https://doi.org/10.20965/jdr.2008.p0174

**Review:**

# Threats to Indigenous Biota from Introduced Species on the Bonin Islands, Southern Japan

**Kazuto Kawakami**

Forestry and Forest Products Research Institute
Matsunosato 1, Tsukuba, Ibaraki 305-8687, Japan
E-mail: kazzto@ffpri.affrc.go.jp
[Received December 6, 2007; accepted January 8, 2008]

**High endemism has evolved on the Bonin Islands, a group of oceanic islands in the northwestern Pacific, due to a disharmonic, unique biota. However, human settlements have caused extensive deforestation and the introduction of invasive species over the last 200 years. Insular populations are vulnerable to the devastating effects of introduced predators, competitors, and diseases, because they have evolved in the absence of such factors. Introduced species (e.g., goats, cats, black rats, green anole lizards, invasive plants, and predatory flatworms) have caused population declines and the extinction of indigenous species through direct and indirect effects. Unpredictable events often occur within these food webs. Clearly, efforts must be made to control these introduced populations, and to that end, attempts to eliminate certain species (e.g., goats and rats) have begun. However, some invasive species cannot be completely eradicated from their ranges because of their wide distributions and high population densities. In such cases, these species must be confined to their current ranges, which, for the primary invasive species, is mainly limited to two inhabited islands. Problematically, some introduced species have become essential components of the current ecosystem due to long-term naturalization, and their elimination may cause decreases in native species. Thus, the construction of sustainable ecosystems that include both native and introduced species is a realistic goal of current conservation efforts.**

**Keywords:** black rat, endemism, eradication, introduced species, the bonin islands

## 1. Evolution on Oceanic Islands

The Bonin Islands are oceanic islands located within 2025'–2743' N and 13604'–15358' E in the northwestern Pacific Ocean. They consist of more than 100 islands and rocks and are composed of four main island groups (i.e., the Mukojima, Chichijima, Hahajima, and Volcano Island groups) as well as three small isolated islands (i.e., Nishinoshima, Minamitorishima, and Okinotorishima; **Fig. 1**). The islands are primarily volcanic, dating back to the Tertiary (Mukojima, Chichijima, Hahajima Island groups) or Quaternary (Volcano Island group) [1]. Each island is comparatively small; even the largest island, Chichijima, is only 2400 ha in area. The climate is subtropical, with monthly mean temperatures ranging from 18 to 28°C and an annual mean temperature of approximately 23°C in Chichijima [2]. The monthly precipitation ranges from 60 to 170 mm, with an annual precipitation of approximately 1300 mm [2].

The biota of oceanic islands has many characteristics distinct from continental populations, because the resident species have never contacted their mainland populations [3]. The ancestors of island species arrived by chance across open seas to establish their populations. Wind dispersal, ocean currents, and birds allowed only a limited number of species to reach the Bonin Islands. The biota of island populations often become depauperate and disharmonic and exhibit a different balance of species compared to equivalent areas of the mainland [4]. This tendency is particularly noticeable on smaller and more remote islands that typically lack indigenous land mammals and amphibians [5]. On the Bonin Islands, no land mammals naturally occur except for the Bonin flying fox *Pteropus pselaphon* [6], and there are no native amphibians, snakes, or earthworms [7, 8]. Only two reptiles, 15 land birds, more than 330 insects, approximately 100 land snails, and 450 vascular plants occur on the Bonin Islands [9–11].

Despite low species richness, oceanic island biodiversity remains quite important. The disharmonic biota of islands promotes the evolution of endemism through adaptive radiation due to the lack of competitors and/or predators. The proportion of endemism on the Bonin Islands is 40% for all plants and 70% for arboreal species alone [12], and 80% of indigenous landbirds are endemic species or subspecies [13]. Furthermore, more than 90% of native land snail species are endemic to the islands [14].

While oceanic islands have provided spectacular habitats for evolution and biodiversity, these ecosystems also speak to the vulnerability of insular species in the face of human disturbance. Four main reasons were given for why island species decrease due to human activities: 1) direct predation, 2) introduction of non-native species, 3) spread of disease, and 4) habitat degradation or loss [4]. Island species tend to have small populations

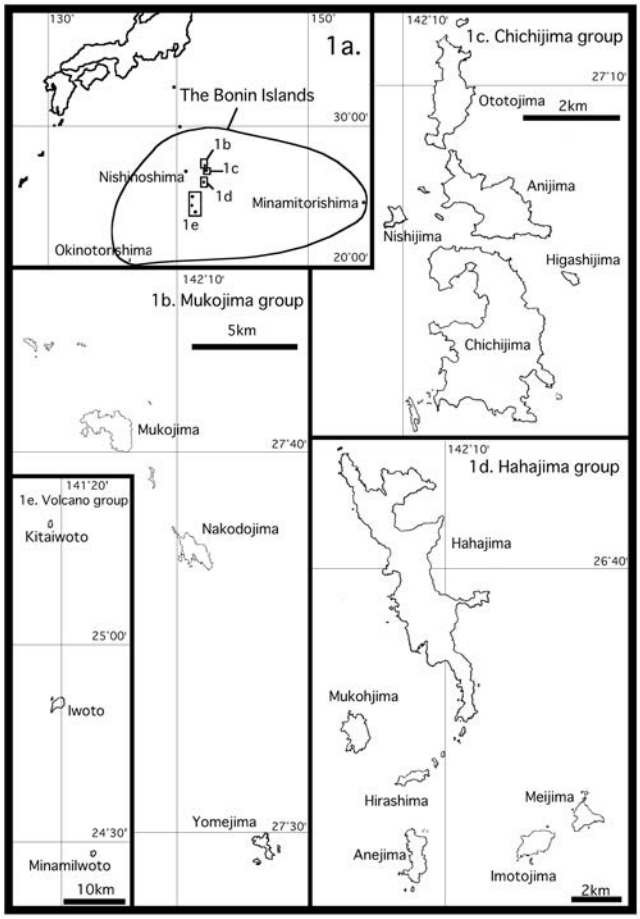


**Fig. 1.** The location of the Bonin Islands.

and thus less capacity to rebound from perturbations that greatly reduce their numbers [15]. Island populations are also vulnerable to the devastating effects of introduced predators, competitors, and diseases, because they have evolved in the absence of such factors. For example, 13 species/subspecies of birds have been described as extinct for all of Japan in the Japanese Red Data Book (RDB); of these, 12 are insular birds and six are endemic to the Bonin Islands [16]. Thus, the Bonin Islands are a "hot spot" for both evolution and extinction.

## 2. History of Human Disturbances

Prehistoric remains (approximately 800-2000 years old) have been found on Kitaiwoto of the Volcano Island group and on Chichijima [17]. Although the origin of these people is not clear, they may have arrived from the Izu Islands and/or the Marianas [17]. On many Pacific islands, some or many of bird species survived until, but not through, their first contact with humans during the prehistoric age [18–20]. While no direct evidence exists, the original fauna and flora may have been disturbed during this age. Prehistoric residents disappeared prior to the recent inhabitation of the Bonin Islands.

During recent history, the first human colonization of the islands involved western and Polynesian populations in 1830. The sea around the islands was used for whaling, and the islands served as whaling stations [21]. The immigrants exploited the forests, established farmlands for crops such as sugarcane, corns and sweet potatoes [21], 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 likely became extinct during this age of colonization.

The Bonin Islands became Japanese territory in 1876, and subsequently, Japanese people began to settle the area. 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 [10]. On the main islands, namely, Hahajima and Chichijima, all areas amenable to cultivation were planted to sugarcane fields until the value of this crop suddenly dropped in 1910 [22]. Subsequently, the sugarcane fields were converted to farmland for vegetables and foliage plants for exportation to the Japanese mainland [23]. At least 14 islands were successively colonized, and the maximum population of the islands reached approximately 7711 people in 1944 [21]. Two endemic species (the Bonin pigeon *Columba versicolor* and the Bonin grosbeak *Chaunoproctus ferreorostris*), two endemic subspecies (the white-browed crake *Poliolimnas cinereus brevipes* and the rufous night-heron *Nycticorax caledonicus crassirotris*), and a subspecies of the endemic Bonin Islands white-eye *Apalopteron familiare familiare* all became extinct during this period [16]. The non-endemic jungle crow *Corvus macrorhynchos* also disappeared from the islands by 1920 [7].

One of the most distinct impacts of this age was the overexploitation of seabirds for feathers, meat, and guano [24]. The short-tailed albatross *Diomedea albatrus*, for example, became locally extinct on the islands [25]. On Minamitorishima, the easternmost island of Japan, Laysan albatross *Diomedea immutabilis* and black-footed albatross *Diomedea nigripes*, whose numbers were described as "exceedingly abundant in former days", were nearly exterminated within only 6 years of the initial colonization in 1896 [26].

World War (WW) II also drastically impacted the biota of the islands. The Japanese government forced approximately 6900 inhabitants to evacuate the Bonin Islands in 1944 [23], and the farmlands were left in uncontrolled conditions. Intensive bombing destroyed the forests on at least Chichijima, Hahajima, and Iwoto [23]. WWII was also the decisive event for many seabird species on Minamitorishima, on which the physical topography was entirely altered during wartime [27]. Approximately 5000 Japanese troops were garrisoned there, and the island was exposed to severe bombardment [27]. Together, exploitation for feathers and WWII caused the local extinction of nine seabird species on Minamitorishima [26–28].

