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Editors

Restoring the Oceanic Island Ecosystem

Impact and Management of Invasive Alien Species in the Bonin Islands

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Chapter 22
Ecology and Control of the Green Anole (*Anolis carolinensis*), an Invasive Alien Species on the Ogasawara Islands

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Abstract The green anole (*Anolis carolinensis*) was introduced from North America to the Ogasawara Islands, where it has become established. The feeding behavior of these animals causes insect population collapse on the islands, and thus the species has been listed as an Invasive Alien Species in Japan since June 2005. Although the green anole population on the islands has not grown rapidly in recent times, its density could nevertheless approach hundreds to thousands of individuals per hectare. Given the biological and ecological characteristics of the species, highest management priority should be given to preventing dispersal to non-invaded islands. Area-specific control is the most practical approach for eradicating established populations. In a series of control projects conducted by Japanese Ministry of the Environment, adhesive traps for animal capture and Teflon sheet fencing to restrict movement were developed. With this technology, continuous green anole capture is now under way around the harbor of Chichijima to prevent dispersal to neighboring uninhabited islands. In addition, an experimental project for regional eradication has been set up on Hahajima in an attempt to resurrect the insect community.

22.1 Introduction

The Ogasawara Islands comprise an oceanic archipelago geographically isolated from any continental land mass, which makes the biological community very distinctive and prevents the immigration of potential predators. Under such conditions, many endemic insect species have evolved, forming a rich fauna on the islands. Recently, the green anole (*Anolis carolinensis*) was introduced artificially, leading to intense predation on native insect populations that have consequently suffered serious declines (Makihara et al. 2004; Karube 2005; Yoshimura and Okochi 2005). Accordingly, in June 2005, the green anole was listed in the Invasive Alien Species by the government of Japan. Many endemic insects on the islands are threatened with extinction (Ministry of the Environment 2006), and conservation of their populations is a matter of great urgency.

To protect these endemic insects, a series of projects are now under way on the Ogasawara Islands. This is probably the first attempt in the world to exterminate an invasive alien lizard species from a habitat in which it is established. The project is being undertaken by Japanese Ministry of the Environment and consists of three parts: prevention of the green anole dispersal to non-invaded islands; establishment of habitat restoration areas for insects native to the Ogasawara Islands, after extirpation of green anole populations; and promotion of the recovery of native insect communities in these habitat restoration areas.

We investigated the status of green anole populations on the islands prior to project implementation, and the results suggested that population control would be laborious. Green anole's population density is high in Chichijima and Hahajima, where the topography is rugged and steep. Since there have been few studies of lizard population control, there are few guidelines. However, while seeking technical solutions to the problem, we conclude that labor-intensive methods are effective for population control, and regional eradication is technically feasible.

Here we summarize results obtained from the field investigation since 2004 and from previous reports on lizard control. We also introduce the Ministry of the Environment approaches that aim at natural environment recovery and prevention and control of the green anole.

22.2 Characteristics of the Green Anole

22.2.1 Genus Anolis

Anolis belongs to the Iguanidae. This is the largest reptile genus, containing about 400 species that are widely distributed from southeastern North America to northern South America.

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These lizards are diurnal, small or medium-sized, and arboreal. They have rows of lamellae, or ruffled structures, on the bottoms of their toes, similar to the Gekkonidae. Like geckos, anoles can move quickly on smooth vertical surfaces (Savage 2002; Lovern et al. 2004). The lamellae of the Gekkonidae stick to vertical surfaces through intermolecular attraction (Autumn et al. 2002), and green anole lamellae are thought to function in the same manner, allowing the animals to climb smooth glass surfaces. Hence, designing fences to exclude green anoles is extremely difficult.

Many species of *Anolis* have green or brown bodies that can blend into their surroundings. However, most have a dewlap on their throat (a fan-shaped structure supported by hyoid bone and used for communication) that is vivid in color (Nicholson et al. 2007). The dewlaps of male anoles are distended when fighting other males or courting females. The body sizes of males are larger than those of females in most species (Savage 2002). Many species of *Anolis* coexist in particular regions of Cuba but use different micro habitats. Each arboreal species prefers different micro habitat among tree crowns, trunks, branches, and twigs. Others occur on flat ground and on cliffs. There are specialized anole "ecomorphs" in each micro habitat (Williams 1969).

