Feral Populations of Amphibians and Reptiles in the Ryukyu Archipelago, Japan

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Abstract

The Ryukyu Archipelago is an assemblage of many continental islands and a few oceanic islands scattered between Kyushu of Japan, and Taiwan. Recent changes in geographic ranges were reviewed for feral amphibian and reptile populations in this archipelago, chiefly on the basis of data and information becoming available after 1995. Six species of amphibians (*Rana catesbeiana*, *Fejervarya* sp., *Polypedates leucomystax*, *Microhyla ornata, Bufo gargarizans miyakonis*, *B. marinus*) and 14 reptiles (*Chinemys reevesii*, *Cuora flavomarginata*, *Mauremys mutica*, *Trachemys scripta elegans*, *Pelodiscus sinensis*, *Hemidactylus frenatus*, *Hemiphyllodactylus typus typus*, *Lepidodactylus lugubris*, *Anolis carolinensis*, *Ramphotyphlops braminus*, *Elaphe quadrivirgata*, *E. taeniura*, *Protobothrops elegans*, *P. mucrosquamatus*) are considered to have one or more feral populations in the Ryukyu Archipelago at present. Some biological aspects of these populations are also reviewed. Possible effects of such feral amphibians and reptiles upon the indigenous biota, including a number of endemic and endangered taxa, are briefly discussed.

Key words: amphibians, artificial transportation, feral population, Japan, reptiles, Ryukyu Archipelago

1. Introduction

The Ryukyu Archipelago is an assemblage of approximately 70 inhabited islands and some uninhabited islets located in the southwestern part of Japan. The main part of this archipelago is composed of an island chain extending from the southwestern side of Kyushu to the northeastern side of Taiwan. This Ryukyu Chain is usually divided into six island groups, the Osumi Group, the Tokara Group, the Amami Group, the Okinawa Group, the Miyako Group, and the Yaeyama Group, in order from northeast to southwest (Kizaki, 1985). Supposedly, the land corresponding to this region first emerged as an eastern extension of the Eurasian Continent during the Late Mesozoic and then insularized with the subduction of the Ryukyu Trough. This process is considered to have commenced no later than the Late Miocene (Kizaki & Oshiro, 1980).

The remaining part of the archipelago includes the Senkaku Group, an assemblage of several uninhabited islands *ca*. 150 km north of the Yaeyama Group, and the Daito Group, which is located *ca*. 320 km southeast of the Amami Group (Kizaki, 1985). Of these, the Senkaku Group is situated on the eastern margin of the current continental shelf and thus is considered to have been connected to the continent during the Late Pleistocene Glacial Maxima (*ca*. 15-20 thousand years ago: Ota *et al*., 1993; Ota, 1998; but see Ota (2004a) for a different view). In contrast, islands composing the Daito Group are of pure oceanic origin and have never been involved in a dry-land connection to other land masses (Kizaki, 1985).

The fauna of the Ryukyu Archipelago is characterized by a high ratio of endemic taxa and genetically diverged populations, most of which have supposedly been isolated from their relatives as a result of island formation (*e.g*., Ikehara, 1996; Ota, 1998, 2000a). At present, many of such Ryukyu endemics are seriously threatened. For example, eight out of 17 species/subspecies of amphibians (47.1%) and 13 out of 42 reptiles (31.0%) endemic to the Ryukyus are assigned to one of the endangered categories (i.e., Endangered IA, IB, and II) in the latest version of the Red List of Japan (Environment Agency of Japan, 2000: also see Ota (2000b)).

Artificial habitat destruction and commercially-based collecting have generally been considered the most serious threats to the survival of such endangered taxa of the Ryukyus (see Environment Agency of Japan (2000) for cases of amphibians and reptiles). However, several recent studies suggest that ecological and genetic impacts from artificially introduced alien species also constitute another sort of serious threats to the indigenous endangered taxa there (*e.g*., Ito *et al*., 2000; Murakami & Washitani, 2002).

Numerous alien organisms have been recorded in the Ryukyu Archipelago, many of which have already established breeding populations (Takehara *et al*., 1997; Murakami & Washitani, 2002). The number of such established alien species in the Ryukyus is ever increasing, and in many cases, their geographic ranges also seem to be rapidly extending within the archipelago. Data regarding such on-going dynamics of the alien species are essential to the prediction of their impact upon the native biodiversity and elaboration of effective measures for their control.

Some amphibians and reptiles, such as *Bufo marinus* and *Boiga irregularis*, are highly invasive in areas where they have arrived by artificial means, having serious negative impacts on native ecosystem and indigenous biodiversity (Rodda *et al*., 1999; Lever, 2001). Ota (1999) reviewed the status of nonnative amphibian and reptile populations of the Ryukyu Archipelago on the basis of data available at the end of 1995. In this article, we provide additional data for feral amphibian and reptile populations in this archipelago that have become available mostly from the beginning of 1996 to the end of 2004, with remarks chiefly regarding their impacts on the conservation of native biota. We also provide critical comments on and corrections to recent reviews as needed (Ota, 1999; Lever, 2003).