The Bonin Islands were under US occupation from the end of WWII until the return to Japan in 1968 [22]. Only

a few locals and the US army remained on Chichijima, Iwoto, and Minamitorishima during this period [22, 29, 30]. Secondary forests vastly covered the cultivated lands and former residential areas, and introduced plants such as *Leucaena leucocephala* and *Bischofia javanica* expanded their distributions [10, 31]. The green anole *Anolis carolinensis*, an invasive lizard, was also introduced during this time [32].

When the islands were returned to Japan, they were recolonized by both former and new inhabitants. Only Chichijima and Hahajima were inhabited by civilians, and the other islands remained uninhabited, 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 2400, and transportation from the mainland occurs by ship once a week [33]. 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, introduction of diseases, hybridization, and grazing. Particularly important examples of these factors are discussed in the following chapter.

## 3. Effects of Introduced Species

### 3.1. Destruction of Vegetation by Feral Goats

Goats *Capra aegagrus*, cows *Bos taurus*, pigs *Sus scrofa domesticus*, deer *Cervus mariannus*, cats *Felis catus*, and rabbits *Oryctolagus cuniculus* have all been intentionally introduced to the islands [34]. Only goats, pigs, and cats have survived to date. Feral pigs currently occur only on Ototojima, and eradication efforts by the Ministry of the Environment are ongoing.

Goats have been released to at least 20 of the Bonin Islands [35]. This species has been introduced as a food resource several times since the initial stage of colonization [36]. Certain physiological traits, such as low metabolism, an efficient digestion system, low water requirements, high reproductive rates, and a generalized diet, allow the goats to increase in number under conditions unsuitable for many other herbivores. Eradication of this species was primarily conducted on 13 relatively small islets in the 1970s [37]. A second stage of eradication was conducted on Nakodojima, Mukojima, Yomejima, and Nishijima since 1997, and the current distribution of goats is limited to three islands, Chichijima, Anijima, and Ototojima [38]. Feral goat eradication was relatively easy on the other islands, because nearly all forests had been altered to grasslands by grazing and few shelters existed. However, Chichijima, Anijima, and Ototojima are still predominantly covered by forests, they are larger, and the topography is more rugged than that of the other islands [38]. These conditions make the eradication of goats particularly difficult on these islands. The Tokyo Metropolitan Government has been attempting to exterminate the goats on Anijima since 2005 [39].

In general, the flora of oceanic islands has evolved in the absence of large herbivores and thus lacks adaptations to mammalian herbivory [3]. Goat grazing alters the structure and composition of plant communities and accelerates soil erosion [40]. Furthermore, feral goats forage on grasses and herbs on cliffs and exterminate rare plant species. Endemic threatened herbs such as *Lobelia boninensis*, *Cirsium boninense*, and *Ajuga boninsimae* have nearly become extinct on Chichijima [41]. In addition, goats eat seedlings and saplings of trees, clearing the forest floor and halting forest succession when canopy trees die [10].

Of all Bonin Islands, Nakodojima is the most severely affected by feral goats [36]. This island was originally covered with dense forests, which have subsequently been changed to vast grasslands and bare ground due to grazing and trampling by goats [42, 43]. Moreover, aquatic biota has also been impacted by the outflow of soil caused by erosion [35], and feral goats also affect seabird populations [28, 35]. In fact, islands on which goats became feral harbor fewer seabird species, likely because the goats have disturbed breeding of shearwaters through nest destruction by trampling and soil erosion by overgrazing [28]. The absence of seabirds can reduce soil fertility due to the disruption of sea-to-land nutrient transport by seabirds [44, 45], which may also indirectly affect plant communities on islands with goats.

Feral goats were completely eradicated on Nakodojima in 1999 [46]. Since the eradication, some bare ground has shifted to grassland due to release from goat herbivory [43]. Despite the disappearance of goats, the forests have not yet recovered, however, likely due to the lack of seed rain [43]. The long-term impacts on vegetation include decreases in tree reproduction, seedlings, and the seed bank. While forest ecosystems clearly require long recovery times after goat eradication, vegetation has recovered in some areas [12, 47].

Problematically, several introduced plants, such as *Leucaena leucocephala* and *Pseudosasa japonica*, have expanded their ranges, thus preventing the reproduction of native species [47]. Therefore, it is necessary to monitor changes in the flora and fauna and to conduct countermeasures that account for interspecific relationships. In addition, the effects on vegetation subsequently influence other taxa, because plant communities provide habitats for countless species. Thus, complete feral goat eradication may not be an appropriate goal without the subsequent maintenance of balance of nature.

### 3.2. Feral Cat Predation on Birds

The Bonin Islands lacked terrestrial carnivores until human colonization in 1830. Thus, native animals were vulnerable to introduced carnivores. Domestic cats were introduced to the islands, and many escaped or were re-

**Table 1.** Estimated foraging habitat of native birds in the Bonin Islands.

| Species | Range | Current status | Foraging habitat | Notes |
|---|---|---|---|---|
| Rufous Night-Heron | Endemic (subsp.) | Extinct | Riverside | |
| Common Buzzard | Endemic (subsp.) | Abundant | Aerial | |
| Peregrine Falcon | Endemic (subsp.) | Extinct ? | Aerial | Range: Volcano Isls. |
| White-browed Crake | Endemic (subsp.) | Extinct | Ground | Range: Volcano Isls. |
| Japanese Wood-Pigeon | Endemic (subsp.) | Decline | Ground | |
| Bonin Pigeon | Endemic | Extinct | Ground | |
| Brown-eared Bulbul | Endemic (subsp.) | Abundant | Arboreal | |
| Blue Rock-Thrush | Wide distributed | Abundant | Ground | |
| Bonin Thrush | Endemic | Extinct | Ground | |
| Japanese Bush-Warbler | Endemic (subsp.) | Abundant | Arboreal | |
| Japanese White-eye | Endemic (subsp.) | Abundant | Arboreal | Range: Volcano Isls. |
| Bonin Isladns White-eye | Endemic | Extinct / Abundant | Arboreal & Ground | One of two subspecies was extinct |
| Oriental Greenfinch | Endemic (subsp.) | Decline | Ground | |
| Bonin Grosbeak | Endemic | Extinct | Ground | |
| Jungle Crow | Wide distributed | Local Extinct | Arboreal & Ground | |

leased from residential areas. These cats had already become feral during the early human history of the islands, and a large number of feral cats lived in the wild on Chichijima in 1853 [48]. Feral cats have been observed on four inhabited and at least three uninhabited islands (Anijima, Ototojima, and Mukohjima) [49].

On Hahajima, about 100 feral or half-feral cats were estimated to be distributed across the island [50]. A seabird colony once existed on the southernmost area of the island but was destroyed by feral cats during the last decade [51, 52]. Some seabird species, such as shearwaters and boobies, cannot quickly take flight from the ground, because their wings are adapted for gliding rather than flapping. In addition, landbirds are also preyed upon by feral cats [53]. For example, the endemic subspecies of the Oriental greenfinch, *Carduelis sinica kittlitzi*, and the Bonin Islands white-eye are listed as threatened in the Japanese RDB [16, 50].

Although at least five islands had maintained populations of the Oriental greenfinch prior to WWII besides two of Volcano Islands group and uninhabited out-islands of the Hahajima group where this species currently breeds [7, 54, 55]. The endemic subspecies of Japanese wood pigeon *Columba janthina nitens* has also decreased in number and is classified as a critically threatened species in the Japanese RDB [16]. These two species are currently the most vulnerable landbirds on the islands. Both species forage primarily on seeds on the ground, thus facilitating attacks by feral cats and reducing their populations. The extinct landbirds of the islands, the Bonin pigeon and the Bonin grosbeak, were also seed-eaters, and the Bonin thrush, the white-browed crake, and the rufous night-heron were also likely to frequently forage on the ground (**Table 1**) [7, 56]. Such microhabitat use in the presence of introduced terrestrial carnivores may accelerate the extinction of various bird species [57].

Not surprisingly, the diet of cats is not limited to birds. Cat feces collected from Chichijima and Hahajima contained the cicada *Meimuna boninensis* [58, 59], which is listed as a National Natural Monument and has drastically decreased in number since the late 20th century [38]. In addition, cat feces also contained high proportions of the native skink *Cryptoblepharus nigropunctatus* [59], which has decreased on inhabited islands [60]. These species are also affected by the green anole, an invasive lizard [38, 61]. Clearly, native small animals suffer from predation by multiple invasive predators.

The local government of Ogasawara began countermeasures for cat control [49]. For example, an ordinance to register domestic cats was declared in 1999. In an effort to initiate stepwise population decreases, the government has also captured feral individuals for sterilization and subsequently released them at the sites of capture. However, positive results are doubtful because of the difficulty in capturing all individuals. To this day, many feral cats and kittens are frequently observed. Thus, the best method for eradicating feral cats is to remove them from the ecosystem.

In the southernmost region of Hahajima where the seabird colony was destroyed, a cat fence was established to separate the colony from the mainland. Feral cats have been removed from the exclosure since 2006 and are fostered on the mainland in Tokyo [52]. These efforts were conducted in partnership with researchers, local residents, the local government, and the Tokyo Veterinary Medical Association. Because it is difficult to reach consensus concerning the extermination of captured cats, such collaborations are fundamental to balance conservation with social opinions.

### 3.3. Effects of Green Anole Lizard on Insects

While goats and cats were introduced during the 19th century, the green anole became feral in the mid-20th century when the Bonin Islands were under US occupation [32]. These small lizards originate from North America [53] and were introduced in the early 1960s via Guam [32]. Pets or individuals hidden in cargo may also have established the wild population on the islands [38, 49]. The anole lizard was initially found in northern Chichi-

jima and then expanded its distribution to the entire island [60]. In the 1980s, this species subsequently invaded Hahajima and expanded its range along roadways [60]. The average population density of 1270 per ha on Chichijima was much higher than in Saipan, which the same species had previously invaded [62].