22.2.2 The Green Anole as an Alien Species

The anoles introduced to Ogasawara were green anoles (Hasegawa 1986). The species is native to the southeastern United States (ranging from North Carolina to Florida and Texas in the east); other anoles occur mostly in Mexico, Cuba and central and south America. The natural distribution range of the green anole overlaps with those of other species only where there are anthropogenic influences (Behler and King 1979). This is the only anole species whose natural distribution range extends into temperate zones.

Green anoles are medium-sized and have well-developed limbs. They are arboreal and specialized to live in tree crowns. Even though the body is generally green, the lizards can change to greenish brown or blackish brown within about 1 min.

This species has been transported to islands in the Pacific Ocean. It is currently found on the Hawaiian islands of Kauai, Oafu, Molokai, Maui, and Hawaii; and on Guam, Saipan, Tinian, Lota, Yap, Palau, Okinawajima, Chichijima, and Hahajima (Hasegawa 1986; Hasegawa et al. 1988; Ota et al. 1995; McKeown 1996).

Although quantitative data are insufficient, green anoles have not formed large populations on the Micronesian islands (Arthur C. Echternachit, personal communication). Preliminary investigations on Okinawajima (Naha city) were undertaken in February 2006 and November 2007. The presence of the green anole was confirmed, but the population density was thought to be much lower than on the Ogasawara Islands (Mitsuhiko Toda, unpublished data). The underlying factors accounting for limited population development on islands other than Ogasawara have not been identified but may include the organization of the islands' natural biological communities (including natural enemies or competitors).

22.3 Ecology and Population Control of Anoles on Ogasawara

22.3.1 Introduction and Expansion of Population Range

There is no definitive information on how green anoles arrived on Ogasawara. Circumstantial evidence indicates that they came to Ohmura on Chichijima in about 1965 or 1966 and became established between 1968 and 1972 (Hasegawa 1986; Hasegawa et al. 1988; Miyashita 1991; Suzuki 2000). Because Chichijima was under the jurisdiction of American forces at the time of their introduction, anoles may have been brought unintentionally from Guam with supplies or as pets of American military personnel (Levern 2003). They were first found in Ohmura in 1972 and in Komagari in 1979, and later range expansion radiated from these two locations. The anoles then came to occupy the whole island (Miyashita 1991; Suzuki 2000).

Another suggestion is that green anoles were brought into the southernmost village (Motochi) on Hahajima from Chichijima more than once in the early 1980s (Suzuki 2000). Distribution expanded from Motochi to either northern or southern parts of the island (Miyashita 1991). The animals were seen in 1994 around Kitamura, located in the northern section of the island, and they were later found throughout Hahajima (Suzuki 2000).

There are no comprehensive data on the current distribution range. Based on our own knowledge and on anecdotal information from other researchers and locals, green anoles may be distributed over almost all of Chichijima and Hahajima. Except for harbors, where there is no vegetation, the lizards are widely reported from the coasts to the mountains, in natural and secondary forests, in urban districts and farmland. The distribution area of this species in Ogasawara is estimated at 44 km^2.

22.3.2 Population Density

We estimated anole population density in an arboretum operated by the Forestry and Forest Products Research Institute in Kiyose on Chichijima in autumn 2004. The area consists of secondary forest containing rosewood (*Schima mertensiana*), among other species. A mark and recapture program was run for 19 days from mid-September to the beginning of October. A total of 171 anoles were marked. On the assumption that the population was closed, an analysis done with "Capture" software (http://www.mbr-pwrc.usgs.gov/software/capture.html) estimated a population density of 1,450 individuals/ha within the study area. The estimated number of anoles on all of the Ogasawara Islands was 6.38 million (calculated using density estimates within the distribution ranges on Chichijima and Hahajima).