Following Ota (1999), we assumed establishment of a feral population (i.e., a non-captive breeding colony deriving from artificially introduced individuals) of a given bisexual species on a given island if more than ten individuals were found thereon during the last 30 years; more than five individuals including gravid females or hatchlings were found on the island during the last 30 years; or more than one individual was found on the island during the last 30 years and more than one inhabitant of the island, apparently having reliable knowledge on local animals, verified that the species had recently been occurring there. With respect to parthenogenetic species, successful colonization of a given island was assumed if more than one animal was found there during the last 30 years.

2. Species Accounts

2.1 Amphibia

2.1.1 *Rana catesbeiana*

On the basis of data and information obtained by the end of 1995, Ota (1999) referred to this large carnivorous North American frog (*e.g.*, Bury & Whelan, 1984) as being possibly established on two islands of the Amami Group, seven islands of the Okinawa Group, and two islands of the Yaeyama Group (see Appendix). However, our recent surveys on Tokashikijima (in 2001 and 2002: H. Ota, unpublished data) and Tonakijima (in 1996, 2000, and 2001: H. Ota, unpublished data) of the Okinawa Group, and Ishigakijima (in 1996-2004: H. Ota, unpublished data) of the Yaeyama Group failed to obtain any evidence of the persistence of *R. catesbeiana*, such as its characteristic calls and tadpoles, nor was there information from inhabitants regarding recent observations of this prominently gigantic frog. It is thus likely that populations of this frog have already disappeared on these islands. On the other hand, several individuals were observed and calls heard on Sesokojima of the Okinawa Group (in 1997: Takahashi & Miyahira, 1998; H. Ota, unpublished observation), and this strongly suggests that this island also has a feral population of this frog.

Referring to Ikehara (1974) as a source of information, Lever (2003) listed Kerama Retto as an island in addition to Tokashikijima and six other islands of the Okinawa Group (see above) having a population of *R. catesbeiana*. Kerama Retto, in fact, however, refers to a small subgroup of islands within the Okinawa Group, in which *R. catesbeiana* has been recorded only from Tokashikijima (Ota & Masunaga, 2004).

Recently Ota (2004b) confirmed an occasional syntopy of this frog with a critically endangered snake, *Opisthotropis kikuzatoi*, on Kumejima of the Okinawa Group (Ota, 2000b). Outside Japan, there are a number of records of predation by *R. catesbeiana* upon such small-sized snakes as *O. kikuzatoi* (see Bury & Whelan (1984) for a review). One immature frog, collected from a site where *O. kikuzatoi* is frequently observed (Ota, 2004b), had two small individuals of the endangered freshwater crab, *Candidiopotamon kumejimense*, in its stomach (H. Ota, unpublished data). Because the freshwater crab is the sole known food item for *O. kikuzatoi* (Ota, 2004b), there are concerns that *R. catesbeiana* has been having a negative effect on this critically endangered snake not only through direct predation but also through competition for food since its initial introduction to Kumejima in 1953 (Ota, 1999). Intensive field studies are strongly desirable to examine this problem and devise effective measures for eradication of *R. catesbeiana* from the natural habitat of *O. kikuzatoi*.

2.1.2 *Fejervarya sp.*

This frog, presently called the ‘Sakishima numa gaeru’ in Japanese (meaning ‘southern Ryukyu marsh frog’), was formerly considered identical to the broadly distributed paddy frog, *Fejervarya limnocharis*. However, because recent genetic studies have revealed distinct divergence of the southern Ryukyu populations from the remaining East Asian popula-

tions (Toda *et al*., 1997; Toda, 1999), Maeda and Matsui (1999) recognized this form as a distinct species but did not officially describe it.

On the basis of data available at the end of 1995, Ota (1999) recognized feral populations of *Fejervarya limnocharis* (sensu lato, as *Rana limnocharis* then: see Dubois & Ohler (2000) for a discussion relevant to its recent separation from *Rana*) on two islands of the Daito Group, one island of the Miyako Group, and one island of the Yaeyama Group (see Appendix). Toyama (1998) clarified that the frog, currently occurring on Yonagunijima of the Yaeyama Group in high densities, is also nonnative, originating from an introduction from Ishigakijima in or before the early 1920s. All these nonnative populations actually belong to the southern Ryukyu *F.* sp., not *F. limnocharis* sensu stricto (Maeda & Matsui, 1999).

Ota (1999) surmised that this frog was first introduced to the Daito Group in the early 1970s. However, according to additional information becoming available after 1995 (Osawa & Osawa, 1997, personal communication; Okudo, 2000), *F*. sp. seems to have already been introduced to the Daito Group before the World War II, most likely as early as 1921.

Lever (2003), citing from Ota (1999), stated that "The nominate form of *R. limnocharis* (actually *F.* sp.: see above) was brought to Kohamajima and Iriomotejima prior to the 1930s by tourists as souvenirs to attract inhabitants' attention." There is no evidence, however, of an exotic origin of these two island populations nor such a statement in Ota (1999).