The invasion of the green anole has received a great deal of attention in terms of insect conservation. On the two inhabited islands, researchers have reported a continuous decline in some groups of endemic insects, such as dragonflies, butterflies, bees, and longicorn beetles [38, 63–65]. By comparing collection records of insects from before and after range expansion of the lizard on Hahajima, it was shown that only diurnal longicorn beetles had declined, whereas nocturnal species had not exhibited a marked decline [64]. Decreasing insects are limited to diurnal species on Chichijima and Hahajima, likely because the green anole is a diurnal predator. Field observations, stomach content analyses, and feeding experiments have indicated that predation by the lizard may explain the severe declines of these insects [38, 64, 65]. At least five endemic odonates (*Boninagrion ezoin*, *Indolestes boninensis*, *Rhinocypha ogasawarensis*, *Hemicordulia ogasawarensis*, *Boninthemis insularis*) and one endemic butterfly (*Celastrina ogasawarensis*) disappeared on Chichijima and Hahajima, except small populations of *R. ogasawarensis* and *C. ogasawarensis* on the latter [38, 65, 66]. Even a relatively large insect, the endemic cicada *Meimuna boninensis* is preyed upon by the lizard, and this species has been declining on Chichijima and Hahajima [38, 67].

Endemic bees have also experienced rapid declines and are nearly extinct on these two islands, with the exception of the largest bee species, *Mesotrichia ogasawarensis* [66, 68]. It is hypothesized that endemic bee declines were caused by competition with the introduced European honeybee *Apis mellifera* [68]. Additionally, the population reductions are likely attributable in part to lizard predation. Because each insect species functions ecologically as both pollinator and predator, their disappearance will influence other species. For example, the absence of pollinators such as native bees or longicorn beetles will disrupt plant-insect pollination systems. Thus, the green anole can potentially indirectly affect the native flora.

The native skink *Cryptoblepharus nigropunctatus* has also decreased in conjunction with the range expansion of the green anole [60]. This species is completely absent in areas where the anole occurs in high densities [61]. The anole lizard frequently attacks the skink and dominates areas of sympatry, excluding the skink from suitable microhabitats [61]. Additionally, a juvenile skink was discovered in the stomach contents of an anole [61]. The green anole thus serves as both a competitor for suitable microhabitat and a predator of the native skink.

In addition to the predation effects of this lizard, the species may also change the native biota through its role as a prey item. In the 1980s, the bull-headed shrike *Lanius bucephalus* began to breed on Chichijima [69], whereas previously, this species had been a rare migratory bird on the Bonin Islands [70]. The range of the shrike expanded on Chichijima [60], and it reached Hahajima (50 km away) in 1990 [38]. Its distribution appeared to follow the expansion route of the green anole, and the shrike was shown to frequently forage on the lizard on Chichijima [60]. It thus may inhabit the islands because of the sudden appearance of available food items [38]. For unknown reasons, shrike populations have decreased on Chichijima and have disappeared completely from Hahajima [38]. If the bird were to have established stable populations, it would also have preyed on native insects and small land birds. Thus, the extensive consequences of increased green anole populations highlight the often unpredictable effects of introduced species.

The green anole was classified as an "invasive alien species" of Japan in 2005 under the Invasive Alien Species Act (Law No. 78) by the Ministry of the Environment, and the possession and transport of live individuals was restricted. To conserve vulnerable species such as *Celastrina ogasawarensis*, methods to eliminate this lizard from particular areas through the use of adhesive traps and fencing are ongoing [71]. Given the large population density of the lizard and the difficulty in removing small animals, eradication from the Bonin Islands will likely be challenging.

### 3.4. Introduced Amphibians as Insect Predators

The Bonin Islands originally lacked amphibians, as these animals could not migrate across the sea. However, two species, the American bullfrog *Rana catesbeiana* and the marine toad (cane toad) *Bufo marinus*, have been introduced. These species have been listed in the "100 of the World's Worst Invasive Alien Species" [72]. The bullfrog is a waterside predator and was introduced for human consumption probably via the mainland of Japan [38]. The current range of this species is restricted to the northern part of Ototojima [38]. The bullfrog forages on many species, including terrestrial hermit crabs and dragonflies. Since 2004, endemic dragonflies have rarely been observed near ponds inhabited by the bullfrog (although droughts may have similar effects) [71]. Bullfrog eradication programs are ongoing, and the population density of this frog has declined as a result [71]. The density of this bullfrog was not extremely high even before the programs, probably because it suffered from the predation pressure by feral pigs. The pig eradication was begun following the bullfrog eradication started in order to avoid their increase.

The marine toad, which was introduced as a biological control agent for scolopendras and scorpions, was brought to Chichijima from Saipan in 1949 and to Hahajima in 1974 [73]. This toad preys on ground animals and especially affects ground beetles. The endemic ground beetles species, *Colpodes yamaguchi*, *C. boninensis*, and *Chlaenius ikedai*, have seldom been observed and are near extinction on Chichijima and Hahajima, likely due to predation by the toad [66]. In one area of Hahajima, its population density was estimated at the extremely high value

of 3000 per ha [38]. An analysis of toad stomach contents indicated that the species richness of its diet in 2004 was lower than in 1979, potentially because of the exhaustion of food resources [71]. To prevent further declines in ground animal communities, proper countermeasures are necessary to control marine toad populations.

### 3.5. Predation on Snails by Introduced Predators

As mentioned above, land snail fauna exhibit high diversity and endemism on the Bonin Islands. However, these species have experienced dramatic declines. Approximately half of the 14 species of the genus *Hirasea* and four species of the genus *Ogasawarana* went extinct relatively early because of deforestation for agriculture and habitat alteration by introduced mammals such as feral goats [14]. After WWII, nearly all areas of Chichijima and Hahajima were covered by secondary forests that had established on agricultural lands. However, reforestation did not halt the decline of land snails on these islands. Recent decreases in snails on Chichijima may be caused by the introduced predatory flatworm *Platydemus manokwari*, which was introduced accidentally in the early 1990s [74–77]. This flatworm was introduced to several Pacific islands to control the African land snail *Achatina fulica*, an introduced pest of agriculture, and caused native snail declines [78, 79]. The predatory rosy wolfsnail *Eugalandina rosea* was also introduced to Chichijima. Thus, the land snail fauna has suffered serious declines due to these introduced predators [75, 80].

Although the range of *P. manokwari* has been limited to Chichijima, land snails (e.g., *Mandalina*) have also declined on Hahajima [81]. These declines may be due to three potentially introduced predatory flatworms, *Bipalium* sp., *Australopacifica* sp., and *Platydemus*? sp. [81]. Furthermore, *Mandalina* also suffers from predation by black rats. Because these small introduced species are as difficult to eliminate as the green anole, the best remaining option is to confine them to their current distributions.

### 3.6. Plants Out of Place

Invasive alien species are often plants as well as animals. Various types of introduced plants negatively affect native plant species. For example, *Bischofia javanica* was introduced into Chichijima, Hahajima, and Ototojima as fuelwood in the early 1900s [12]. This species initially escaped from areas of afforestation during the US occupation and has expanded its range throughout the islands [10]. *B. javanica* exhibits several traits favorable to rapid establishment, including the rapid growth of seedlings and saplings, a large quantity of seeds, and strong shade tolerance; thus, this species can easily outcompete native trees [10, 82–84]. Native plants have been excluded from the range of *B. javanica*, and pure uniform forests of the invasive are establishing in certain areas. This species favors wet woodlands with well-developed soils [82], which characterizes one of the common primary forest types of the islands. *B. javanica* has also invaded protected areas that shelter remnants of primary forests, e.g., the central region of Hahajima. Conversions of forest to monocultures with uniform structure subsequently decrease faunal diversity, because an uncomplicated plant community cannot support diversified habitats for various animal species. In addition, a forest composed of single species can not provide seeds all the year round, which lacks the food availability for seed eaters such as vulnerable pigeons and finches. In order to maintain a foraging habitat for them, a forest must maintain species diversity, supplying seeds throughout the seasons. On the Bonin Islands, *B. javanica* was released from the limiting factors (e.g., competitors and predators) of its original locality in Southeast Asia, within which it was not a dominant species [10]. Although an eradication program for this species is currently being conducted by the Forestry Agency, *B. javanica* remains difficult to completely control due to its large population and ability to produce a soil seed bank [10, 84].

The range expansion of *B. javanica* may also have been accelerated by birds. The indigenous brown-eared bulbul *Hypsipetes amaurotis* is apparently a very effective seed disperser [82]. Similarly, several other introduced plants, e.g., *Morus australis*, *Solanum nigrum*, and *Rivina humilis*, are also frequently dispersed by birds. In addition to the bulbul, the Bonin Islands white-eye and the introduced Japanese white-eye *Zosterops japonicus* often forage on these introduced plants, and their fruits may partially sustain the bird populations. Clearly, mutual interdependences between native birds and introduced fruits have developed.

