U.S. Fish & Wildlife Service

Draft Revised Recovery Plan for the Aga or Mariana Crow

(Corvus kubaryi)

Cover illustration by H. Douglas Pratt, Ph.D., Louisiana State University. Used with permission.

Draft Revised Recovery Plan for the Aga or Mariana Crow (*Corvus kubaryi*)

(May 2005)

Original plan approved: September 28, 1990
Native Forest Birds of Guam and Rota of the
Commonwealth of the Northern Mariana Islands

Region 1
U.S. Fish and Wildlife Service
Portland, Oregon

Approved: XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Regional Director, U.S. Fish and Wildlife Service

Date: XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

DISCLAIMER

Literature citation of this document should read as follows:

U.S. Fish and Wildlife Service. 2005. Draft Revised Recovery Plan for the Aga or Mariana Crow, *Corvus kubaryi*. Portland, Oregon. x + 147 pp.

An electronic version of this recovery plan is available at:

<http://pacific.fws.gov/ecoservices/endangered/recovery/default.htm> and
<http://endangered.fws.gov/recovery/index.html>

Authors:

Celestino Aguon [1], Paul Banko [2], Jon Bart [3], Justine De Cruz [4], Michael Lusk [5], Mike McElligott [6], John Marzluff [7], John Morton [8], Sheldon Plentovich [9], and Gordon Rodda [10]

Other Contributors:

Fred Amidon [11](incorporating comments and assembling drafts)
Mark Metevier [11](maps)

[1] Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, 192 Dairy Road, Mangilao Guam 96921

[2] Biological Resources Division, U.S. Geological Survey, Pacific Islands Ecosystem Research Center, Kilauea Field Station, P.O. Box 44, Hawai`i Volcanoes National Park, Hawai`i 96740

[3] Biological Resources Division, U.S. Geological Survey, Snake River Field Station, Boise State, 970 Lusk Street, Boise, Idaho 83706

[4] Division of Fish and Wildlife, Department of Land and Natural Resources, Wildlife Section, P.O. Box 10007, Saipan, Northern Mariana Islands 96950

[5] U.S. Fish and Wildlife Service, Cabeza Prieta National Wildlife Refuge, 1611 North 2nd Avenue, Ajo, Arizona 85321

[6] Andersen Air Force Base, 36 CES/CEV, Unit 14007, APO, Armed Forces Pacific 96543

[7] University of Washington, College of Forest Resources, Ecosystem Science and Conservation Division, Box 352100, Seattle, Washington 98195

[8] Kenai National Wildlife Refuge, U.S. Fish and Wildlife Service, Ski Hill Road, P.O. Box 2139, Soldotna, Alaska 99669

[9] University of Hawai`i, Department of Zoology, Edmondson Hall, 2538 The Mall, Honolulu, Hawai`i 96822

[10] Biological Resources Division, U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Avenue, Building C, Fort Collins, Colorado 80526

[11] U.S. Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, 300 Ala Moana Boulevard, Room 3-122, Box 50088, Honolulu, Hawai`i 96850

ACKNOWLEDGMENTS

The preparation of this draft revised recovery plan benefited from the collaboration, advice, and assistance of many individuals, agencies, and organizations over the past several years. We, the U.S. Fish and Wildlife Service, are especially indebted to the 1999 and 2000 Endangered, Threatened, and Sensitive Species Management classes at the University of Washington's College of Forest Resources for their draft recovery plan text, analyses, and edits. The Mariana Crow Recovery Team would like to thank the following people (former recovery team members italicized) and apologize to anyone who may have been omitted from this list inadvertently:

Rick Camp, Earl Campbell, Kathy Dean-Bradley, Tom Fritts, *Heidi Hirsh*, *Nathan Johnson*, *Kelly Knutson*, Erik Neatherlin, Julie Savidge, Katie Swift, and *Stan Taisacan*.

EXECUTIVE SUMMARY

Current Species Status: The Mariana crow (*Corvus kubaryi*) or aga is federally listed as an endangered species. Historically, aga were found on the islands of Guam and Rota in the Mariana archipelago. The last known native aga is believed to have disappeared from Guam sometime in 2002 or 2003. Ten aga survive in the wild on Guam today, all individuals originating from Rota. Current estimates for Rota indicate that approximately 85 pairs of aga persist on the island, but that this population may be experiencing a serious decline.