2.1.3 *Polypedates leucomystax*

Ota (1999) recognized establishment of feral populations of this originally Southeast Asian tree frog on five islands of the Okinawa Group at the end of 1995 (see Appendix). Since then, this frog has been recorded from Iheyajima (first in 1999: Ota, unpublished data), Izenajima (in 1996: H. Ota, unpublished data), Iejima (in 2000: Kawauchi, 2002), and Tonakijima (in 2001: H. Ota and Ma. Toda, unpublished observation) of the Okinawa Group, Miyakojima (in 1997: Iwanaga, 1998; Nohina *et al*., 1998), Irabujima (in 2002: Yoshigou *et al*., 2003), Kurimajima (some time between November 1997 and March 2001: Nakata, 2001) and Taramajima (in 2002: Shiroma & Ota, 2004) of the Miyako Group, and Ishigakijima (some time between 1995 and 2001: Japan Wildlife Research Center, 2001) of the Yaeyama Group. Of these islands, Ishigakijima may not have an established population yet, because the record derives from a single observation (Japan Wildlife Research Center, 2001), and no other recent surveys on this island have yielded any evidence of its occurrence (Mi. Toda, unpublished data). On the other islands, a number of individuals including calling males, or more than one egg mass characterized by a foamy outer layer, or both, have been observed, and it is almost certain that the species has already established breeding colonies on these islands.

The impact of this species upon the native ecosystem remains to be investigated. Hasegawa (1993) found helminth parasites in the gonads of male *P. leucomystax* from Okinawajima that were completely unknown in the native species despite recent intensive surveys of the helminth fauna parasitizing Ryukyu amphibians by his colleagues and himself (see Hasegawa & Asakawa (2004) for a review). There is concern that this parasite most likely entered the Ryukyus from Southeast Asia through an accidental introduction of *P. leucomystax* in the early 1960s (Ota, 1999) and will have negative effects on native Ryukyu amphibians through infection.

2.1.4 *Microhyla ornata*

Ota (1999) recognized a feral population of this species on Suwanosejima of the Tokara Gruop, Taramajima of the Miyako Group, and Kuroshima of the Yaeyama Group. Referring to Ota (1983, 1999), Lever (2003) wrote that *M. ornata* was also successfully introduced to Yonagunijima of the Yaeyama Group. Actually, however, there are no such records in these and other publications (Ota, 1999). Moreover, recent surveys of Yonagunijima by H. Ota yielded no evidence of the occurrence of *M. ornata* (H. Ota, unpublished data collected in 1998 and 2001). Thus, Lever's (2003) statement as above is obviously in error.

2.1.5 *Bufo gargarizans miyakonis*

Ota (1999) recognized feral populations of *B. g. miyakonis* in the northern part of Okinawajima, as well as on two islands of the Daito Group (see Appendix). Since 1999, however, no individuals have been found at the northern Okinawajima site, where this toad was observed in fairly high densities in the mid-1980s (M. Toyama & Y. Chigira, private communication; H. Ota, unpublished data). Such a recent decline is probably a consequence of the enthusiastic eradication effort by M. Toyama, Y. Chigira, and their colleagues and inhabitants from the late 1980s to the middle 1990s. Indeed, a large number of toads were hand-captured, and eggs and larvae removed from breeding ponds several times (M. Toyama & Y. Chigira, private communication). On the two islands of the Daito Group, *B. g. miyakonis* seems even now to maintain dense populations (H. Ota, unpublished data).

2.1.6 *Bufo marinus*

Ota (1999) recognized established populations of this highly invasive toad (Lever, 2001) from two islands of the Daito Group, and Ishigakijima of the Yaeyama Group (see Appendix). A survey on Hatomajima of the Yaeyama Group in 2001 by G. Masunaga yielded four specimens of adult *B. marinus* (given to the Zoological Collection of Kyoto University Museum as KUZ R52784-787). Results of interviews of seven inhabitants then indicated that Hatomajima had an established population of this toad and that it

originated from an introduction of no more than ten individuals from Ishigakijima in the late 1980s or early 1990s by a school teacher. Information from inhabitants also suggests that the population density, though once remarkably raised, has been dropping, most likely as a result of inhabitants' efforts to control it by killing individuals when encountered and minimizing surface water available for its reproduction.

Bufo marinus has also been found on Iriomotejima of the Yaeyama Group no less than 30 times involving at least 24 individuals, since the capture of one individual at the mouth of the Urauchigawa River in 1986 (Japan Wildlife Research Center, 2003, 2004). These records are considered to represent accidental entries of individuals, most likely in association with construction materials transported from Ishigakijima. To date, there has been no evidence of reproduction of this toad on this island. From the cases at two neighboring islands (Ishigakijima and Hatomajima: Ota, 1999; see above), however, establishment of dense population of this toad on Iriomotejima is highly likely once even a small number of individuals start to reproduce successfully.