Population density has been continually monitored in the study area. Estimates were made 12 times over two or three 1-week periods per year from autumn 2004 to autumn of 2008 (*1). In each study week, we estimated density (using the Lincoln Index Method) at about 500–800 individual/ha (Fig. 22.1). At this site, anole density decreased over time. Sex ratio varied spatially, with a male majority in the Forestry and Forest Products Research Institute arboretum in Kiyose, a 50:50 ratio in some areas, and a female majority in others. More females were seen in grassland and shrub areas, whereas more males were seen in areas with poorly developed swards of grass.

Okochi et al. (2006) reported the population densities of anoles on Chichijima. They used a mark and recapture method at 11 sites on Chichijima in June 2004, and estimated a population density of 600–2,570 individuals/ha, with an average of 1,270. Our results are in line with this.

In sum, the population density of anoles on Ogasawara is several hundred to several thousand per hectare. On the whole islands, there are several million.

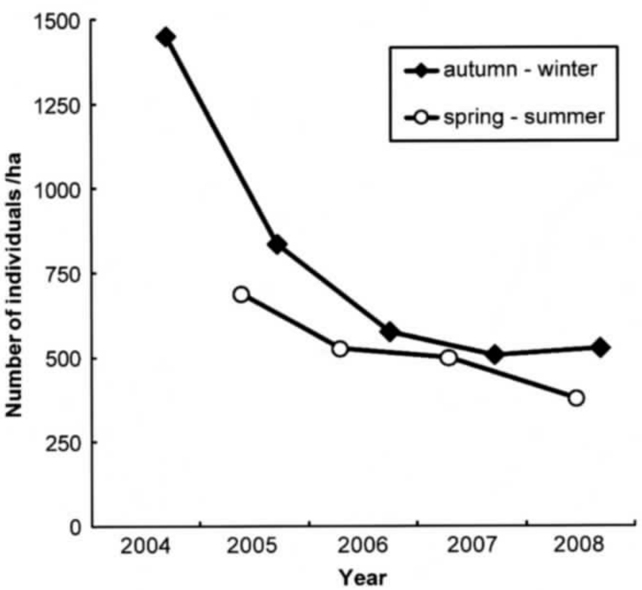

Fig. 22.1 Fluctuation of population density of green anoles in Kiyose, Chichijima

22.3.3 Growth and Maturation

Unlike other lizards, anoles lay only one egg, which is produced in alternating sequence by the left and right ovaries (Savage 2002; Lovern et al. 2004). Ten Female anoles from Chichijima lay 138 eggs from May to October in captivity, and the average number of eggs laid in one season by one female is 13.8 (Noriyuki Komatsu, personal communication, *1).

The incubation period is about 40 days (Hasegawa 1994). The snout-vent length (SVL) in five individuals just after incubation in captivity was 21.7–24.9 mm. A field survey of hatchling anoles demonstrated SVLs of 20–30 mm. Hatchlings started to appear from the beginning of June. They were seen most frequently in September and were not found from December to May of following year. Because immature individuals are absent from May to the beginning of June, the breeding season of this species is estimated to extend from April to October, with a maturation period of about 1 year.

According to Suzuki (2000), the SVL of the smallest male with visibly distinguishable penis or testes is 42 mm and the smallest SVL of a female with an egg is 43 mm, thus it is considered these are the sizes of sexual maturity for the two sexes. From observations of immature marked individuals, we confirmed that SVL reaches 40–60 mm 1 year after hatching. However, it is not clear whether small males of about 42–55 mm can breed in the wild.

Males of this species are much larger than females. The SVL of Ogasawara males reaches a maximum of 74 mm, whereas that of a female attains a maximum of only 60 mm. Tail length is about double SVL; total length of the largest individuals is 210 mm, and maximum weight is about 8 g.

Maximum longevity in the United States exceeds 7 years and 1 month in captivity (Bowler 1977); the oldest individual from the Ogasawara Islands attained more than 6 years and 3 months (Toda 2005). Because all individuals in the Ogasawara Islands study were males and were already mature when captured, the potential longevity of this species is estimated to exceed 7–8 years.