*Casuarina equisetifolia* is an invasive arboreous plant that has also established uniform forests, particularly in dry evergreen forest, one of typical forests of the islands [85]. Due to wind dispersal, the distribution of this species includes various uninhabited islands that neighbor inhabited islands [38, 82]. The arrival of *C. equisetifolia* has both costs and benefits, as this invasive species excludes native plants but also protects the brittle land from erosion. If the plant were to be completely removed from its current range, coastal areas would not retain their soils. In addition, this tree provides nest sites for the threatened subspecies of the Oriental greenfinch on the satellite islands of Hahajima [54]. This bird has survived only on these islands and the Volcano group [54, 55, 86]. Thus, *C. equisetifolia* plays a significant role in the conservation of these birds. The rapid elimination of this invasive plant would disrupt the current ecosystem established by both native and introduced species. Control measures should be conducted wisely, taking into consideration the interspecific relationships between the native and non-native species.

Competition for habitat is not the only negative effect of introduced species. For example, the introduced mulberry *Morus australis* reduces the reproduction of the closely related native mulberry *M. boninensis* through hybridization [87]. More than 300 introduced vascular plants have been found on the Bonin Islands, whereas the islands harbor at most 450 native species [9, 38]. Non-native plants are repeatedly transported to the Bonin Is-

lands for the purposes of agriculture, gardening, roadside tree plantings, and soil erosion remediation. Such plants experience many opportunities for escape from controlled areas. Official regulations requiring searches for invasive species when arriving at the islands are necessary to ameliorate the current situation of unrestricted and rapid introductions.

### 3.7. Effects on Aquatic Organisms

Aquatic fauna are also seriously affected by introduced species. The freshwater snail *Melanoides tuberculata* was initially found in brackish water areas of Chichijima in 2005 [88]. This species was introduced to the entire pantropical region and recently to neotropical areas, primarily as the result of the aquarium plant trade [89, 90]. In the area of Chichijima in which *M. tuberculata* has been introduced, the native freshwater snail and confamilial (Thiaridae) species *Stenomelania boninensis* also occurs and occupies a similar niche [88]. This native species is ranked as vulnerable (VU) in the Red List of the Ministry of the Environment. In the case of these two snails, the introduced species may not entirely exclude the native species. However, when their shared habitat is temporarily disturbed (e.g., for riverside modification or dredging), causing the native species to escape, *M. tuberculata* may fill the niche prior to the return of *S. boninensis*. In fact, introduced species often replace natives via intermediary human disturbances, and similar patterns occur frequently within plant communities.

Numerous interactions between introduced and native species occur in aquatic systems on the Bonin Islands. For example, the guppy *Poecilia reticulata*, the mosquitofish *Gambusia affinis*, and the cichlid *Oreochromis mossambicus* are introduced species that can function as predators of young native fish [38]. However, the overall effects of introduced aquatic species on native species remain unclear due to our minimal understanding of interactions within aquatic systems. Before the conditions within aquatic systems worsen, more research is necessary for effective conservation efforts.

## 4. Complex Relationships Between Invasive Rats and Native Species

### 4.1. Introduction of Rodents

Alien rodents were likely accidentally introduced to the Bonin Islands. Rats and mice are often unintentionally introduced to islands via ships. Because the presence of many rodents throughout the islands was reported in 1877 [91], these species were likely introduced during an early stage of colonization. Three rodent species have been reported on the Bonin Islands: the house mouse *Mus musculus*, the Norway rat *Rattus norvegicus*, and the black rat *R. rattus* [6, 92].

The house mouse occurs on Chichijima and Hahajima [49, 92, 93], primarily on farmlands and in forests of introduced *Leucaena leucocephala* in lowland environments [93]. Because the habitat of *M. musculus* is limited to areas impacted by humans, the native ecosystem has not been seriously affected by its presence [49].

The Norway rat is one of the most invasive species in the world and poses serious threats to island ecosystems [94–96]. On the Bonin Islands, *R. norvegicus* has been captured on Chichijima, Hahajima, and Hirashima [6, 49, 92, 97], but has disappeared from Chichijima [92]. The population density of this rat on the islands is not particularly high, and so far, no strong effects on the native biota have been detected [49].

In contrast, the black rat is a grave conservation concern and occurs on at least 16 of the Bonin Islands [27, 49]. *Rattus rattus* is one of the most invasive species on the islands, and its negative effects include several general aspects of biodiversity conservation on oceanic islands. This species is a representative example of the complex relationships involving invasive species, because the rat serves various roles in the ecosystem; i.e., predator, competitor, prey, and disperser (**Fig. 2**).

### 4.2. Effects on Plants

The primary food item of the black rat is plant material. It is reported that plants comprised approximately 90% of the stomach contents of the rat, more than 50% of which consisted of fruits and seeds [98]. It was showed that smaller fruits were consumed more frequently [99]. Rats feed on numerous indigenous plant species, including *Terminalia catappa*, *Pandanus boninensis*, *Hibiscus glaber, H. tiliaceus, Schima mertensiana, Rhaphiolepis wrightiana, Ochrosia nakaiana*, and *Elaeocarpus photiniaefolius* [100]. The diet of rats also includes threatened species such as *Piper postelsianum*, *Pittosporum parvifolyum*, and *Melastoma tetramerum*, which are listed as critically endangered (CR) on the Red List [100–103]. Thus, rats can clearly affect forest succession.

Seeds of *E. photiniaefolius*, a native canopy dominant, are frequently consumed by the black rat [84]. Because the rats are arboreal, they feed on approximately 30% of *E. photiniaefolius* seeds before dispersal and 40-100% of seeds after dispersal [84]. Because this seed is one of the main food items of a native, critically endangered pigeon (population size of less than 50 individuals), the rat functions as a competitor of the bird [16, 104].

Damage to plants is not limited to predation on seeds and fruits. The rats sometimes forage on bark [105] and remove twigs of certain plant species such as *H. glaber*, *Trema orientalis*, and *Planchonella obovata*, likely to obtain sap [100, 103]. The rat also affects threatened species, such as *Claoxylon centenarium* (CR), *Morinda umbellata var. hahazimensis* (VU), and *Geniostoma glabrum* (VU) [101, 103]. Such damage is not fatal for healthy individuals within large populations but may significantly damage vulnerable species in small populations.

Rats sometimes play important roles as seed dispersers, and certain plant species may be dispersed by these introduced species [106]. It is suggested that plants which produce large fruits (e.g., *T. catappa*, *P. boninensis*, and

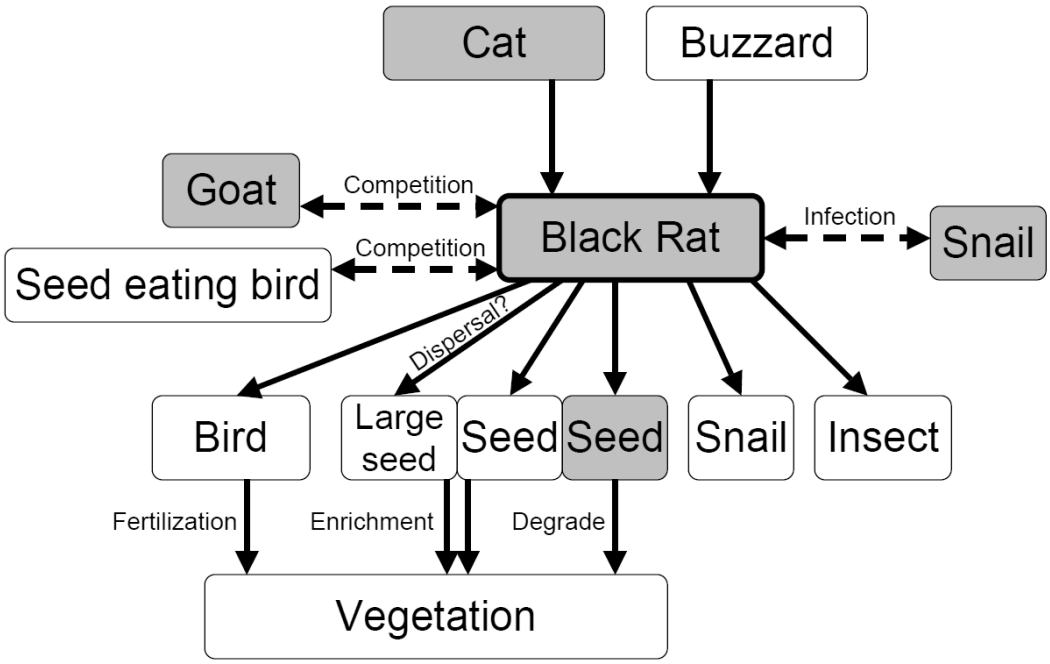


**Fig. 2.** The interspecific relationships regarding to the introduced black rats. The white and shaded boxes are the native and introduced species, respectively. Arrows without captions show the predation vector.

*O. nakaiana*) may be dispersed by feral rats, but the frugivory pressure on the regeneration of target species may be more serious for trees [99]. The Bonin flying fox, the only indigenous land mammal on the Bonin Islands, has decreased in number, particularly on Chichijima and Hahajima [107]. On oceanic islands, flying foxes are important seed dispersers of large fruits that cannot be carried by birds [108, 109]. Some large fruits may no longer be adequately dispersed because of the decline of flying fox populations on the islands. Therefore, introduced rats potentially target the dispersal of only certain plant species.

### 4.3. Effects on Seabirds

Because the rat is omnivorous, this species poses a particularly severe threat to bird conservation [94]. The black rat has affected various bird species through direct predation on eggs, chicks, and adult individuals all over the world. When eggs and chicks are preyed upon, only reproduction is disturbed. However, predation on adults is by far more serious, because adult mortality reduces the population source. This scenario has been realized on the Bonin Islands. Small seabirds, such as Tristram's storm-petrel *Oceanodroma tristrami* and Bulwer's petrel *Bulweria bulwerii*, are being preyed upon in colonies on Mukotorishima and Higashijima [28, 110]. On the latter islands, hundreds of bird carcasses were found in 2006 [110]. These bird species are unable to quickly fly away when attacked, because their slender wings do not allow a quick response. Furthermore, the nesting habit of small burrows hinders escape from predators. Without appropriate countermeasures, the local populations of these birds will become extinct within a few years.