In some areas outside Japan where *B. marinus* has successfully colonized, considerable impacts upon native ecosystems are reported (Lever, 2001). Relevant data have yet to be collected and analyzed with respect to those islands of the Ryukyus that already have feral populations of this toad. A mass death of domestic ducks, once occurring on Hatomajima, is believed by some inhabitants of the island to have been caused by poison of toadlets that were eaten by ducks around a breeding pond (T. Toji, private communication). This case deserves particular attention in the context of economic damage caused by this toad, although the effect of toadlet poison on ducks still needs careful verification.

2.2 Reptilia

2.2.1 *Chinemys reevesii*

This freshwater species is originally known only from the main islands of Japan, Taiwan, and the eastern continent (Iverson, 1992). However, Masuno *et al*. (1998) collected five individuals, including two hatchlings, of *C. reevesii* from a pond in the south-central part of Okinawajima, and also referred to another individual observed in a nearby river. Also, two individuals were collected from the same pond in 2003 (H. Ota, unpublished data). It is thus highly likely that this species has already established a breeding population, at least in the south-central part of Okinawajima. A few individuals of *C. reevesii* have also been found on Kumejima of the Okinawa Group (Ota & Hamaguchi, 2003), but its establishment of a breeding colony on this island remains to be studied.

Masuno *et al*. (1998) also demonstrated that on Okinawajima hatchlings of this species are commonly sold as pets. They thus surmised that the putative feral population there had been derived from such pet individuals, as in the case of *Trachemys scripta elegans* (see below). The impact of this omnivorous freshwater turtle upon the native ecosystem of Okinawajima remains to be studied.

2.2.2 *Cuora flavomarginata*

Two subspecies, *C. f. flavomarginata* from Taiwan and the eastern continent, and *C. f evelynae* from the Yaeyama Group, are recognized for this species (Yasukawa & Ota, 1999). However, because the range of morphological variation more or less overlaps between these subspecies (Yasukawa & Ota, 1999), it is almost impossible to identify with certainty each individual captured outside the native geographic range at the subspecies level. Therefore, we use only the species name here and defer the problem regarding the subspecific allocation of each individual or putative feral population to future investigations.

As is mentioned above, the natural distribution of this terrestrial species in Japan is confined to Ishigakijima and Iriomotejima of the Yaeyama Group. However, it has occasionally been brought to Okinawajima since as early as the 19th Century (Fritze, 1894). Recently, in particular, turtles of putative Taiwanese origins have been sold in pet shops on this island (*e.g*., Masuno *et al*., 1998), and one may sometimes discover individuals in the field that have been released, or have escaped from captivity.

Ota (1999) indeed referred to a few records of *C. flavomarginata*, as well as its putative hybrids with a native turtle *Geoemyda japonica*, on Okinawajima between the early 1980s and the early 1990s. However, he deferred a conclusion regarding its establishment on Okinawajima to future studies. In 1996, 1999 and 2001, a total of five turtles were captured in the southern part of Okinawajima (H. Ota, unpublished data), but all were found in the urban areas of Naha City and Urasoe City and thus are considered as escaped or released individuals rather than representatives of a feral self-breeding population. Therefore, establishment of this turtle on Okinawajima still remains to be carefully examined.

Recently, *C. flavomarginata* has also been recorded on Kumejima of the Okinawa Group (from the middle 1990s to the early 2000s: Ota & Hamaguchi, 2003), Miyakojima of the Miyako Group (in 2003: Oka, 2004; Shiroma & Ota, 2004), and Kuroshima of the Yaeyama Group (in 2001 and 2003: H. Ota, unpublished data; N. Kamezaki, private communication; information from three anonymous inhabitants). Establishment of a feral population remains uncertain for Kumejima, but is highly likely for the latter two islands, considering the number of individuals observed in a single year (five in 2003: Miyakojima) and information from inhabitants (arguing that the turtle is not so rare: Kuroshima).

Emergence of putative hybrids between *C. flavomarginata* and *G. japonica* (Ota, 1999) predicts an occurrence of introgression into the latter species once *C. flavomarginata* has successfully colonized

Okinawajima or Kumejima where *G. japonica* occurs as the only native turtle species (Ota & Hamaguchi, 2003). The impact of this omnivorous terrestrial turtle on the native ecosystem of an island to which it has successfully colonized remains to be studied.

2.2.3 *Mauremys mutica*

As in the case of *C. flavomarginata*, two subspecies are recognized of this species, *M. m. mutica* from Taiwan and the eastern continent, and *M. m. kami* from the Yaeyama Group (Yasukawa *et al*., 1996). As in the case of *C. flavomarginata*, however, the range of morphological variation more or less overlaps between these two subspecies (Yasukawa *et al*., 1996), making it occasionally difficult to identify with certainty each individual captured outside the native geographic range at the subspecies level. Therefore, we only use the species name here and defer the problem regarding the subspecific allocation of each individual or putative feral population to future investigations.