Recovery Priority Number: The recovery priority number for this species is 5C on a scale of 1 to 18 based on its status as a full species, a high degree of threat, low potential for recovery (at present, as defined by the need for intensive management, need for better understanding of ecological factors limiting the species, and the difficulty of alleviating threats to the species; see Appendix 1), and high potential for conflict with human activities.

Habitat Requirements and Limiting Factors: Aga utilize a wide variety of forested habitats including limestone, strand, ravine, agricultural forests, and secondary forests. However, all evidence suggests aga are most abundant in native limestone forests. On both Guam and Rota, aga nests have been found exclusively in native tree species, and native trees also serve as the primary sources for foraging aga.

Habitat loss, nutritional deficiencies, human persecution, contaminants, and introduced species such as disease organisms, cats (*Felis catus*), rats (*Rattus* spp.), black drongos (*Dicrurus macrocercus*), monitor lizards (*Varanus indicus*), and brown treesnakes (*Boiga irregularis*) have all been suggested as factors in the population decline of this species. However, the brown treesnake is believed to be the overriding factor in the extirpation of aga from Guam; habitat loss, human persecution, and possibly rat predation on nests are believed to be major factors in the decline on Rota. Therefore, the majority of the recovery actions address the brown treesnake threat, habitat loss, and human persecution.

Recovery Objective: Conserve and recover the species to the point where we can downlist to threatened status and then delist (remove from the list of endangered and threatened species).

Recovery Criteria: ***Downlisting.*** The aga may be considered for downlisting from endangered to threatened status when all of the following criteria are met:

1. Aga occur in 2 populations, 1 on Rota consisting of a minimum of 75 territorial pairs, and 1 in northern Guam consisting of a minimum of 75 territorial pairs;
2. Both populations are stable or increasing based on quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0 over a period of at least 10 consecutive years;
3. Sufficient aga habitat, based on quantitative estimates of territory and home range size, is protected and managed to achieve criteria 1 and 2 above (Recovery Actions 2.1, 2.2, 2.3, 3.3.2);
4. Brown treesnakes and other introduced predators found to be a threat to aga are controlled at sufficient levels to achieve criteria 1 and 2 above (Recovery Actions 3.1.2, 3.3.1.1, 3.3.1.3);
5. Brown treesnake interdiction efforts are in place to prevent the establishment of brown treesnakes on Rota (Recovery Actions 3.1.1.1 through 3.1.1.4); and
6. Efforts to resolve aga and landowner conflicts have been implemented (Recovery Actions 1.2.1.2.1 through 1.2.1.2.4, 1.2.2.5).

Delisting. The aga may be removed from the Federal list of threatened and endangered species when all of the following criteria are met:

1. Aga occur in 3 populations, 1 on Rota consisting of a minimum of 75 territorial pairs, 1 on northern Guam consisting of a minimum of 75 territorial pairs, and 1 in southern Guam consisting of a minimum of 75 territorial pairs;
2. All 3 populations are stable or increasing based on quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0 over a period of at least 10 consecutive years;
3. Sufficient aga habitat, based on quantitative estimates of territory and home range size, is protected and managed to achieve criteria 1 and 2 above (Recovery Actions 2.1, 2.2, 2.3, 3.3.2);
4. Brown treesnakes and other introduced predators are controlled at sufficient levels to achieve criteria 1 and 2 above (Recovery Actions 3.1.2, 3.3.1.1, 3.3.1.3);
5. Brown treesnake interdiction efforts are in place to prevent the establishment of brown treesnakes on Rota (Recovery Actions 3.1.1.1 through 3.1.1.4);
6. Efforts to resolve aga and landowner conflicts have been implemented (Recovery Actions 1.2.1.2.1 through 1.2.1.2.4, 1.2.2.5); and
7. A monitoring plan has been developed and is ready for implementation, to cover a minimum of 5 years post-delisting, to ensure the ongoing recovery of the species and the continuing effectiveness of management actions.