22.3.4 Feeding Behavior and Its Impact on the Ecosystem

Many kinds of lizards are secondary consumers in food webs, preying on small animals including insects and spiders, and being preyed upon by birds, snakes, or mammals. Green anoles are also insectivorous, preying mainly on Coleoptera, Hemiptera, and Araneia on Hahajima, according to Suzuki (2000). Moreover, according to analyses of stomach contents by the Japan Forest Technology Association, anoles prey most frequently on Hemiptera and Coleoptera on Chichijima and Hahajima; they also eat Lepidoptera (mainly larvae) and Hymenoptera (mainly ants; Japan Forest Technology Association 2005). Because of the relationship between the expanding distribution range of anoles and the depleted numbers of entomofauna, local extinctions or decreases in the endemic butterfly *Celastrina ogasawarensis*, endemic Odonata, diurnal Cerambycidae, and endemic cicada *Meimuna boninensis* are considered to be the result of anole predation (Karube 2004; Makihara et al. 2004; Takakuwa and Suda 2004; Karube 2005; Yoshimura and Okochi 2005; Karube and Suda 2004).

The Ogasawara snake-eyed skink *Cryptoblepharus nigropunctatus* is the only terrestrial reptile native to Chichijima and Hahajima. Anoles have a body only slightly larger than that of the skink but have a much more massive head and mouth (head width is 1.6-fold larger, on average; Japan Wildlife Research Center, unpublished data). Anoles have powerful jaws and well-developed teeth. When they prey on large insects, they chew up the prey in a few minutes and then swallow it, breaking the exoskeleton. The cicada *Meimuna boninensis* is one of the largest anole preys; in one instance after catching a cicada, a male anole cut it into small strips and abraded it against a tree after chewing the thorax. The lizard subsequently swallowed only one portion of the cicada (Mitsuhiko Toda, unpublished data). Green anoles are able to prey on much larger insects than native skinks, and the anole toe lamellae allow the animals to hunt on narrow branches and leaves. Anoles also have superior jumping abilities due to their long hind legs. The animals occur in a variety of environments at high densities, and their impact on the insect populations of Chichijima and Hahajima is likely enormous. Within the food chains of these islands, the primary consumers (insects) are in a state of decline, whereas the new secondary consumer (alien green anole) is flourishing. Hence, the structure of the island ecosystem has been massively altered.

Anoles are competitors and predators of the native skink, whose population may have significantly decreased compared with pre-invasion densities (Suzuki 2000). Reptile census data from 1984 (Hasegawa et al. 1988) and preliminary enumerations made by the Japan Wildlife Research Center (unpublished data) show that as the distribution of anoles extends, skink population density decreases.

Nevertheless, skinks may be more frequently observed than anoles in some parts of Hahajima (Mitsuhiko Toda, unpublished data); apparently, coexistence is possible at certain times and places. Unfortunately, there are no data on skink population densities before the green anole invasion, making definitive historical statements on impacts impossible. However, the ecological relationships between the two reptile species can be quantitatively analyzed within the current ecosystem structure, making it possible to construct projections of likely outcomes of the interaction of skinks and anoles.

22.3.5 Population Structure

From the results of anole surveys with continuous mark and recapture methods between 2004 and 2008, the survival rate at each life stage was calculated (Table 22.1, *1), and a life table was constructed as follows: the average number of eggs laid in one season by one female was 13.8 (*1), the hatching rate was 0.9 (from Lovern et al. 2004), the survival rate from hatchling to yearling adult was 11.5%, from 1 to 2 years of age was 35.5% (*1), and from 2 to 3 years of age was 33.3%; females produced eggs in the year after hatching; the sex ratio was estimated to be 50:50. Based on these values, it was estimated that from 1,000 eggs, 103.5, 36.7, 12.2, 4.1, 1.4 individuals would survive after 1, 2, 3, 4, 5 years, respectively (*1).

Age-specific survival and fertility rates were used to construct a matrix projection model of the population (using Ramas EcoLab, http://www.ramas.com/ecolab.htm). The starting population density in the model was the value obtained in autumn 2004 (1,450 individuals/ha). The virtual population increased 14.5-fold after 15 years when there was no trapping of reptiles. This projection does not match empirical observations of changes in population density through age classes; the number of eggs produced or the survival rate was likely overestimated. We also made a projection assuming that 90% of adults were trapped and removed from the population each year. The outcome was complete extirpation in 4 years.