As is mentioned above, in Japan the original range of *M. mutica* was supposedly confined to Ishigakijima, Iriomotejima, and Yonagunijima of the Yaeyama Group (Yasukawa *et al*., 1996). On the basis of data and information obtained by the end of 1995, Ota (1999) recognized feral populations of this species on two islands of the Okinawa Group and one island of the Miyako Group (see Appendix). He also referred to records of *M. mutica* from two other islands of the Okinawa Group (Sesokojima and Zamamijima), but with no information regarding its population status on these islands (Ota, 1999).

Since then, seven individuals, including two hatchlings, have been found on Sesokojima (in 1998-1999: H. Ota unpublished data), and this suggests establishment of a feral population of *M. mutica* on this island. This turtle has also been found on Iheyajima (in 2002: Honda *et al*., 2002; H. Ota, unpublished observation), Tonakijima (in 1998: H. Ota, unpublished observation), Kumejima (some time between the middle 1990s and the early 2000s: Ota & Hamaguchi, 2003) of the Okinawa Group, Kurimajima of the Miyako Group (in 2003: Shiroma & Ota, 2004), and Haterumajima of the Yaeyama Group (in 1999 and 2004: K. Kinjo, private communication; Ota *et al*., 2004). Furthermore, Osawa and Osawa (1997), in their photographic guide to the nature of Minamidaitojima, mentioned the presence of turtles, most likely representing this species, on this island. On Haterumajima, *M. mutica* occurs in high densities in some canals, and this obviously reflects establishment of a breeding colony on this island (Ota *et al*., 2004). The status of this species on the other islands remains to be studied.

Shiroma and Ota (2004) were concerned about the effect of this omnivorous turtle upon the endemic, highly endangered freshwater crab (*Geothelphusa miyakoensis*) on Miyakojima. However, there are almost no actual data on the impact of *M. mutica* on the indigenous species of islands to which it has been introduced.

2.2.4 *Trachemys scripta elegans*

On the basis of data and information obtained by the end of 1995, Ota (1999) recognized a feral population of this North American turtle on Okinawajima of the Okinawa Group. He also referred to records of *T. s. elegans* from Amamioshima of the Amami Group and two islands of the Yaeyama Group, but deferred a conclusion regarding its status on these three islands to future studies due to insufficient data available at that date. Lever (2003) surmised that this turtle had already established a feral population on Amamioshima, but without showing any additional data.

Since then, this turtle has been recorded from Iejima (in 2002: Toyama, 2002) and Kumejima of the Okinawa Group (some time between the mid-1990s and early 2000s: Ota & Hamaguchi, 2003), Minamidaitojima of the Daito Group (some time between the late 1980s and the mid-1990s: Osawa & Osawa, 1997; Okudo, 2000), and Miyakojima of the Miyako Group (in 2003: Oka, 2004; Shiroma & Ota, 2004). On Kumejima, Minamidaitojima, and Miyakojima, more than ten individuals were seen within small areas (Ota & Hamaguchi, 2003; H. Ota, unpublished observations), and it is almost certain that this turtle has already established feral populations on these islands. Its population status on Iejima and Kumejima remains to be studied.

Masuno *et al*. (1998) reported that in Okinawa Prefecture juvenile *T. s. elegans* were sold in large numbers at all pet shops they visited. It is thus likely that the putative feral populations in this region (see above) have originated from such pet individuals through accidental escapes or intentional releases as in many other regions of various countries (Lever, 2003). Various types of impacts on the indigenous biodiversity have been shown for feral populations of *T. s. elegans* outside Japan (see Lever (2003), and Cadi & Joly (2004), for a review). However, no pertinent data are available yet for the Ryukyu populations.

2.2.5 *Pelodiscus sinensis*

On the basis of data and information obtained by the end of 1995, Ota (1999) recognized feral populations of this soft-shelled turtle from two islands of the Okinawa Group and two islands of the Yaeyama Group (see Appendix). Since then, data have been collected in large quantities on the origin and distribution of *P. sinensis* within the Ryukyu Archipelago (Sato *et al*., 1997; Sato & Ota, 1999). Analyses and syntheses of these data indicate that: (1) breeding populations of this turtle also occur on Kikaijima, Amamioshima and Tokunoshima of the Amami Group, Iheyajima of the Okinawa Group, Minamidaitojima of the Daito Group, and Iriomotejima of the Yaeyama Group; (2) none of these or other Ryukyu populations are native; (3) sources of introductions differ between the islands of Okinawa Prefecture (Okinawa, Daito, and Yaeyama Groups) and those of Kagoshima Pre-

fecture (Amami Group) (Taiwan for the former and the main islands of Japan for the latter); and (4) introductions were carried out chiefly or exclusively for the purpose of farming this turtle for food (Sato *et al*., 1997; Sato & Ota, 1999). The result of questionnaire surveys of inhabitants also suggests that most such introductions were carried out during a period from the early 1950s to the late 1970s (Sato *et al*., 1997; Sato & Ota, 1999). It is obvious from information given in old newspapers, however, that on Okinawajima and Ishigakijima some individuals were released earlier than 1909 and 1931, respectively (Toyama, 1998).