Recovery Zones: To better address the recovery needs of the aga, recovery zones have been identified within the best remaining aga habitat to guide where recovery efforts should be focused. Recovery zones in this plan are defined as those areas that will allow for the long-term survival and recovery of the aga. Recovery zones reflect a biological evaluation of areas important for the recovery of the aga and convey no legal obligation on the part of any entity to manage their lands for aga recovery. The foremost concern in identifying aga recovery zones is determining the distribution of the remaining large tracts of good quality forest within the current and historical distribution of the aga in which recovery actions may occur.

Actions Needed: To prevent the extinction of aga, three categories of recovery actions are highest priority. First, the threat of the brown treesnake to Rota and Guam must be further researched and reduced. Especially important in this respect is development of means to reduce treesnakes over wide areas on Guam, reducing treesnakes at ports and cargo areas, and detecting treesnakes on Rota and elsewhere where potential incipient populations are likely to be small (Recovery Actions 3.1.1.2, 3.1.1.3, 3.1.1.4, 3.1.2). Second, important habitat on Rota and Guam must be protected. This includes protecting current reserves on Guam and Rota as well as areas of high aga density and habitat quality on Rota (2.1, 2.2.1, 2.2.2). Third, essential research into the population status of aga and its viability on Rota must be reestablished and led by an experienced scientist (1.1.3, 1.3, 1.3.1). This includes detailed research into the relative importance of presumed important limiting factors (rats and human persecution) to the survival and reproduction of aga on Rota (3.3.1.1, 3.3.1.4, 3.3.3.1, 3.3.3.2.2), surveying and monitoring of the Rota aga (4.1.1, 4.1.2, 4.1.3), and development of an aga data center (1.1.3). Accomplishment of these recovery actions will do much to assist the restoration of aga. However, recovery in the complex human sociopolitical environment that characterizes the region is critically dependent on the trust and cooperation of the people of Guam and Rota. All participants in the aga recovery effort must work to earn this trust and cooperation as they carry out stipulated recovery actions.

Date of Recovery: Because recovery objectives and criteria are defined in terms of long-term population stability and reestablishing populations on Guam, the date of recovery will be dependent upon the effectiveness of management strategies in controlling limiting factors and upon the response of aga populations. Controlling brown treesnakes on Guam and reestablishing populations there will both require extensive commitments of time and resources and some of these efforts cannot begin immediately. Therefore, we expect that recovery will take approximately 50 years and the estimated recovery date is the year 2055.

<u>Total Estimated Cost of Recovery</u>: Total estimated cost of recovery is $661,420,000 over the estimated 50 years it will take to recover the aga. This figure may be substantially reduced with the development of more effective methods to address threats, specifically brown treesnake control. Certain costs, such as reestablishing aga in southern Guam, are not determinable at this time due to their dependence on the successful completion of other recovery objectives, such as reestablishing a stable aga population in northern Guam. A detailed cost breakdown with expected annual costs for the first 5 years of recovery implementation is provided in the Implementation Schedule. The cost for the first 5 years of implementation is estimated at $171,180,000.

The total estimated cost above is broken down by recovery action priority number as follows:

> Priority 1 actions: $322,650,000
> Those actions that must be taken to prevent extinction or prevent the species from declining irreversibly in the foreseeable future.
>
> Priority 2 actions: $89,620,000
> Those actions that must be taken to prevent a significant decline in species population or habitat quality, or some other significant negative impact short of extinction.
>
> Priority 3 actions: $249,150,000
> All other actions necessary to meet recovery objectives.

Of the total estimated toward recovery, $611,450,000 is also expected to benefit the Guam Micronesian kingfisher (*Halcyon cinnamomina cinnamomina*), Guam rail (*Gallirallus owstoni*), and Mariana fruit bat (*Pteropus mariannus mariannus*) on Guam (the two birds are listed as endangered, the bat as threatened), and the Rota bridled white-eye (*Zosterops rotensis*) on Rota (listed as endangered), as well as other native species.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. Overview

The Mariana crow (*Corvus kubaryi)* is an omnivorous, shy, forest-dwelling bird, endemic to the two southernmost islands of the Mariana archipelago, Rota and Guam (Figure 1). The Mariana crow is more generally known as the aga, the name given to the species by the Chamorro, the indigenous people of these islands. On August 27, 1984, we, the U.S. Fish and Wildlife Service (USFWS), listed the aga as endangered under the Endangered Species Act (16 U.S.C. 1531 *et seq*.) (USFWS 1984). This species is also listed as endangered by the Territory of Guam (Guam Public Law 15-36), threatened/endangered by the Commonwealth of the Northern Mariana Islands (Commonwealth Register 1986), and endangered by Birdlife International (Stattersfield and Capper 2000).