22.3.6 Basic Concepts of Population Control

The life span and reproductive rate of green anoles are very similar to those of mammals and birds. Females produce about 14 eggs per year, comparable to prolific mammals and birds. The green anole has an 8-year life span and a 30–50% survival rate after maturity, both much higher than in the case of small rodents. The body mass of the green anole is several grams, which is less than most mammals and birds but greater than insects. However, green anole population density is estimated to exceed 1,000 individuals/ha, much higher than for mammals and birds but similar to large insects. Hence, the green anole appears to have biological characteristics intermediate between those of large terrestrial animals (e.g. mammals and birds) and small animals (e.g. insects). This should be taken into account

Table 22.1 Life table for Kiyose population of green anole

Stage	x	N_x	S_x	M_x
Egg		1,000.0		
0–1 yr	0	900.0*	0.115	6.165
1–2 yr	1	103.5	0.355	6.165
2–3 yr	2	36.7	0.333	6.165
3–4 yr	3	12.2	0.333	6.165
4–5 yr	4	4.1	0.115	6.165

*hatchling rate was estimated from Lovern and Passek (2002).

when determining the direction of the green anole population control project.

Below we summarize basic concepts that must be considered when attempting to control the green anole population on the Ogasawara Islands.

22.3.6.1 Prevention of Population Dispersal

The green anole is widely distributed on both Chichijima and Hahajima, but we have not measured increases in densities. Although population declines of endemic insects have been reported for both islands, endemic insects are frequently observed on neighboring islands that have not been invaded (Yoshimura and Okochi 2005). Because eradication after invasion is so difficult, highest priority should be given to preventing anole dispersal to these neighboring islands. The green anole has a strong tolerance for starvation; it is very evasive, is well camouflaged, and spreads rapidly. Eradication after establishment is extremely labor intensive. Of particular importance is control of vectors such as building supplies and materials in which anoles can hide. Preventing its range expansion to other islands should take priority over controlling the population on the infested islands of Chichijima and Hahajima.

22.3.6.2 Area-Specific Control

The population of green anoles in Chichijima and Hahajima is estimated to be in the millions; simultaneous eradication of all of these individuals would involve a huge effort. As a first step to total eradication, green anoles should be excluded from those areas that are most important for biodiversity conservation (e.g. the points from which green anoles disperse and where native insects still exist). It is also necessary to block their movement so as to fragment their distribution range.

22.3.6.3 Establishing a Method for Capture

Green anoles are small, they reproduce rapidly, and their population density on the Ogasawara Islands is high. Thus, methods used to capture large mammals and birds will likely be unsuitable. Instead, techniques for pest control, such as setting traps and spraying pesticide, would be more appropriate. A preferred method would exert continuous pressure on the green anole population in key areas, even when capture rate per unit time is inefficient.

22.3.6.4 Regional Characteristics

Green anoles occur in various population densities in forests, grasslands, farmlands, urban areas, and a variety of other habitats. Ease of capture and accessibility of trapping sites also vary by habitat. Thus, it is necessary to develop and apply techniques according to regional characteristics.

22.3.6.5 Adaptive Management to Monitoring Data

Periodic measurements are necessary to evaluate the efficacy of population control in targeted sites, and management plans should be developed based on these evaluations. It is important to monitor the population and community structure of both the eradication target (green anole) and the conservation target (native insects). These monitoring data should be taken into account during the continuous improvement of the management plan.

22.4 Ongoing Projects on the Ogasawara Islands

The Ministry of the Environment has an ongoing project for population control of the green anole based on basic tenets outlined in Sect. 22.3. Two projects, "Control around the harbor in Chichijima to prevent unintentional dispersal to neighboring islands" and "Regional eradication within the habitat of endemic insects in Hahajima," have been running concurrently since 2005, using methods developed during previous studies to capture green anoles. Here we outline these methods and the equipment being used to restrict the movement of the green anole.

