, HH, OT, ANI (MKU: naturally disappeared)	Predation on birds	Locally removed on CC and HH Eradicating on OT	10, 11
Norway rat (*Rattus norvegicus*)	HH, HR (CC: naturally disappeared)	Disturbance of succession		23
Black rat (*Rattus rattus*)	Almost all islands	Disturbance of succession; predation on birds and small animals	Eradicating on NS, HG and MK	8, 9, 23
House mouse (*Mus musculus*)	CC, HH	Disturbance of succession		23
Reptilia				
Green anole (*Anolis carolinensis*)	CC, HH	Predation on invertebrates	Locally removed around harbor on CC and from exclosure on HH	12, 13, 20, 21, 22
Amphibia				
American bullfrog (*Rana catesbeiana*)	OT	Predation on aquatic invertebrates	Nearly finished to eradicate on OT	20
Cane toad (*Bufo marinus*)	CC, HH	Predation on soil animals	Developing eradication technique	20
Gastropoda				
Rosy wolfsnail (*Euglandina rosea*)	CC	Predation on land snails		3, 4, 18
Giant African snail (*Achatina fulica*)	CC, HH (OT, ANI, HG, HR: naturally disappeared)	Predation on plants		18
Turbellaria				
Platydemus manokwari	CC	Predation on land snails	Preventing range expansion from CC	3, 4, 5, 6, 7, 18, 19
Magnoliopsida				
Bischofia javanica	CC, HH (OT, HR: nearly eradicated)	Forming uniform forest; competitive exclusion	Eradicating on CC and HH	15, 24, 25, 26
Casuarina equisetifolia	CC, HH, OT, ANI, NS, MKU, ANE	Forming uniform forest; competitive exclusion	Eradicating on ANI and MKU	20
Leucaena leucocephala	Almost all islands	Forming uniform forest; competitive exclusion	Eradicating on MK and NK	16
Lantana camara	CC, HH, MK, OT, ANI	Disrupting succession	Developing eradication technique	
Ficus microcarpa	CC, HH, MK, OT, ANI, HR	Strangling surrounding plants	Developing eradication technique	

CC Chichijima, *HH* Hahajima, *MK* Mukojima, *NK* Nakodojima, *YM* Yomejima, *OT* Ototojima, *ANI* Anijima, *NS* Nishijima, *HG* Higashijima, *MN* Minamijima, *HT* Hitomarujima, *HT* Hyotanjima, *MKU* Mukoujima, *HR* Hirashima, *FT* Futagojima, *ANE* Anejima, *IM* Imotojima, *MI* Meijima
Brackets show former distributions

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Part II
Impacts of Invasive Alien Species

Chapter 2
Impacts of Invasive Alien Species on Native Ecosystems on the Bonin Islands

Naoki Kachi

Abstract This part introduces quantitative studies on the impacts of invasive alien animals and plants on native ecosystems on the Bonin Islands. Predation by alien predatory flatworms such as *Platydemus manokwari* has caused the rapid decline or extinction of many endemic land snails. In addition, predation by black rats can cause microevolutionary changes in shell morphology and habitat use of endemic land snails. Feral cats prey upon land birds as well as seabirds characteristic to the Bonin Islands. An introduced lizard, the green anole (*Anolis carolinensis*), has caused serious damage to many insect populations, resulting in changes in the pollination systems of many native plants. Grazing and trampling by feral goats has caused destruction of vegetation, leading to accelerated soil erosion on some islands. An alien tree, *Bischofia javanica*, has replaced native trees due to its greater survival and seedling growth than those of native tree species. Invasion and dominance of an exotic shrub, *Leucaena leucocephala*, have prevented the establishment of some native woody species. Scientific understanding of the impacts of invasive species and their interactions with native species is essential for conservation and restoration of the native Bonin Island ecosystems.