Although aga were once relatively widespread and abundant on both islands, the population on Guam began to decline soon after the introduction of the brown treesnake (*Boiga irregularis*) sometime around 1950. The aga had disappeared from southern Guam by the 1960's, from central Guam by the 1970's, and by the 1980's only a small remnant population survived at the northernmost part of the island. The original Guam population has now been completely extirpated. Although 10 aga presently survive on Guam, all of these are individuals that have been translocated from Rota.

Reductions in the numbers of aga on Rota became apparent in the early 1980's, but the cause is not clear, as Rota does not have an established brown treesnake population. The most recent evidence indicates that aga may have declined by as much as 94 percent on Rota since 1982; the remaining population is currently estimated at 85 breeding pairs (Amar *et al.*, in review). Stabilization of the aga population on Rota is of critical importance, as the recovery of the species is now entirely dependent upon this population.

The recovery priority number for this species is 5C on a scale of 1C (highest) to 18 (lowest), reflecting the aga's status as a full species, a high degree of threat, and, at present, a low potential for recovery which our guidance defines as the need for intensive management, need for further information on ecological factors limiting the recovery of the species, and the presence of pervasive threats that are difficult to alleviate (Appendix 1). The "C" indicates the potential for conflict with human activities.

A recovery plan for the aga and five other federally listed bird species on the islands of Guam and Rota (Guam rail [*Gallirallus owstoni*], Guam Micronesian kingfisher [*Halcyon cinnamomina cinnamomina*], Guam broadbill [*Myiagra freycineti*], and bridled white-eye [*Zosterops conspicillata conspicillata*]) was approved on September 28, 1990