22.4.1 Development of Methods for Regional Eradication of Anoles

22.4.1.1 Capturing Methods

Small reptiles are not important as human foodstuff, nor do they cause any serious damage in agriculture and forestry. Hence, there are no traditional reptile-capture techniques to match those available for hunting, fishing, and insect control (Toda and Yoshida 2005). Developing such reptile-capture techniques is important to control the green anole. To proceed, the following should be clear:

- No special technology should be required, and regular work staff must be able to operate any devices.
- It should be possible to capture anoles during periods of inactivity, thus maintaining long-term continuous pressure on their populations.
- Effects on native species (that are being conserved), the natural environment, and human health must be minimized.

Since 2004, angling has been used to capture animals during ecological surveys. Although this method is efficient (a skilled worker can catch 20–30 anoles per hour when angling in high-density habitats on sunny mornings from April to June) it is restricted by season, time of day, and weather, and can only be used when anoles are feeding.

Repellent spray against habu vipers is available to consumers. Its efficacy against anoles was investigated, but the possibility of negative environmental impacts precluded its adoption.

Dr. Tsuyoshi Ono of the Subtropical Agriculture Center of Tokyo Metropolitan Government advised us that anoles are often caught by the adhesive traps that are used outdoors for insect surveys. Thus, adhesive traps for cockroaches were set on tree trunks, and many anoles were caught.

In 2005, we paint-marked 13–41% of anoles and set 700 adhesive traps per hectare on some plots in Chichijima. Within a few days, 10–50% of the marked individuals were caught. Anoles can be trapped on tree trunks without baiting as they frequently pass between the crown and the ground. Although capture is much less efficient than angling, use of adhesive traps is superior because each trap exerts long-term continuous pressure. We made improvements in terms of ease of trap deployment, replacement, and collection. Weather resistance was upgraded, and traps were fabricated for repeated use. Traps were also designed for easy separation into burnable and nonflammable waste after use, and production cost was reduced. Currently, polypropylene traps are being developed during previous studies used on Chichijima and Hahajima (Fig. 22.2).

22.4.1.2 Exclusion Barriers

Field surveys showed that individuals caught by adhesive traps were replaced by immigrants from elsewhere. Consequently, blocks to immigration were required. It is difficult to design fences to guard against anoles because anoles can rapidly climb smooth barriers. Pacara et al. (1983) introduced fences against anoles that had an added roof on the top. The roof was 20 cm wide and made of polypropylene. At the Caribbean study site, vegetation was pruned for 2 m outside the fence to prevent anoles from jumping over the barrier. Three species of *Anolis* (not *A. carolinensis*) released inside the fence were unable to escape over a period of weeks.

Because the landscape of the Ogasawara Islands is complicated and the area is prone to large typhoons, adding a roof to the top of fences was considered impractical. Indoor and field trials showed that Teflon sheeting was the most appropriate material because the intermolecular attraction is small, making it difficult for anoles to climb, and the plastic is highly weather resistant and easy to fabricate. A Teflon sheet 30 cm high was installed on the top of a stainless-steel mesh fence 0.8–1 m high. The whole structure was inclined outward about 15°. Anoles were unable to scale this two-piece fence. It was necessary to remove vegetation from 2-m wide buffer zones on either side of the barrier to prevent lizards from jumping from surrounding trees or shrubs. A 4-m wide clearing could be problematic for native tree vegetation. However, careful selection of a fence route through alien vegetation would serve a second function of reducing stands of plant invaders.

An exclusion fence has been installed on Hahajima (Fig. 22.3) as part of an operation to keep anoles out of 4 ha of naturally regenerated vegetation.

Fig. 22.2 An adhesive trap for capturing green anoles

22.4.2 Capturing Anoles in the Vicinity of the Harbor to Prevent Dispersal to Neighboring Islands

Most sightseeing ships heading to islands of the Chichijima group (e.g. the uninhabited islands Anijima, Ototojima) and Mukojima leave from Futami harbor. Although no anoles have been recorded on these islands, there is always a risk of some being transported there. Tourists are taken aboard from four piers for transport to the uninhabited islands. Our goal was to reduce anole population density around the piers and to make it difficult for anoles to board the ships. Mr. Yuji Takafuji, a Chichijima resident, played a central role in implementing this concept. He worked with seven other laypeople who kindly contributed their time. About 1,000 traps were deployed around the piers from December 2006 through August 2009 (*1). In addition, 34 volunteers trapped lizards in a residential area not far from the piers. More than 5,000 (*1) animals were caught. By comparing densities around the harbor before trap deployment with data from October 2007, we concluded that the procedure reduced density around the harbor by 35%.