Besides those islands, Kitadaitojima of the Daito Group (S. Shokita, private communication), and Kohamajima (Tanaka, 2004) and Haterumajima of the Yaeyama Group (Ota *et al*., 2004) may also have feral populations of *P. sinensis*. Further surveys on these islands are thus much desired.

Because of the putative predatory nature of *P. sinensis*, impact of its feral populations upon the indigenous freshwater fauna is of much concern (Lever, 2003). Nevertheless, no concrete data are available regarding the feeding habits of this species in the field. Further studies are thus strongly desired regarding this aspect of feral populations on each colonized island.

2.2.6 *Hemidactylus frenatus*

Ota (1999) did not refer to the Ryukyu populations of *Hemidactylus frenatus* as nonnative. However, several lines of evidence, such as the geographic genetic pattern (Moritz *et al*., 1993), temporary changes in known ranges (Hunsaker, 1966; Case *et al*., 1994), and the absence of populations on many uninhabited islands (see Kohno & Ota (1991) and Ota *et al*. (1993) for examples within the Ryukyu Archipelago), strongly suggest that the original range of *H. frenatus* was confined to South and Southeast Asia and that its current populations on most Oceanian and East Asian islands including those of the Ryukyus have derived from recent human-associated dispersals (Lever, 2003). Because Stejneger (1907) referred to a specimen collected on Okinawajima in 1854, however, it is almost certain that *H. frenatus* had already colonized to the Ryukyu Archipelago by the middle of the 19th Century.

In the Ryukyu Archipelago, the distributional range of *H. frenatus* had long been confined to islands south of Amamioshima and adjacent islets (Ota, 1989). Recently, however, this species has started to appear on Kikaijima (in 1991: Ma. Toda, unpublished observation) and Amamioshima (in 2000: Kuze & Ota, 2001) of the Amami Group. Because more than ten individuals were observed in Nase on Amamioshima and Wan on Kikaijima in 2004 (H. Ota, unpublished observations), it is obvious that this species has already established breeding colonies on these islands.

Considering that Tokunoshima, an island approximately 50 km southeast of Amamioshima, had long been the northernmost range extremity of *H. frenatus* (Ota, 1989), such abrupt range extensions during the last decade are puzzling. As of the late 1980s, several authors suspected that low winter temperatures had been playing a crucial role in preventing northward colonization of this originally tropical human commensal (see Ota (1989) and papers cited therein). If this is the case, then, such northeastward colonization of this species may be attributable to the recent rise in global air temperatures (*e.g*., Domoto *et al*., 2000). This needs substantial verification by examining the relationships between annual fluctuations of low winter temperatures and population sizes of *H. frenatus* on these islands, and also by comparing low temperature tolerance between *H. frenatus* and other gekkonid species showing greater northward extensions of ranges.

In the Ryukyu Archipelago, colonization by this gecko may have been causing declines in a few indigenous geckos through competition (*e.g*., Ota, 1989), as in some Pacific islands which *H. frenatus* has also recently colonized (Case *et al*., 1994). Future studies are needed to verify this possibility.

2.2.7 *Hemiphyllodactylus typus typus*

On the basis of data obtained by the end of 1995, Ota (1999) assumed successful colonization of this gecko on Miyakojima of the Miyako Group and Iriomotejima of the Yaeyama Group. Since then, *Hemiphyllodactylus typus typus* has also been recorded on Taramajima of the Miyako Group (in 1998: Kikukawa & Toda, 1998), and Ishigakijima (in 1999: Japan Wildlife Research Center, 2001) and Haterumajima (in 2004: Ota *et al*., 2004) of the Yaeyama Group. However, because only one individual has been confirmed on each of these three islands, the status of this gecko on these islands remains uncertain. In 2004, Tanaka (2004) also observed an individual gecko, most likely belonging to *H. t. typus*, on Kohamajima of the Yaeyama Group. This record, however, needs verification on the basis of voucher material.

Hemiphyllodactylus t. typus is broadly distributed among the insular and coastal regions of Southeast Asia and Oceania (Bauer & Henle, 1994), and individuals recently found in the southern Ryukyus most likely derive from recent accidental entries from one or more localities within these regions (Ota, 1990; Lever, 2003). Because all Ryukyu specimens hitherto collected have been females (n=12: H. Ota, unpublished data), assemblages in this region are likely to be parthenogenetic, like those in the southern Pacific islands (Zug, 1991). The impact of colonization of *H. t. typus* upon the indigenous biota remains to be studied.

2.2.8 *Lepidodactylus lugubris*

In the Ryukyu Archipelago, this parthenogenetic gecko currently occurs in the southern half of the continental island chain (i.e., the Okinawa, Miyako, and Yaeyama Groups) and the oceanic islands of the Daito Group (Ota, 1999). Assemblages on the latter islands, known since the middle 1930s, include a variety of

endemic clones and thus are obviously native to this region (Yamashiro *et al*., 2000). In contrast, assemblages in the Ryukyu Chain, first recorded in the early 1970s, consist solely of a single clone with a broad extralimital distribution and thus are considered to have originated from recent accidental human transportation (Yamashiro *et al*., 2000; Ota *et al*., 2004).