Rat effects on bird species are not restricted to these two islands. For example, relatively small burrow-nesting species (i.e., Bonin petrel *Pterodroma hypoleuca*, Audubon's shearwater *Puffinus lherminieri bannermani*, Bulwer's petrel, Tristram's storm-petrel, and Matsudaira's storm-petrel *Oceanodroma matsudairae*) became locally extinct, whereas larger and/or open-nesting species survived (i.e., wedge-tailed shearwater *Puffinus pacificus*, brown booby *Sula leucogaster*, and red-tailed tropicbird *Phaethon rubricauda*) on Kitaiwojima, which harbors a large introduced black rat population [28, 111]. In contrast, Minamiiwojima, a neighboring island with similar geographic conditions and no rodents, has retained populations of both small and large burrow-nesters [86]. The numbers of known colonies of small burrow-nesters are small, and unknown colonies may have been destroyed by introduced predators prior to discovery.

Because seabirds forage at sea and nest on islands, their colonies function in the transport of nitrogen from the sea to land via guano, feathers, carcasses, eggs, and prey items [44, 45, 112]. The construction of burrow nests cultivates the soil and improves soil conditions. Additionally, healthy seabird colonies annually supply numerous chick carcasses that serve as an important resource for necrophagous invertebrates, such as flies, buffalo bugs, earwigs, and sow bugs. When a seabird colony is destroyed, these critical functions are lost, further disrupting the balance of the island ecosystem.

### 4.4. Effects on Other Species

In addition to birds, rats affect several other species. For example, It was indicated that *Mandarina anijimana*, an endemic land snail, changed its shell morphology and habitat use under predation pressure from black rats [113].

The snail shell has become taller, smaller, and darker in areas of high predation [113]. In addition, the snail has shifted its habitat from shallow, broad-leaved litter to deep palm litter, which provides shelter from rat predation [113]. The morphological changes may have been caused by this habitat shift. The original morphology and ecology of the snail were the results of evolution in the unique environment of oceanic islands. Thus, even if *M. anijimana* survives these disturbed conditions, such evolutionary effects are a serious threat to biodiversity.

Although it is unclear which specific animals are preyed upon by the rats, these invasive species likely forage on many types of ground animals. In addition to rats, ground invertebrates simultaneously suffer predation pressure from the green anole and the marine toad.

The population of feral cats depends on the population of black rats, because approximately 90% of fecal material of cats consists of rats [59]. In turn, feral cats increase in number and prey on other animal species (i.e., the residual 10% of fecal material). Thus, if rat populations decrease, the population size and predation pressure of feral cats may also decrease. Rats clearly augment the effects of feral cats on native species.

### 4.5. Zoonosis Vector

In combination with the introduced African land snail (itself a threat to the sustainability of crop systems and native ecosystems), rats also pose a risk to human health. While not a danger to native biota, this issue is a significant problem mediated by rats and is worthy of discussion. The land snail, a vector of zoonosis, is an intermediate host of *Angiostrongylus cantonensis* [98]. This parasite is found in the land snail on Chichijima and Hahajima [97, 114, 115]. Rodents are the definitive host of this nematode, and the black rat on Chichijima is infected by the parasite due to consumption of infected land snails [97, 98]. The prevalence of the parasite in rats was 7.5% on Chichijima [97].

Humans infected with this nematode develop meningoencephalitis. Fortunately, human infections have never been reported on the Bonin Islands, but at least 54 cases have been reported in Japan, particularly in Okinawa Prefecture [116]. In the worst case, a boy died from the infection [117]. Infection to humans is caused only by intermediate hosts and never by rats [116]; however, rats act as carriers and can expand the distribution of the disease.

Although this example of the effects of rats involves a human infection, various studies have examined the effects of introduced diseases on insular indigenous species. On the Hawaiian Islands, introduced diseases, especially avian malaria, are thought to have caused the extinction of various birds [118, 119]. The role of introduced species as disease vectors is important for the conservation of insular species, which often serve as naive hosts.

### 4.6. Rat Eradication Trial

On Nishijima (0.5 $km^2$), an uninhabited island near Chichijima, an eradication of the black rat by poisoning was experimentally conducted in the spring of 2007. Poison bait was placed in bait stations to prevent consumption by native animals. The vegetation of the island is species poor and covered by grasslands and forests primarily composed of the alien tree *Casuarina equisetifolia*. Although the grasslands had been grazed by goats, the goats were nearly completely removed in 2002 and 2003 prior to the rat eradication trial [38]. Seedlings of native trees are rare, likely due to the effects of feral goats and rats. The eradication of rat seems successful, and neither rats nor signs of rats have since been observed.

Such operations should be immediately conducted on the other islands to avoid native species extinctions. In particular, Higashijima warrants quick action, as local seabirds are intensively consumed by rats. In addition, changes in the ecosystem must be monitored after such eradication efforts, because there are unknown effects of the disappearance of such an integrated species in an already disturbed ecosystem. For example, when feral goats were eradicated from Nakodojima, the black rat, which had likely competed with feral goats, subsequently increased and began consuming plant seeds [47].

Additionally, interspecific interactions in the target area should be examined prior to the onset of eradication efforts. For example, the endangered endemic subspecies of the common buzzard *Buteo buteo toyoshimai* might decrease when rats are completely removed. Introduced animals comprised more than 90% of the diet of this bird, and half of that consisted of the black rat [120]. The invasive rats have become important prey items for the buzzard, which cannot sustain its population without rats. This situation was caused by the extinction of native birds and the decline of flying foxes. Fortunately or unfortunately, Nishijima has been drastically altered and halted raptor reproduction. If rat eradication is applied on other islands where the endangered raptor breeds, appropriate planning will be necessary.

A serious obstacle facing rat eradication efforts involves reinvasion from neighboring islands, because rats can swim from nearby islands [121]. In the case of Nishijima, black rats occur on the two nearest islands, Hitomarujima and Hyotanjima, which are approximately 1 km away. To ensure complete rat eradication on Nishijima, similar control efforts should be conducted on these nearby islands.

## 5. Conclusions

To maintain biodiversity, invasive species must clearly be controlled on the Bonin Islands. Without adequate countermeasures, these species will expand their ranges, exclude native species, and degrade biodiversity. The above-mentioned cases on the Bonin Islands suggest that predators and species that change the habitat structure can severely affect native species. Unfortunately, the examples detailed here are only the proverbial tip of the iceberg. It is reported that the number of newly detected introduced insects has rapidly increased over the last two decades [49]. The case of the freshwater snail *Melanoides*

**Table 2.** The Distribution of major invasive species. +: current existence, -: former existence (eradicated).

| | Mukojima | Nakodojima | Yomejima | Ototojima | Anijima | Chichijima | Hahajima | Mukohjima | Hirashima |
|---|---|---|---|---|---|---|---|---|---|
| Goat (*Capra aegagrus*) | - | - | - | + | + | + | | - | - |
| Pig (*Sus scrofa domesticus)* | | | | + | | - | | | |
| Cat (*Felis catus*) | | | | + | + | + | + | | |
| Norway Rat (*Rattus norvegicus*) | | | | | | - | + | | + |
| Black Rat (*Rattus rattus*) | + | + | + | + | + | + | + | + | + |
| House Mouse (*Mus musculus*) | | | | | | + | + | | |
| Green Anole (*Anolis carolinensis*) | | | | | | + | + | | |
| American Bullfrog (*Rana catesbeiana*) | | | | + | | | | | |
| Marine Toad (*Bufo marinus*) | | | | | | + | + | | |
| Rosy Wolfsnail (*Euglandina rosea*) | | | | | | + | | | |
| Freshwater snail (*Melanoides tuberculata*) | | | | | | + | | | |
| Flatworm (*Platydemus manokwari*) | | | | | | + | | | |
| Vascular plant (*Bischofia javanica*) | | | | + | | + | + | | |

*tuberculata* suggests that introduced species continue to arrive at the islands.

When an introduced species is determined to be invasive, elimination is one obvious control method. However, some species are impossible to completely eradicate from their current ranges because of wide distributions and/or high population densities. The distributions of the primary invasive species are limited to two inhabited islands, Chichijima and Hahajima, and several neighboring uninhabited islands (**Table 2**). Some native species that have decreased or vanished from the two islands have survived on their satellite islands [65, 68]; thus, introduced species must be confined to their current ranges. These satellite islands are used by tourists, fishermen, and researchers, all of whom should take particular care to avoid being carriers of introduced species. When introduced species expand their ranges to other islands, they should be eliminated during initial stages before establishing irreversible relationships with native species. However, the goat eradication efforts suggest that the subsequent transition of biota should continue to be monitored after the target species is completely removed.

Prioritization is also necessary for eradication act, because partial eradication is not effective for certain species. Introduced *Cenchrus echinatus* is a representative example, which has fastly spread its range throughout the islands including uninhabited islands. Since its seed is likely dispersed to other islands by attached to seabird feathers, the spreading can not be prevented without the simultaneous eradication throughout its range or eradication of seabirds. Such object should not be aimed to completely eradicate, since the fund is not illimitable.