Although the number of anoles declined from spring to early summer 2007, there was a rapid increase in trapping from August to October. We believe most of the autumn increase occurred through the immigration of individuals from the mountainsides, across a paved road, and onto the dock. We had expected this double-lane road to act as a barrier to anole movement, but this was not the case. Unfortunately, it is difficult to set barrier fences along roads or in urban areas.

After 3 years (*1) of capturing anoles, we have identified transit points through which the animals frequently pass.

Fig. 22.3 A fence to block green anoles invading the nature revitalization area in Shin-Yuhigaoka, Hahajima

These should be future sites of intense trap deployment, preferably with barrier fences to block anole movement.

22.4.3 Preventing Local Extinction of Insect Species Endemic to the Ogasawara Islands

On Hahajima, the history of anole invasion is quite short. There are more surviving native insects on Hahajima than on Chichijima, where there have been no sightings in the past decade of the endemic butterfly *Celastrina ogasawarensis* or the endemic dragonfly *Rhinocypha ogasawarensis* (a few of each survive on Hahajima; Karube 2004; Takakuwa and Suda 2004). The sighting frequency of native skink is also higher on Hahajima than on Chichijima. In the Hahajima island group, there is no alternative environment to forest vegetation for insects that occur specifically within this habitat. Hahajima should be given priority over Chichijima in attempts to regenerate natural vegetation through the control of anoles. Procedures should be aimed at maintaining the native insect community and other flora and fauna.

The Ministry of the Environment first installed a fence in 2006 to control anole invasion in an attempt to regenerate natural vegetation. Shin-Yuhigaoka was selected as the first site on Hahajima. The second site chosen was at the southern tip of Minamizaki. Shin-Yuhigaoka supported many native insects characteristic of the Ogasawara Islands. A local organization for native butterfly conservation ("Ogasawarashijimi no Kai") and "Japan Butterfly Conservation Society," a nationwide nonprofit organization, have conducted continuous censuses of insect species, patrolled for poachers, and controlled anoles. The two sites chosen for this work are important in the local community. Furthermore, as roads are very winding, deforestation is minimized around the fences.

At Shin-Yuhigaoka, forests consisting of rosewood *Schima mertensiana* have been regenerated and maintained. Exotic trees such as *Bischofia javanica* and *Morus australis* have been trimmed, and experience has shown that the anole exclusion fences can help regenerate insect populations. A fence of more than 944 m (*1) was completed in spring 2008 (Fig. 22.3). In summer 2008, more than 5,300 adhesive traps were deployed in a naturally regenerating area (ca. 2 ha) surrounded by fence. Anole and insect monitoring continue, and a project for the regional eradication of anoles has progressed.

A fence blocking cats and anoles has been completed at the southern tip of Minamizaki on Hahajima. Within the 2-ha area enclosed, there has been an attempt to recover a breeding colony of the brown booby *Sula leucogaster*. This seabird no longer breeds on the inhabited Ogasawara Islands. In addition to the seabird colony, the management is attempting to restore grassland vegetation and native insect fauna.

22.5 Epilogue

Genus *Anolis*, a world largest lizard genus, are very diverse in morphology, ecology, and behavior, ranging from about 10 to 50 cm in length. Caribbean *Anolis* has been the subject of evolutionary biology studies for more than 40 years. Green anoles have been paid particular attention, and, among reptiles, sequencing of their genome is the most advanced.

However, anoles have achieved notoriety as alien invaders of Pacific islands. Their destructive effects on native ecosystems should be terminated. This is particularly important on Okinawajima, which was invaded only 14 years ago (*1), and where the alien lizard population seems to be in a type of incubation period that precedes an outbreak (as was the case on Chichijima). The Okinawajima anole population should be extirpated before it does irreparable damage.

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