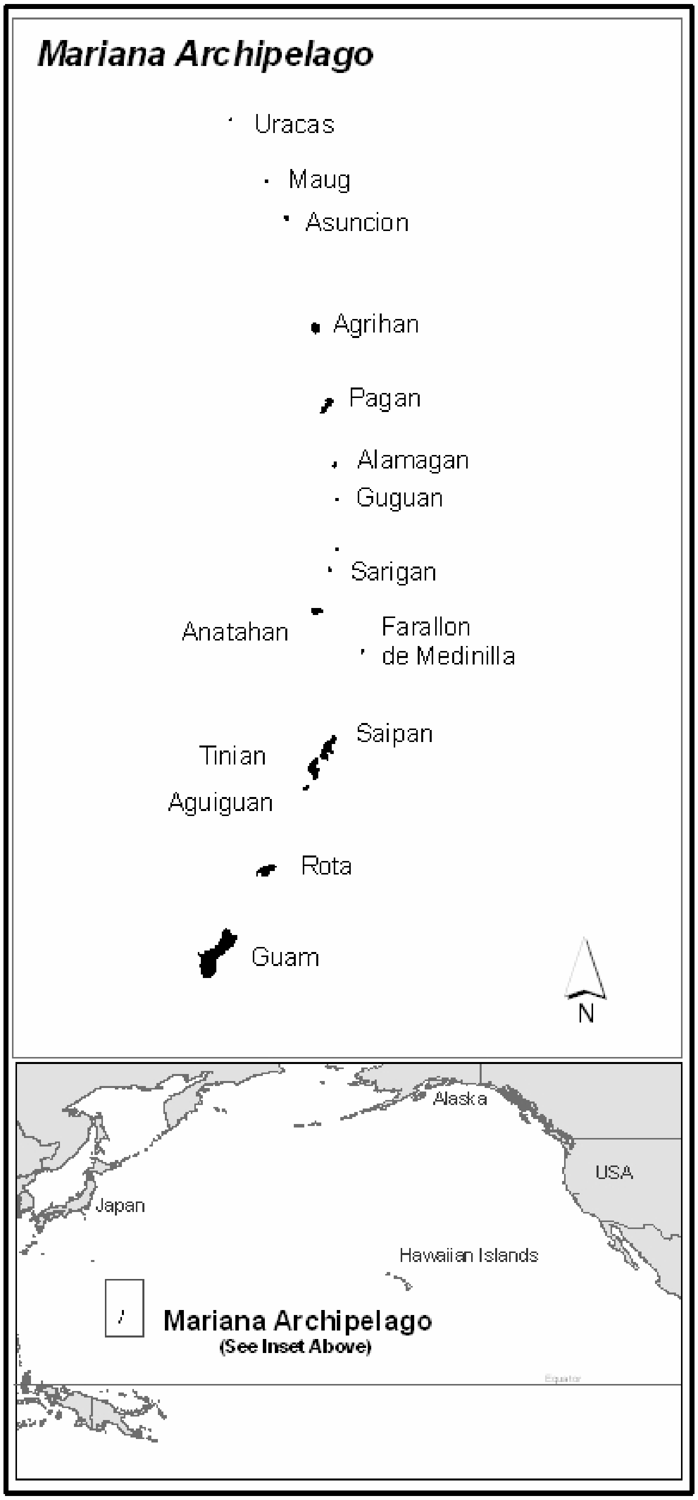

Figure 1. Location and composition of the Mariana archipelago.

(USFWS 1990). In 1997, the National Research Council (NRC) recommended that we establish a recovery team for the aga that would revise the 1990 recovery plan. This draft revised recovery plan represents the recovery team's revision of that plan for the aga only.

B. Species Description and Taxonomy

The aga is a member of the family Corvidae, which includes birds such as crows, ravens, magpies, and jays. The aga is the only representative of this family to occur in Micronesia (Jenkins 1983), and appears to be most closely related to the house crow (*Corvus splendens*) from southern Asia (R. Fleischer, National Zoo, pers. comm. 2000). Black in color, the adult aga has a dark green gloss to its head, neck, and back, and a bluish tint to the tail. During molt, a short gray feather-base is visible around the body and neck region and grows lighter toward the head. The aga has brown eyes, a slender, black bill, and short visible nasal bristles. On average, females weigh less (242 grams [8.5 ounces], n = 11) than males (256 grams [9.0 ounces], n = 5) (Baker 1951), although otherwise the sexes appear outwardly similar. With the exception of the occasional brown gloss to its tail, the immature aga closely resembles the adult bird.

There have been no genetic or morphological differences documented between aga on Rota and Guam. Prior to the disappearance of the native aga population from Guam (the last known bird of Guam origin disappeared in 2002 or 2003), preliminary genetic studies indicated that the Rota population was most likely a genetic subset of the Guam population (Tarr and Fleischer 1999). Genetic diversity is therefore lower than it was a decade ago and is lower than that of mainland corvids, presumably due to the highly restricted natural range of the aga (Tarr and Fleischer 1999).

Culturally, local (Chamorro and Carolinian) sources have indicated that aga were once viewed as a positive symbol and were respected as wild, native animals. In fact, some aga were kept as pets and were believed to "converse" with their owners. However, the same sources indicated that a majority of today's generation do not maintain the old beliefs, and that some now view the aga as a messenger of negative spirits, superstitions, and news that is potentially harmful to one who observes the bird in its natural habitat. Aga also appear in the traditional "singing poetry" that is unique to the Mariana Islands. For example, in one poem reported by the Mendiola family on Rota, an aga and an octopus converse about betel nuts (M. Lusk, U.S. Fish and Wildlife Service, pers. comm. 2001; betel nuts or “palm nuts” are traditionally chewed by native islanders in the Pacific).

C. Aga Distribution and Abundance

Although it is accepted that aga were present on both Rota and Guam prehistorically, fossil confirmation has not yet been discovered (Steadman 1992, 1995, 1998, 1999). Steadman (1999) is of the opinion that aga most likely occurred on all five of the large southern Mariana Islands (Guam, Rota, Aguijan, Tinian, and Saipan) at some point in time, but there is no direct evidence to support this claim.

1. Rota

In 1976, aga were considered relatively common and widely distributed on Rota (Pratt *et al*. 1979). The first island-wide survey of aga on Rota in 1982 resulted in a population estimate of 1,318 individuals (Engbring *et al.* 1986; Table 1). Surveys conducted since the early 1980's indicate that the aga population on Rota has been declining.