Introduced species sometimes cause unexpected events. For example, the establishment of the green anole led to the unpredicted arrival of the bull-headed shrike. White's thrush *Zoothera dauma* provides a similar example of the unpredictable arrival of a new species. This bird species established on the islands during the US occupation, and earthworms were its primary prey item [38]. The Bonin Islands were thought to lack earthworms until human colonization, although they have increased in number with the transportation of plants and soils from the mainland [8]. This increased food availability potentially attracted the thrush, and a once irregular visitor established a new population [38]. This bird can currently be found on nearly all islands around Chichijima and Hahajima, and it has become a prey item of the native buzzard [53, 120]. The unpredictable nature of the effects of introduced species is a particularly problematic aspect of their ecology.

This review has outlined the effects of introduced species through food webs, competition, hybridization, and infection (**Fig. 3**). The examples herein have described typical situations caused by and consequences of introduced species. These case studies have included various types of indirect effects that reach multiple trophic levels. Historically, indirect effects have been neglected during control efforts of introduced species, but these important effects have become integral to the assessment of the impacts of introduced species and countermeasures for their control. However, such operations may unintentionally harm native species. For example, rat eradication may enhance the reproductive success of invasive plants and cause extinctions of native plants. Thus, a better understanding of interspecific relationships is the only solution to such a problem. However, such relationships are often extremely complicated. Although the discussion of introduced rats outlined its complex networks with various species, it was not an exhaustive list of all possible interactions. The flexibility to modify policy in the face of a changing context is required when beginning control efforts.

Problematically, some introduced species have become essential components of the current ecosystem after long-term naturalization. Introduced species can sometimes support vulnerable species. For example, *Melastoma tetranerum*, a critically endangered plant endemic to Chichijima [101], potentially lacked an effective native seed disperser since the local extinction of the Bonin Islands white-eye [102]. The introduced Japanese white-eye has become an effective disperser of this plant species [102]. In this case, the disappearance of the introduced white-eye would lead to the decline of *M. tetranerum*. Similar examples include the rat as buzzard prey and *C.*

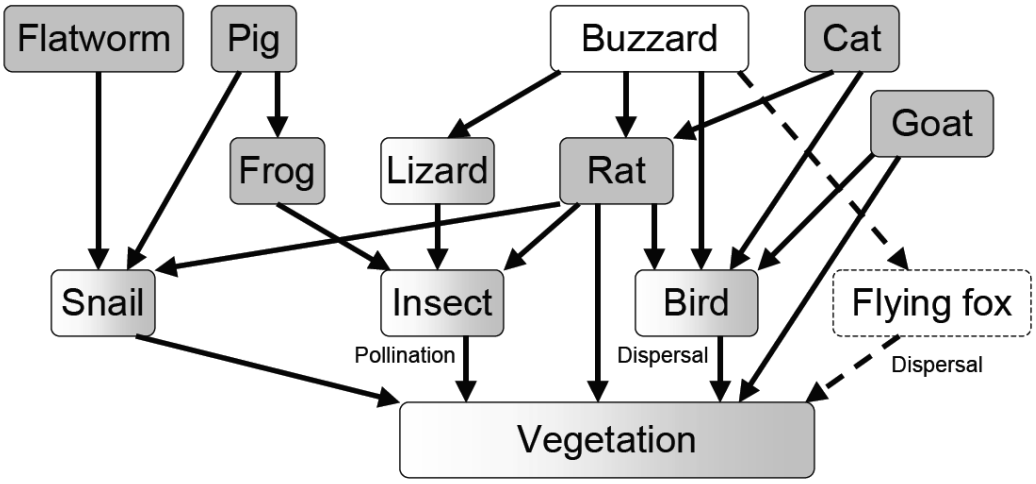


**Fig. 3.** A model of the current ecosystem network composed of native and introduced species in the Bonin Islands. The symbols are the same as in **Fig. 2**.

*equisetifolia* as a nesting tree of the greenfinch. These introduced species clearly have wide-ranging effects on the ecosystem.

Relying solely on the protection or elimination of particular species does not constitute a convincing solution. The ultimate goal of countermeasures is the conservation of the overall balance of the ecosystem, and the protection or elimination of particular species is only one aspect of achieving that goal. Because some components of the original ecosystem have regrettably been lost forever, the current ecosystem may not function without introduced species. A realistic goal of conservation is not the restoration of the primary environment, but the construction of a sustainable ecosystem including both native and introduced species.

New endemic species are continually discovered on the Bonin Islands [e.g., 122, 123, 124]. Among these species, some (e.g., the large grasshopper *Ogasawaracris gloriosus* and three ground beetles, *Colpodes boninensis*, *C. yamaguchii*, and *Chlaenius ikedai*) have rarely been found after their initial discovery, in part because of the effects of introduced predators [66, 125, 126]. Nonetheless, the situation could have been worse, because at least these species were discovered before their extinction. Unfortunately, there have likely been many species that went extinct prior to their discovery. The first step for conservation is to thoroughly, if not exhaustively, record and examine the current biota.

**Acknowledgements**

I thank Kazuo Horikoshi and Kiyoshi Satake for information regarding the literature cited and Shun-ichi Makino for revise of manuscript. I also thank anonymous reviewers for their helpful comments. The Ministry of the Environment (Global Environment Research Coordination System) financially supported this study.

**References:**

[1] T. Kuroda, et al., "Geology of the Bonin Islands," Report on the assessment of the nature of Ogasawara (2), Tokyo Metropolitan Univ., pp. 111-131, 1981 (in Japanese).
[2] Japan Meteorological Agency, "The climatic data of Japan," Japan Meteorological Business Support Center, 2001 (in Japanese).
[3] S. Carlquist, "Island biology," Columbia Univ. Press, 1974.
[4] J. R. Whittaker, "Island biogeography," Oxford Univ. Press, 1998.
[5] A. R. Wallace, "Island life (3rd edn)," Macmillan, 1902.
[6] N. Kuroda, "The geographical distribution of mammals in the Bonin Islands," Bull. Biogeographical Soc. Jpn, 1, pp. 81-88, 1930 (in Japanese).
[7] T. Momiyama, "On the birds of Bonin and Iwo Islands," Bull. Biogeographical Soc. Jpn, 1, pp. 89-186, 1930 (in Japanese).
[8] M. Nakamura, "Earthworms (Annelidae: Oligochaeta) of Ogasawara Archipelagoes," Bull. Chuo Univ., 15, pp. 21-32, 1994.
[9] S. Kobayashi and M. Ono, "The Revised List of Vascular Plants Indigenous and Introduced to the Bonin (Ogasawara) and the Volcano (Kazan) Islands," Ogasawara Research, 13, pp. 1-55, 1987.
[10] Y. Shimizu, "The nature of Ogasawara and its conservation," Global Environ. Res., 7, pp. 3-14, 2003.
[11] T. Ohbayashi, et al., "List of insects in the Ogasawara Islands, Japan (2002)," Ogasawara Research, 29, pp. 17-74, 2004 (in Japanese).
[12] T. Toyoda, "Flora of Bonin Is.," Aboc-sha, 1981 (in Japanese).
[13] "Check-list of Japanese birds Sixth revised edition," Ornithol. Soc. Jpn, 2000.
[14] T. Kurozumi, "Species composition and abundance of land mollusks and factors affecting their extinction in the Ogasawara Islands," Ogasawara Res., 15, pp. 59-109, 1988 (in Japanese).
[15] J. W. Fitzpatrick, "Bird Conservation," Handbook of Bird Biology, Princeton Univ. Press, pp. 104-116, 2004.
[16] Ministry of the Environment, "Threatened wildlife of Japan, Red Data Book 2nd ed. Vol.2. Aves," JWRC, 2002 (in Japanese).
[17] S. Oda, "The Archaeological history of the Bonin Islands," Annual Rep. Curators of Tokyo, 14, pp. 1-82, 1998 (in Japanese).
[18] S. L. Olson and H. F. James, "Fossil birds from the Hawaiian Islands: Evidence for wholesale extinction by man before western contact," Science, 217, pp. 633-635, 1982.
[19] D. W. Steadman, "Prehistoric extinctions of pacific island birds: biodiversity meets zooarchaeology," Science, 267, pp. 1123-1131, 1995.
[20] S. Pimm, et al., "Human impacts on the rates of recent, present, and future bird extinctions," Proc. National Academy of Sciences, 103, pp. 10941-10946, 2006.
[21] T. Tsuji, "The History of the Bonin Islands I," Kindaibungeisha, 1995 (in Japanese).
[22] Y. Kurata, "Album of Ogasawara-Form Discovery to Prewar Era," Aboc-sha, 1983 (in Japanese).
[23] M. Funakoshi, "History of development and destruction," The Nature of Ogasawara, Kokon-Shoin, pp. 38-45, 1992 (in Japanese).
[24] W. L. N. Tickell, "Albatrosses," Yale Univ. Press, 2000.

[25] Y. Higuchi, "List of Birds in Ogasawara Islands, including Iwo Islands and Minamitorishima," Strix, 3, pp. 73-87, 1984 (in Japanese).

[26] W. A. Bryan, "A monograph of Marcus Island," Occ. Pap. B. P. Bishop Mus., 1, pp. 77-126, 1903.

[27] N. Kuroda, "Report on the trip to Marcus Island with notes on the birds," Pac. Sci., 8, pp. 84-93, 1954.

[28] H. Chiba, et al., "The distribution of seabirds in the Bonin Islands, southern Japan," J. Yamashina Inst. for Ornithol., 38, pp. 1-18, 2007.

[29] T. Tsuji, "The History of the Bonin Islands II," Kindaibungeisha, 1995 (in Japanese).

[30] K. Okutomi and T. Iseki, " Vegetation of Minami-torishima (Marcus) Island," the Vegetation Studies Soc. of Tokyo, 2004 (in Japanese).