2.1 Background

Invasive alien species often have strong impacts on native ecosystems through a variety of interspecific interactions (Parker et al. 1999). Ecosystems on oceanic islands are particularly vulnerable to invasions of these species (Loope et al. 1988). On the Bonin Islands, many alien species have invaded since human settlement began (Chap. 1), and some of these invaders have affected native ecosystems on the islands, in some cases causing degradation of ecosystem functioning and loss of biodiversity (Shimizu 2003). Eradication and control of invasive species are essential for the conservation and restoration of native ecosystems. To identify the target species for effective eradication and control programs and to develop conservation strategies for native ecosystems, it is essential to use scientific and quantitative data to evaluate the ongoing and potential future impacts of alien species on native ecosystems and to clarify the mechanisms underlying these impacts.

The impacts of invasive alien species include direct effects, such as prey–predator relationships and competition between plants for limited resources such as light, as well as indirect effects through complex interactions, such as ecosystem engineering and trophic cascades (Richardson et al. 2000). Therefore, invasion of alien species not only can affect the population dynamics of certain native species, but it can also disrupt community structures and ecosystem functioning.

Once an alien species invades and becomes established in a habitat, the alien species is incorporated into the invaded ecosystem, creating new interactions between the alien and native species. These new interactions must be considered when impacts of alien species are evaluated. For instance, some of these interactions may facilitate invasions of other alien species, a process called "invasional meltdown" (Simberloff and Von Holle 1999). In addition, eradication of an alien species incorporated into an ecosystem can cause unexpected changes (Zavaleta et al. 2001).

This part introduces some quantitative studies of the impacts of invasive alien animals and plants on native ecosystems on the Bonin Islands.

2.2 Flatworms

Land snails are a major and highly endemic component of the biotas of Pacific islands, and their dramatic decline has been reported from islands throughout the Pacific (Hadfield and Miller 1989; Cowie and Cook 2001). The decline or extinction of endemic land snails on the Bonin Islands may be caused by predation by several alien predatory flatworms, which were introduced into the islands accidentally and incidentally. Okochi et al. (Chap. 3) described the cause of the

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decline of endemic land snails. Some small endemic snails, such as *Hirasea* spp. and *Ogasawarana* spp., are already rare, and more common endemic snails, such as *Mandarina* spp., are also declining in the northern mountains of Hahajima, one of two human-populated islands. The snail decline cannot be explained by deforestation and subsequent regeneration. Three species of flatworms were found to eat small snails under captive conditions. The distribution of these flatworms is restricted to the northern mountains of Hahajima, where *Mandarina* is declining and its survival is poor. Thus, these predators are plausible candidates as a cause of the decline of the endemic snails.

Ohbayashi et al. (Chap. 4) examined the distribution of *Mandarina* spp., endemic land snails of the Bonin Islands, from 1986 to 2003 on Chichijima and Hahajima, the first and second largest of the Bonin Islands. Many *Mandarina* spp. have declined since the 1990s, and their decline corresponded to the expansion of flatworm populations. Moreover, Chichijima and Hahajima differ in the pace of their respective *Mandarina* declines, perhaps because of differences in the abundance of a predatory flatworm, *Platydemus manokwari*. The flatworm only invaded Chichijima in the 1990s.

Although the ecological impacts of *P. manokwari* on endemic snails have been clarified, the flatworm's feeding habits were poorly understood. Ohbayashi et al. (Chap. 5) examined the distribution and feeding habits of *P. manokwari* on Chichijima. *P. manokwari* was distributed over a large area of the island, and few live land snails were found in the area where *P. manokwari* was distributed. Furthermore, *P. manokwari* fed on live land snails, including predatory species, as well as other food resources such as live flatworms, a land nemertean species, and the carcasses of slugs and earthworms.

To clarify the effect of *P. manokwari* on land snail survival in the field, Sugiura et al. (Chap. 6) examined survival rates of snails placed experimentally in areas where snails were absent (i.e., *P. manokwari* was present) on Chichijima. They found that over 50 and 90% of the snails were dead after 3 and 11 days, respectively, and the main cause of mortality was predation by *P. manokwari*. Sugiura and Yamaura (Chap. 7) evaluated the deteriorative impacts of *P. manokwari* on arboreal snails by examining survival rates of land snails placed experimentally on tree trunks (0.5–2.0 m above the ground) in a forest on Chichijima. Over 40% of the snails placed on tree trunks with snail scent trails were eaten by *P. manokwari* within 7 days.