Some of the most detailed information on the Rota aga population comes from a study by John Morton and his colleagues conducted between 1996 and 1999 (Morton *et al.* 1999; also see Plentovich *et al*., in review). Following their multiple-year study of aga in six intensive study areas on the island, these researchers reported that aga were widely distributed on the island, and concluded that as of 1999, there were most likely 117 pairs of aga on Rota, or 234 breeding adults (Plentovich *et al*., in review).

Table 1. Summary of results of aga surveys on Rota since 1982.

Year	Estimated Number (and/or Range) of Individuals	Survey Method	Source
1982	1,318 (1,136-1,564)	Off-road VCP[a]	Engbring *et al.* 1986
1988	(600-1,000)	Informal Estimate	R. Beck, DAWR, and S. Pimm University of Tennessee (unpubl. data)
1992	(447-931)	Roadside VCP	M. Lusk, DFW, 1995 (unpubl. data)
1993	(336-454)	Roadside VCP	M. Lusk, DFW, 1995 (unpubl. data)
1995	592 (474-720)	Off-road VCP	Fancy *et al.* 1999
1995	(365-607)	Off-road VCP	R. Camp, USGS, 2001 (unpubl. data)
1998	(138-504)	Off-road VCP	R. Camp USGS, 2001 (unpubl. data)
1999	234 breeding adults	Extrapolated from known pairs and density estimates	Plentovich *et al.*, in review
2004	170 breeding adults	Off-road VCP (magnitude of observed decline applied to most recent population estimate)	Amar *et al*., in review

[a] Variable Circular Plot (VCP) survey methodology (see Reynolds *et al.* 1980)

This was based on the presence of 85 known aga pairs, extrapolating the mean pair density of 1 pair per 22 hectares (54 acres) of forested habitat to an area of approximately 755 hectares (1,866 acres) that had not been fully surveyed to yield an additional 32 pairs possible.

A more recent analysis shows that counts of aga along transects decreased by 27 percent between 1999 and 2004; applying this level of population decrease to the earlier estimate of Plentovich *et al*. suggests that there are currently about 85 breeding pairs of aga on Rota (Amar *et al*., in review; Table 1) (Note that numbers of breeding pairs are not directly comparable to counts of individuals, as the latter includes nonbreeding birds as well).

There is some debate as to the actual magnitude of the decline of aga on Rota, due to differences in survey methods and seasonal variation in many of the surveys over the years. It has been suggested, for example, that the variable circular plot methodology tends to overestimate the number of aga, and that the initial estimate of 1,318 aga in 1982 may be somewhat inflated (Morton *et al.* 1999). A reexamination of count data by the aga recovery team suggests that the number of aga detected per station declined by 83 percent between 1982 and 1998, and population estimates have decreased by 67 percent (Appendix 3; Plentovich *et al*., in review). The most recent analysis, based on surveys from 2003 and 2004, estimates that aga detections per count station may have decreased by as much as 94 percent over the last two decades (Amar 2004; Amar *et al*., in review).

2. Guam

Aga were once widely distributed in limestone forests throughout Guam, with a higher density in mature limestone forests, but were mostly absent from the savannas and areas of human settlement (Michael 1987; G. Michael and R. Beck, unpubl. data). By the mid-1960's, aga had disappeared from the southern region of Guam, and by the mid-1970's, they were also absent from central Guam (Jenkins 1983; Figure 2) and were present only in the northern cliffline forests (USFWS 1990; NRC 1997).

Table 2 chronicles the decline of aga on Guam, beginning with the years 1901 and 1945, in which aga were reported as "abundant" in the forested areas of the island. By 1981, the Guam aga population was estimated at fewer than 400 individuals, with the majority of these restricted to the best remaining habitat in the cliffline forests of northern Guam (Engbring and Ramsey 1984). Only a few years later in 1985, Michael (1987) estimated the population to be fewer than 100 birds, indicating a precipitous decline from 1981. Successful breeding of the native Guam population, unaided by human intervention, was last confirmed in 1985 with the sighting of a wild fledgling. Ten years later, in 1991, the Guam Division of Aquatic and Wildlife Resources estimated that Guam supported fewer than 50 individuals