[31] K. Yoshida and S. Oka, "Impact of biological invasion of *Leucaena leucocephala* on successional pathway and species diversity of secondary forest on Hahajima Island, Ogasawara (Bonin) Islands, northwestern Pacific," Jpn J. Ecol. 50, pp. 111-119, 2000 (in Japanese).

[32] M. Hasegawa, et al., "Range expansion of *Anolis c. carolinensis* on Chichi-Jima the Bonin Islands," Jpn J. Herpetol., Vol.12, pp. 115-118, 1988.

[33] "Shimadas," National Institute for Japanese Islands, 2004 (in Japanese).

[34] T. Tsuyama and S. Asami, "The nature in the Bonin Islands" Hirokawa-shoten, 1970 (in Japanese).

[35] "Report on the urgent research about damage of feral goats on plants and animals in the Ogasawara Islands," JWRC, 1992 (in Japanese).

[36] K. Tokida and S. An, "Problems on the feral goats in the Bonin Islands" Iden, 54, pp. 81-85, 2000 (in Japanese).

[37] K. Tokida, "Damage caused by feral goats and what to do about it," Animals and Zoos, 53, pp. 124-127, 2001 (in Japanese).

[38] "Galapagos in the Orient: the Attraction and Crisis of the Endemic Species," Kanagawa Prefect. Mus. of Nat. Hist., 2004 (in Japanese).

[39] "Report on the Impacts of a Feral Goat Outbreak on the Nature in the Bonin Islands," JWRC, 2006 (in Japanese).

[40] K. Campbell and C. J. Donlan, "Feral goat eradications on islands," Conserv. Biol. 19, pp. 1362-1374, 2005.

[41] Y. Shimizu, "Natural history of the Ogasawara Islands," Forest Sci., 25, pp. 42-45, 1999 (in Japanese).

[42] Y. Shimizu, "Vegetation of Mukojima Island Group in the Bonin (Ogasawara) Islands with reference to the ecology of *Ardisia* dominant forest and the influence of feral goats," Komazawa Geography, 29, pp. 9-58, 1993 (in Japanese).

[43] K. Hata, et al., "Effects of an alien shrub species, *Leucaena leucocephala*, on establishment of native mid-successional tree species after distubance in the national park in the Chichijima island, a subtropical oceanic island," Tropics 16, pp. 283-290, 2007.

[44] D. A. Croll, et al., "Introduced predators transform subarctic islands from grassland to tundra," Science 307, pp. 1959-1961, 2005.

[45] T. Fukami, et al., "Above- and below-ground impacts of introduced predators in seabird-dominated island ecosystems," Ecol. Letters, 9, pp. 1299-1377, 2006.

[46] "Report on the confirmation of feral goat eradication in the Ogasawara Islands" JWRC, 2007 (in Japanese).

[47] K. Tokida, "A report on the public symposium at IMC9-part 4: The feral goat eradication program on the Ogasawara Islands," Mammal. Sci., 46, pp. 93-94, 2006 (in Japanese).

[48] G. Jones, "States Japan Expedition by Com. M. C. Perry Vol.1," A. O. P. Nicholson, 1856.

[49] Ecological Society of Japan, "Handbook of Alien Species in Japan," Chijin Shokan, 2002 (in Japanese).

[50] K. Kawakami and H. Higuchi, "Predation by domestic cats on birds of Hahajima Island of the Bonin Islands, southern Japan," Ornithol. Sci., 1, pp. 143-144, 2002.

[51] K. Kawakami and M. Fujita, "Feral cat predation on seabirds on Hahajima, the Bonin Islands, Southern Japan," Ornithol. Sci., 3, pp. 155-158, 2004.

[52] K. Horikoshi, "Bird conservation and feral cat problems," Iden, 61, pp. 68-71, 2007 (in Japanese).

[53] K. Kawakami, "Bird deaths in the Bonin Islands," Animals and Zoos, 52, pp. 12-16, 2000 (in Japanese).

[54] R. C. Conant "A field guide to reptiles and amphibians of eastern and central North America," Houghton Mifflin Co., Boston, 1985.

[55] H. Nakamura, "Ecological Adaptations of the Oriental Greenfinch *Carduelis sinica* on the Ogasawara Islands," Jpn. J. Ornithol, 46, pp. 95-110, 1997.

[56] "Report on designation of national wildlife refuge, 2004 (the Volcano Islands)," Yamashina Insti. Onithol., 2005 (in Japanese).

[57] F. H. von Kittlitz, "Ueber die Vogel der Inselgruppe von Boninsima. Beobachtet zu Anfang May 1828," Mem. Acad. Imp. Sci. St. Petersbourg, 1, pp. 231-248, 1831.

[58] J. C. Greenway, "Extinct and Vanishing Birds of the World," Dover Pub., 1967.

[59] "Report on the conservation of endangered Japanese Wood-Pigeon *Columba janthina nitens*," Tokyo Regional Forest Office, 2003 (in Japanese).

[60] K. Kawakami, "Diet of the feral cat *Felis cattus* in Hahajima, the Bonin Islands, Japan," Ogasawara Kenkyu Nenpo, 31, pp. 41-48, 2008 (in Japanese).

[61] "Report of the Second General Survey of Natural Environment of the Ogasawara (Bonin) Islands 2," Tokyo Metropolitan Univ., 1991 (in Japanese).

[62] A. Suzuki and M. Nagoshi, "Habitat utilization of the native lizard, *Cryptoblepharus boutoni nigropunctatus*, in areas with and without the introduced lizard, *Anolis carolinensis*, on Hahajima, the Ogasawara Islands, Japan," Tropical Islands, Herpetofauna: Origin, Current Diversity, and Conservation, Elsevier Science, pp. 155-168, 1999.

[63] I. Okochi, et al., "High population densities of an exotic lizard, *Anolis carolinensis* and its possible role as a pollinator in the Ogasawara Islands," Bull. FFPRI, 5, pp. 265-269, 2006.

[64] H. Karube, "On a critical situation of the endemic dragonflies from the Ogasawara Islands," Gekkan-mushi, 369, pp. 22-32, 2001 (in Japanese).

[65] H. Makihara, et al., "An evaluation of predation impact of the introduced lizard *Anolis carolinensis* on the endemic insect fauna of the Ogasawara Islands based on insect collection records and feeding experiments, with special reference to longicorn beetles (Insecta: Coleoptera: Cerambycidae)," Bull. FFPRI, 3, pp. 165-183, 2004 (in Japanese).

[66] M. Yoshimura and I. Okochi, "A decrease in endemic odonates in the Ogasawara Islands, Japan," Bull. FFPRI, 4, pp. 45-51, 2005.

[67] "Changing insect fauna in Ogasawara," Res. Rep. Kanagawa Prefect. Mus. of Nat. Hist., 12, 2004 (in Japanese).

[68] T. Ohbayashi, "*Anoris carolinensis* preying on Meimuna boninensis," Cicada, 16, pp. 1, 2001 (in Japanese).

[69] M. Kato, et al., "Impact of introduced honeybees, *Apis mellifera*, upon native bee communities in the Bonin (Ogasawara) Islands," Res. Popul. Ecol., 41, pp. 217-228, 1999.

[70] H. Chiba, "First breeding record of the Bull-headed shrike from the Ogasawara Islands," Jpn J. Ornithol. 38, pp. 150-151, 1990 (in Japanese).

[71] Wild Bird Society of Japan, "Survey on the protected birds," Ministry of the Environment, 1975 (in Japanese).

[72] "Plans on conservation and restoration of nature in the Bonin Islands," Ministry of the Environment, 2007 (in Japanese).

[73] S. Lowe, et al. "100 of the World's Worst Invasive Alien Species: A selection from the Global Invasive Species Database," ISSG, SSC, IUCN, 2000.

[74] K. Miyashita, "Introduced species in the Bonin Islands," Ogasawara Kenkyu Nenpo, 4, pp. 47-54, 1980 (in Japanese).

[75] M. Kawakatsu, et al., "A preliminary report on land planarians and land nemertine from the Ogasawara Islands," Occ. Publ. Biol. Lab. of Fuji Woman's College 32, pp. 1-8. 1999.

[76] S. Chiba, "Species diversity and conservation of *Mandarina*, an endemic land snail of the Ogasawara Islands," Global Environ. Res., 7, pp. 29-37, 2003.

[77] T. Ohbayashi, et al., "Food habit of *Platydemus manokwari* De Beauchamp, 1962 (Tricladida: Terricola: Rhynchodemidae), known as a predatory flatworm of land snails in the Ogasawara (Bonin) Islands, Japan," Applied Entomol. and Zool., 40, pp. 609-614, 2005.

[78] S. Sugiura and I. Okochi, "High predation pressure by an introduced flatworm on land snails on the oceanic Ogasawara Islands," Biotropica, 38, pp. 700-703, 2006.

[79] D. R. Hopper and B. D. Smith, "Status of tree snail (Gastropoda: Partulidae) on Guam, with a resurvey of sites studied by H. E. Crampton in 1920," Pac. Sci., 46, pp. 77-85. 1992.

[80] L. G. Eldredge and B. D. Smith, "Triclad flatworm tours the Pacific," Aliens 2, pp. 11, 1995.

[81] T. Ohbayashi, et al., "Rapid decline of endemic snails in the Ogasawara Islands, Western Pacific Ocean, "Applied Entomol. and Zool., 42, pp. 479-485, 2007.

[82] I. Okochi, et al., "The cause of mollusk decline on the Ogasawara Islands," Biodiversity and Conserv., 13, pp. 1465-1475, 2004.