On the basis of data and information available at the end of 1995, Ota (1999) tentatively referred to *L. lugubris* on two islands of the Okinawa Group, two islands of the Miyako Group, and six islands of the Yaeyama Group as already established (see Appendix). Subsequent surveys have yielded data that indicate establishment of successfully reproducing assemblages of this clonal gecko on Akajima (in 1996-2003: H. Ota, unpublished data), Zamamijima (in 1996: Yamashiro *et al*., 2000), Kubajima (in 2001 and 2002: Ota & Masunaga, 2004) and Yakabijima (in 1999: Yamashiro *et al*., 2000) of the Okinawa Group, Ogamijima (in 1997: Nohina *et al*., 1998) and Taramajima (in 1998: Yamashiro *et al*., 2000) of the Miyako Group, and Kohamajima (in 2004: Tanaka, 2004) of the Yaeyama Group. As in the case of *H. t. typus*, the impact of colonization of *L. lugubris* on the indigenous biota remains to be studied.

2.2.9 *Anolis carolinensis*

Ota (1999) referred to a dense population of *A. carolinensis*, which was found in a limited area (Shuri, Naha City) in the southern part of Okinawajima in 1994 (also see Ota *et al*., 1995). This population may have declined subsequently, because a survey carried out at this site in 2004 yielded no individual lizards at all (H. Ota, unpublished data). However, this assumption needs careful verification.

In August 2001, three adult males were collected (KUZ R52571-52573) and three other males were observed at Kanagusuku (Naha City), a site approximately 6 km southwest of Shuri (H. Ota, A. Kikukawa, & Ma. Toda, unpublished data). The population status around Oroku also needs careful assessment on the basis of additional data. Serious efforts at eradication should be made if the resultant data indicate the presence of a breeding population.

The impact of colonization of *A. carolinensis* on the indigenous biota of Okinawajima remains to be studied. Nevertheless, serious negative effects upon some indigenous lizards through competition and upon some insects through predation are highly likely, judging from the situation in the Ogasawara Archipelago, where feral *A. carolinensis* populations occur in high densities (*e.g*., Suzuki & Nagoshi, 1999; Karube & Suda, 2004; Takakuwa & Suda, 2004).

2.2.10 *Ramphotyphlops braminus*

In the Ryukyu Archipelago, this parthenogenetic blind snake has long been known from many islands south of Suwanosejima of the Tokara Group (Ota *et al*., 1991; Hikida *et al*., 1992). In 2000, however, several individuals were found in a limited area of Tanegashima of the Osumi Group (Kazuki, 2001). This strongly suggests that the species was recently introduced to this island and has already started reproduction successfully. The impact of colonization of *R. braminus* upon the indigenous biota of Tanegashima remains to be studied. Also, the origin of current assemblages of this skillful colonizer (Lever, 2003) on other Ryukyu islands needs careful investigation.

2.2.11 *Elaphe quadrivirgata*

This snake, originally endemic to the main islands of Japan and a few adjacent islets, has a feral population on Kuchinoshima of the Tokara Group. Nagai (1938) stated that this population is derived from an artificial introduction from Kuchinoerabujima of the Osumi Group (also see Hikida *et al*., 1992). The impact of its colonization upon the native Kuchinoshima biota remains to be studied.

2.2.12 *Elaphe taeniura*

This polytypic species originally occured in the Miyako and Yaeyama Groups, Taiwan, the eastern and southeastern continent, and some Southeast Asian islands (Schultz, 1996). On the basis of data available at the end of 1995, Ota (1999) surmised that there is an established feral population of *E. taeniura* in the south-central part of Okinawajima, and that it has most likely been derived from individuals artificially introduced from Taiwan or the eastern continent. In 2003, two individuals were found from the northern forested part of Okinawajima (T. Otani, personal communication). The impact through predation of this snake on the indigenous mammals and birds, mostly concentrated in this part of the island (Ito *et al*., 2000), is of great conservation concern (Murakami & Washitani, 2002).

The name of the endemic Taiwanese subspecies, *E. t. friesi*, is usually applied to the feral population of Okinawajima (*e.g.*, Otani, 1993, 1998; Murakami & Washitani, 2003). Indeed, specimens from Okinawajima are morphologically distinct from several other subspecies, including *E. t. schmackeri*, in the southern Ryukyus (H. Ota, unpublished data). However, it still remains unclear as to whether they can be identified as the Taiwanese or eastern continental subspecies (i.e., *E. t. taeniura* or *E. t. mocquardi*: H. Ota unpublished data). We thus refer to the Okinawajima population simply as *E. taeniura* here.

Utiger *et al*. (2002) described a new genus, *Orthriophis*, on the basis of molecular phylogenetic analysis of the genus *Elaphe* sensu lato, to accommodate *E. taeniura* and a few other species. However, because the bootstrap support to the validity of this new genus is not necessarily sufficient, we here take a conservative stance on this matter.