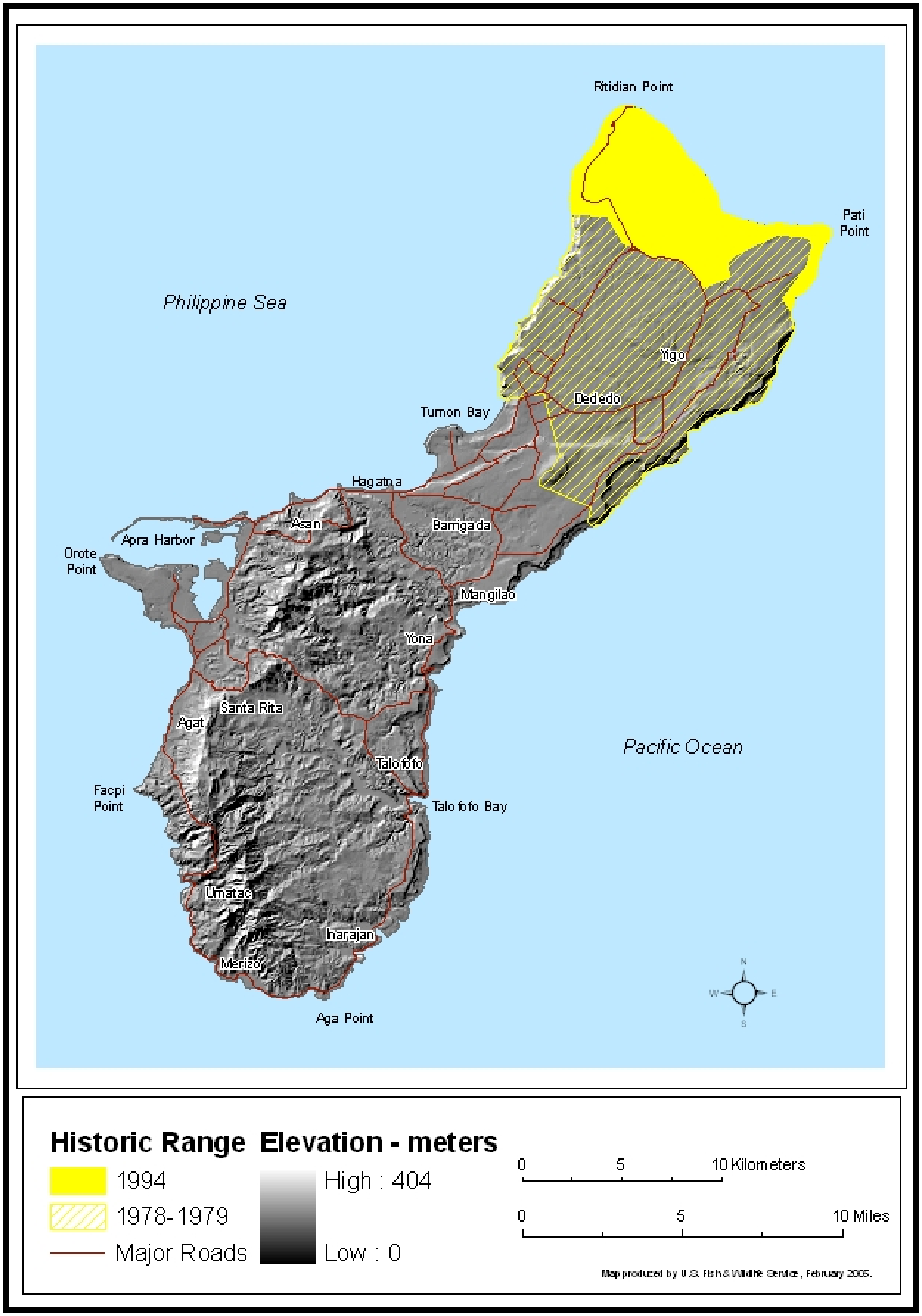

Figure 2. Historical range of aga on the island of Guam. This map reflects only recorded occurrences of aga from official surveys, not historical anecdotal accounts of aga distribution.

Table 2. Estimated number of aga on the island of Guam from 1901 to 2004; the geographic origin is also indicated after translocations from Rota began in 1997.