[83] T. Tanimoto and T. Toyoda, " Survivorship and growth of Akagi (*Bischofia javanica* BI) seedlings under the forest canopy and different temperature conditions," Bull. FFPRI, 370, pp. 1-19, 1996 (in Japanese).

[84] N. Yamashita, et al., "Acclimation to sudden increase in light favoring an invasive over native trees in subtropical islands, Japan," Oecologia, 125, pp. 412-419, 2000.
[85] N. Yamashita, et al., "Seed and seedling demography of invasive and native trees of subtropical Pacific islands," J. Vegetation Science, 14, pp. 15-24, 2003.
[86] Y. Shimizu, "A vegetation change during a 20-year period following two continuous disturbances (mass-dieback of pine trees and typhoon damage) in the *Pinus-Schima* secondary forest on Chichijima in the Ogasawara (Bonin) Islands: which won, advanced saplings of new seedlings?," Ecol. Res., 20, pp. 708-725, 2005.
[87] Y. Tsukamoto, "Avifauna of Minami-Iwojima Island," The Nature of Minami-Iwojima Island, JWRC, pp. 249-285, 1983 (in Japanese).
[88] N. Tani, et al., "Development of SCAR markers distinguishing pure seedlings of the endangered species *Morus boninensis* from *M. boninensis* × *M. acidosa* hybrids for conservation in Bonin (Ogasawara) Islands," Conserv. Genetics, 4, pp. 605-612, 2004.
[89] K. Satake, et al., "First record of the parthenogenetic snail *Melanoides tuberculata* (Gastropoda: Thiaridae) from Chichijima Island, Ogasawara Islands," Chiribotan, 37, pp. 112-117, 2006 (in Japanese).
[90] H. Madsen and F. Frandsen, "The spread of freshwater snails including those of medical and veterinary importance," Acta Tropica, 46, pp. 139-146, 1989.
[91] B. Facon, et al., "A molecular phylogeography approach to biological invasions of the New World by parthenogenetic Thiarid snails," Molecular Ecol., 12, pp. 3027-3039, 2003.
[92] S. Obana, "Ogasawarajima-Yoroku I," 1877 (in Japanese).
[93] T. Yabe and T. Matsumoto, "A survey on the Murine Rodents on Chichijima and Hahajima, the Ogasawara Islands," J. of Mammal. Soc. Jpn, 9, pp. 14-19, 1982.
[94] T. Tateishi and Y. Takada, "Distribution, morphological characteristics and reproduction of feral house mice (*Mus musculus*) on Chichijima, Ogasawara Islands," Mammal. Sci., 34, pp. 1-16, 1994 (in Japanese).
[95] I. A. E. Atkinson, "The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas," Conservation of island birds, ICBP, pp. 35-81, 1985.
[96] R. Seitre and J. Seitre, "Causes of land-bird extinctions in French Polynesia," Oryx 26, pp. 215-222, 1992.
[97] F. Courchamp, et al., "Mammal invaders on islands: impact, control and control impact," Biol. Rev., 78, pp. 347-383, 2003.
[98] E. Hori, et al., "A survey of *Angiotrongylus cantonensis* in the Hahajima, Ogasawara Islands," Jpn J. Parasitol., 23, pp. 138-142, 1974 (in Japanese).
[99] T. Yabe, "*Angiotrongylus cantonensis* of rats," The nature and animals, 9-9, pp. 7-11, 1979 (in Japanese).
[100] T. Abe, "Predator or disperser? A test of indigenous fruit preference of alien rats (*Rattus rattus*) on Nishi-jima (Ogasawara Isalnds)," Pacific Conserv. Biol., 13, pp. 213-218, 2007.
[101] K. Watanabe, et al., "Native plants disrupted by alien rat, *Rattus rattus*, on the Ogasawara Islands," Ogasawara Kenkyu Nenpo, 26, pp. 13-31, 2003 (in Japanese).
[102] Ministry of the Environment, "Threatened wildlife of Japan – Red Data Book 2nd ed. Vol.8. Vascular plants," JWRC, 2000 (in Japanese).
[103] K. Kawakami, "Seed dispersal of *Melastoma tetramerum* in Chichijima Island of the Bonin Islands, Southern Japan," Strix 24: pp. 159-164, 2006 (in Japanese).
[104] F. Nobushima, "Herbivory of native plants on Hahajima Island by rats," Ogasawara Kenkyu Nenpo, 26, pp. 33-37, 2003 (in Japanese).
[105] H. Takano, " Current status and conservation of *Columba janthina nitens*," Iden, 56-1, pp. 92-96, 2002 (in Japanese).
[106] E. Kitahara and H. Sato, "Bark-stripping of *Leucaena leucocephala* by the black rat, *Rattus rattus*, on the Bonin Islands," Forest Pests, 49, pp. 125-127, 2000 (in Japanese).
[107] S. B. Vander Wall, "Food hoarding in animals," Univ. Chicago Press, 1990.
[108] M. Inaba, et al., "An urgent appeal for conservation of the Bonin flying fox, *Pteropus pselaphon* Layard, an endangered species," Jpn J. Conserv. Ecol., 7, pp. 51-61, 2002 (in Japanese).
[109] K. R. McConkey and D. R. Drake, "Extinct pigeons and declining bat populations: are large seeds still being dispersed in the tropical Pacific," Frugivory and seed dispersal: evolutionary and conservation perspectives, CAB International, pp. 381-395, 2002.
[110] K. R. McConkey and D. R. Drake, "Flying foxes cease to function as seed dispersers long before they become rare," Ecology, 87, pp. 271-276, 2006
[111] K. Horikoshi, et al., "Impacts of invasive mammals on seabirds in the Bonin Islands," Proc. 54st annual meeting of Ecol. Soc. Jpn, 2007 (in Japanese).
[112] Institute of Boninology, "Report on biota of Kitaiwojima," Ogasawara Branch of Tokyo Metropolitan, 2001 (in Japanese).
[113] C. P. H. Mulder and S. N. Keall, "Burrowing seabirds and reptiles: impacts on seeds, seedlings and soils in an island forest in New Zealand," Oecologia, 127, pp. 350-360, 2001.
[114] S. Chiba, "Morphological and ecological shifts in a land snail caused by the impact of an introduced predator," Ecol. Res. 22, pp. 884-891, 2007.
[115] E. Hori, et al., "A survey of *Angiotrongylus cantonensis* in the Chichi-jima, Ogasawara Islands," Jpn J. Parasitol., 22, pp. 347-353, 1973 (in Japanese).
[116] T. Kanazawa, et al., "An Epidemiological Survey of *Angiostrongylus Cantonensis* in Chichijima, Ogasawara Islands," Chiba Medical J., 60, pp. 377-381, 1984 (in Japanese).
[117] K. Yoshimura, "*Angiotrongylus cantonensis*", Infectious Deseases Weekly Rep. Jpn, 6-25, pp. 16-18, 2004 (in Japanese).
[118] H. Hattori, et al., "Eosinophilic meningitis caused by *Angiotrongylus cantonensis* infection in Okinawa," J. Jpn Pediatric Soc., 105, pp. 719-721 (in Japanese).
[119] R. E. Warner, "The role of introduced diseases in the extinction of the endemic Hawaiian avifauna," Condor, 70, pp. 101-20. 1968.
[120] C. S. Van Riper III, "The impact of introduced vectors and avian malaria on insular passeriform bird populations in Hawaii," Bull. the Soc. of Vector Ecologists, 16, pp. 59-83, 1991.
[121] Y. Kato and T. Suzuki, "Introduced animals in the diet of the Ogasawara buzzard, an endemic insular raptor in the Pacific Ocean," J. Raptor Res. 39, pp. 173-179, 2005.
[122] J. C. Russell, et al., "Intercepting the first rat ashore," Nature, 437, pp. 1107, 2005.
[123] M. Hasegawa, "Discovery of a new *Olenecamptus* (Coleoptera, Cerambycidae) from the Ogasawara Islands, Japan, Elytra, 32, pp. 225-228, 2004.
[124] K. Satake and Y. Cai, "*Paratya boninensis*, a new species of freshwater shrimp (Crustacea: Decapoda: Atyidae) from Ogasawara, Japan," Proc. Biol. Soc. Washington, 118, pp. 306-311, 2005 (in Japanese).
[125] T. Niisato and H. Karube, "A new *Chlorophorus* (Coleoptera, Cerambycidae) from Muko-jima Island of the Ogasawara Islands," Elytra, 34, pp. 221-222, 2006.
[126] S. Kasahara, "Three new Carabid beetles from Ogasawara Islands," Elytra, 19, pp. 243-250, 1991.
[127] G. Ito, "*Ogasawaracris gloriosus*, a new genus and species of possibly extinct grasshopper (Orthoptera: Acrididae) from the Ogasawara Islands," Entomol. Sci., 6, pp. 85, 2003.

**Name:**
Kazuto Kawakami

**Affiliation:**
Senior Researcher, Laboratory of Wildlife ecology, Forestry and Forest Products Research Institute (FFPRI)

**Address:**
Matsunosato 1, Tsukuba, Ibaraki 305-8687, Japan

**Brief Career:**
1999 Joined Tama Forest Science Garden, FFPRI
2006- Lab. of Wildlife Ecology, FFPRI

**Selected Publications:**
• "Interspecific relationships between the native and introduced white-eyes in the Bonin Islands," Ibis, Vol.145, pp. 583-592, 2003.

**Academic Societies & Scientific Organizations:**
• The Ornithological Society of Japan (OSJ)
• Ecological Society of Japan (ESJ)