2.2.13 *Protobothrops elegans*

This species, as well as the next venomous snake, was previously referred to as a member of *Trimeresurus*, a genus actually consisting almost exclusively of

Southeast Asian arboreal species (*e.g*., Malhotra & Thorpe, 2004). Although it was originally endemic to the Yaeyama Group, *P. elegans* currently also occurs in high densities around Itoman City in the southern part of Okinawajima (*e.g*., Nishimura & Akamine, 2002). The impact of colonization of this species upon the indigenous biota of Okinawajima remains to be studied.

2.2.14 *Protobothrops mucrosquamatus*

This venomous snake, originally distributed in Taiwan and the southeastern continent, has recently been recorded in Nago City in the north-central part of Okinawajima (first in 1995: Akamine & Nishimura, 1998). It is highly likely that there is a dense population of this species around Bi-mata in the city at present (*e.g*., Terada, 2003). Impact of colonization of *P. mucrosquamatus* upon the indigenous biota of Okinawajima remains to be studied.

2.3 Other species possibly having feral populations in the Ryukyu Archipelago

2.3.1 *Geoemyda japonica*

The known range of this turtle has long been confined to Okinawajima, Tokashikijima, and Kumejima of the Okinawa Group. Recently, however, a few individuals were found on Gerumajima of the Okinawa Group (Ota & Hamaguchi, 2003; Watanabe, in press). According to several inhabitants, this turtle, though not originally occurring on Gerumajima, has been occasionally observed on this island during the last few decades (H. Ota, unpublished information). Thus its occurrence on Gerumajima as a feral population is highly likely, although this needs future verification.

2.3.2 *Gehyra mutilata*

Lever (2003) surmised that the Ryukyu populations of this species were of exotic origins. He stated that Toyama (1984) recorded *G. mutilata* as a recent arrival on Okinawajima. Actually, however, there is no such statement in this report. Indeed, the species was recorded in the Ryukyu Archipelago earlier than the beginning of the 20th Century (Stejneger, 1907). We, therefore, tentatively retain this species as native to the Ryukyu Archipelago, and defer the problem to future studies.

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Appendix. List of islands of the Ryukyu Archipelago, where occurrence of nonnative amphibian or reptile population is assumed. TG, Tanegashima. KN, Kuchinoshima. SW, Suwanosejima. AM, Amamioshima. KK, Kikaijima. YR, Yorojima, TK. Tokunoshima. IH, Iheyajima. IZ, Izenajima. IE, Iejima. OK, Okinawajima. MN, Minnajima. SS, Sesokojima. YB, Yabuchijima. YG, Yagajijima. IK, Ikeijima. TS, Tokashiki. AK, Akajima. ZM, Zamamijima. KM, Kumejima. MD, Minamidaiotojima. KD, Kitadaitojima. MY, Miyakojima. KU, Kurimajima. OG, Ogamijima. IB, Irabujima. TR, Taramajima. IG, Ishigakijima. TT, Taketomijima. KR, Kuroshima. KH, Kohamajima. HT, Haterumajima. HM, Hatomajima. IR, Iriomotejima. YN, Yonagunijima.

Species	Osumi Gr.	Tokara Gr.	Amami Gr.	Okinawa Gr.	Daito Gr.	Miyako Gr.	Yaeyama Gr.
Rana catesbeiana			YR*, TK*	IH*, IZ*, IE*, OK*, TS*#, TN*#, KM*, SS			IG*#, KH*
Fejervarya sp.					MD*, KD*	TR*	KR*, YN**
Polypedates leucomystax				OK*, SS*, YB*, YG*, IK*, IH, IZ, IE, TN		MY, IB, KU, TR	
Microhyla ornata		SW*				TR*	KR*
Bufo gargarizans miyakonis				OK*#	MD*, KD*		
B. marinus					MD*, KD*		IG*, HM
Chinemys reevesii				OK			
Cuora flavomariginata						MY	KR
Mauremys mutica				OK*, AK*, SS, ZM	MD?	MY*	HT
Trachemys scripta elegans				OK*, KM	MD	MY	
Pelodiscus sinensis			AM, KK, TK	OK*, KM*, IH	MD, KD?		IG*, YN*, IR, HR?
Hemidactylus frenatus			Most inhabited islands**	All inhabited islands**	All inhabited islands**	All inhabited islands**	All inhabited islands**
Hemiphyllodactylus typus typus						MY*	IR*
Lepidodactylus lugubris				OK*, MN* AK, ZM, KB, YK		MY*, KU*, OG , TR	IG*, TT*, KR*, IR*, HR*, YN*, KH
Anolis carolinensis				OK*			
Ramphotyphlops braminus	TG						
Elaphe quadrivirgata		KN					
E. taeniura				OK*			
Protobothrops elegans				OK*			
P. mucrosquamatus				OK			

* Given in Ota (1999).
\# A population, though once established, seems to have disappeared.
** Populations were already known but were not regarded as nonnative at Ota's (1999) date. See text.