2.3 Black Rats

Introduced predators can cause extinction of island endemics. With human settlement, alien rats have colonized many oceanic islands and dramatically affected the endemic ecosystems (Courchamp et al. 2003). Black rats, *Rattus rattus*, frequently cause fatal damage to seabird populations through direct predation. Particularly with small-sized petrels, the impacts are devastating. Kawakami et al. (Chap. 8) described the massive die-off of Bulwer's petrels, *Bulweria bulwerii,* on Higashijima due to rat predation on adult individuals as well as eggs.

The black rats also may cause micro-evolutionary changes in populations of native species. Chiba (Chap. 9) showed that predation by black rats, has resulted in ecological and morphological changes in the land snail *Mandarina anijimana* from Anijima, one of the most well preserved of the Bonin Islands. The close association between shell morphology and habitat use of *Mandarina* spp. suggests that the habitat shift induced by the predation of *R. rattus* has caused changes in the shell morphology of *M. anijimana* over an evolutionarily short period of only 17–19 years.

2.4 Feral Cats

Domestic cats, *Felis catus*, were introduced to the Bonin Islands by settlers and became feral (Obana 1877), and feral cats are now considered to have an adverse impact on the islands' native wild birds. Kawakami and Higuchi (Chap. 10) investigated the extent of predation on native Bonin Island passerines by collecting and identifying the feathers of birds eaten by a domestic cat. The number of passerines predated was particularly high during the breeding season probably because of the greater vulnerability of fledglings. The cat took Japanese white-eye, *Zosterops japonicus*, in proportion to their availability. Predation by cats is a serious problem for two endangered passerines: the endemic Bonin Islands white-eye, *Apalopteron familiare*, and the endemic subspecies of the oriental greenfinch, *Carduelis sinica kittlitzi*.

Feral cats also target seabirds frequently because seabirds cannot move quickly once they have landed. Kawakami and Fujita (Chap. 11) examined the remains of birds to investigate which species are most frequently preyed upon by feral cats in the Minamizaki area of Hahajima. Most remains were those of wedge-tailed shearwaters, *Puffinus pacificus*, a dominant seabird species on the Bonin Islands (Hasuo 1970), which had been killed by feral cats after the birds had landed. Although brown boobies, *Sula leucogaster*, breed in the Minamizaki area (Ministry of the Environment 1980), few remains were found in the sample. These observations support the possibility that cat predation has prevented them from breeding.

2.5 Green Anoles

Green anoles, *Anolis carolinensis*, were introduced into the Bonin Islands in the early 1960s and have the potential to cause mass extinctions of endemic insects on the islands.

The population density of *A. carolinensis* found on Chichijima was much higher than that reported on Saipan and the Bahamas. The higher density may explain why insect populations have declined on some of the Bonin Islands but not on Saipan.

Some male lizards were also observed to have pollen of endemic rosewood, *Schima mertensiana*, on their heads. The pollen may have become attached to their heads when *A. carolinensis* was sucking nectar, as is the case for other known lizard pollinators (Okochi et al. Chap. 12). In addition to serving as potential pollinators, green anoles could also decrease the population sizes of flower visitors, resulting in changes in native pollination systems on islands. Abe et al. (Chap. 13) identified the main cause of the population decline of native pollinating insects by testing four potential causal factors: (1) honeybee competition, (2) forest decline, (3) agricultural insecticides, and (4) anole predation. The results of the predation experiment explained well the composition of flower visitors on the main islands of Chichijima and Hahajima. They concluded that the invasive predatory green anole has changed the pollination systems on the Bonin Islands.

2.6 Feral Goats

Feral goats graze and trample vegetation on many oceanic islands, which often causes destruction of vegetation and accelerates soil erosion (Coblentz 1978; Coblentz and Van Vuren 1987). Therefore, feral goats have been eradicated from many islands. After the eradication, vegetation has recovered on some oceanic islands (Hamann 1975), but it has not on others. Hata et al. (Chap. 14) quantified changes in vegetation on Nakodojima in the Mukojima group, which had been greatly disturbed by feral goats, by comparing aerial photographs taken in 1978, 1991, and 2003. An eradication effort began in 1997, and goats were completely eradicated from the island by 1999. Between 1978 and 1991, some grassland changed to bare ground, which resulted in a decrease in the area of grassland and an increase in the area of bare ground during this period. On the other hand, some bare ground changed to grasslands between 1991 and 2003. A considerable area of forest changed to grassland or bare ground even after the eradication of feral goats.

2.7 Bischofia javanica

The invasion of alien woody species has seriously affected many natural forest ecosystems (Richardson 1998). *Bischofia javanica* is an invasive alien tree on the Bonin Islands. This species shows aggressive growth and competitively replaces native tree species in the natural forests of the islands (Shimizu 1988). Yamashita et al. (Chap. 15) examined the survival and growth of seeds and seedlings, two demographic parameters that might confer an advantage to the establishment of *B. javanica* over native trees, by analyzing these parameters during the early life history of *B. javanica* and *Elaeocarpus photiniaefolius*, a native canopy dominant, in actively invaded forests. Compared with *E. photiniaefolius*, greater seed longevity, less seed predation by introduced rodents, longer fruiting periods, and the ability to form seedling banks under a closed canopy appear to have contributed to the invasive success of *B. javanica* on the Bonin Islands.

2.8 Leucaena leucocephala

The shrub *Leucaena leucocephala* has invaded and formed dense monotypic thickets in disturbed areas on many oceanic islands (e.g., Decker 1992; Yamamura et al. 1999). The dense thickets may prevent seedlings of woody species and understory herbaceous species from germinating or growing under canopies of *L. leucocephala*. In a field experiment, Hata et al. (Chap. 16) investigated the effects of *L. leucocephala* invasion on subsequent establishment of a native mid-successional wooden species, *Schima mertensiana*, at the early-successional stages after disturbance. Germination of seeds and growth of seedlings of *S. mertensiana* were inhibited by *L. leucocephala* at the disturbed site, suggesting that the presence of this invasive alien species changes the early-successional pathway of the plant community.

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Chapter 3

The cause of mollusk decline on the Ogasawara Islands

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Abstract. Decline of land snails on the Ogasawara Islands was studied. In Hahajima, major alien predators such as *Euglandina rosea* and *Platydemus manokwari* are not present, but some small endemic snails, for example, *Hirasea* spp. and *Ogasawarana* spp., are already rare and more common endemic snails, for example, *Mandarina* spp., are also declining in the northern mountains. The decline cannot be directly explained by forest deforestation and by its subsequent regeneration. Three species of flatworms were found to eat small snails under captive conditions. The distribution of these flatworms is restricted to the northern mountains of Hahajima where *Mandarina* is declining and its survival is low. These predators are plausible candidates as a cause of the decline of the endemic snails.

Introduction

Land snails are a major and highly endemic component of the biotas of Pacific islands. Their dramatic decline has been reported from islands throughout the Pacific (Clarke et al. 1984; Hadfield 1986; Murray et al. 1988; Hadfield and Miller 1989; Cowie 1992, 2001; Hadfield et al. 1993; Cowie and Cook 2001). The Ogasawaras are subtropical islands belonging to Japan, lying about 1000 km south of the main Japanese islands. Their land snail fauna is highly endemic but has been subject to significant decline and extinction (Tomiyama and Kurozumi 1992; Tomiyama 1994). The islands were almost entirely deforested prior to World War II, which led to the decline and extinction of many species. However, subsequent secondary regrowth appeared to provide the opportunity for those species remaining to increase again. Why this has not happened and many species continue to decline is the subject of this paper. As such, it is of great interest from the perspective of conservation of island snail faunas in the Pacific.

The snail declines in the Pacific have been mainly caused by two alien predators, a predatory snail, *Euglandina rosea*, and a flatworm, *Platydemus manokwari* (Clarke et al. 1984; Murray et al. 1988; Hopper and Smith 1992; Hadfield et al. 1993; Eldredge and Smith 1995; Cowie and Cook 2001). However, these are only found on Chichijima among the Ogasawara Islands, but the decline also occurs on Hahajima (Tomiyama 1992; Tomiyama and Kurozumi 1992). We suspected that

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