Year	Number of Aga			Reference
1901	Abundant in forests			Seale 1901
1945	Abundant in forests			Baker 1951
1981	357			Engbring and Ramsey 1984
1985	100			Michael 1987
1990	107			Aguon 1990
1991	41			Aguon and Wiles 1991
1992	57			Aguon and Wiles 1992
1993	51			Wiles *et al*. 1993
1994	40			Aguon *et al.* 1994
1995	24			Wiles and Aguon 1995
1996	14			Wiles and Aguon 1996
	Total Aga	**Guam Aga**	**Rota Aga**	
1997	17	13	4	Wiles and Aguon 1997
1998	12	8	4	Wiles and Aguon 1998
1999	7	5	2	Aguon and Henderson 1999
2000	12	5	7	C. Aguon, *in litt.* 2000
2001	13	4	9	DAWR 2002
2002	11	1	10	C. Aguon, *in litt*. 2002
2003	10	1	9	C. Aguon, *in litt.* 2003; DAWR 2003
2004	10	0	10	C. Aguon, *in litt.* 2004

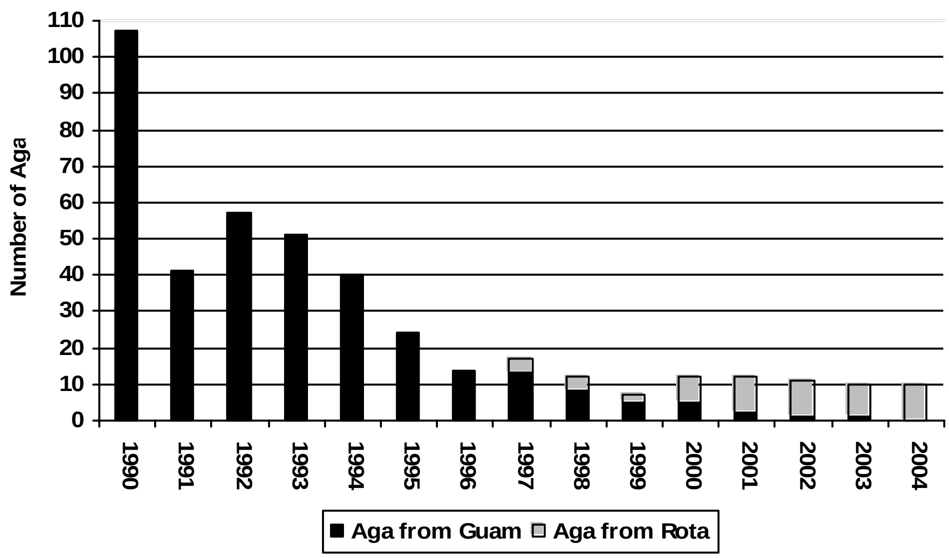

Figure 3. Estimated number of aga on the island of Guam, showing number originating from Guam and the island of Rota, 1990 through 2004.

(Wiles *et al.* 1995). By 1994, only one breeding pair of aga was still producing fertile eggs, but the male of this pair could not be located in 1995 and was believed to be dead. In the early 1990's aga population estimates fluctuated between 24 and 57 birds, until the Guam Division of Aquatic and Wildlife Resources estimated fewer than 20 birds remained in 1996. The few aga that remained on Guam were nearly all restricted to the northernmost region of the island, specifically Andersen Air Force Base (DAWR 1999).

Translocations of aga from the island of Rota to Guam began in 1997. Between 1997 and 2003, 26 aga were released on Guam: 2 were captive-bred birds of Guam origin, 6 were of Rota origin from mainland zoos, and 18 were translocated from Rota (Appendix 2). As of 2004, an estimated 10 aga persist in the wild on Guam. Figure 3 shows the number of aga on Guam from 1990 to 2004, including the relative numbers of birds of Guam origin and those that have been translocated from Rota. Unfortunately the last aga of Guam origin is believed to have disappeared sometime in 2002 or 2003, so all aga now on Guam are of Rota origin. The translocations appear to be successful, however, as the reintroduced birds are pairing and producing fertile eggs. Eleven eggs have been produced in the last 2 years, nine have hatched, and one nestling has successfully fledged to become the first fledgling aga hatched in the wild on Guam in a decade.

D. Political and Ecological Descriptions of Guam and Rota

Guam and Rota are similar in their origin and ecology but vary in some physical characteristics as well as ecological and political histories (NRC 1997). Ethnically they are part of Micronesia, which stretches from the equator to 20° North latitude, and from the International Date Line to 130° East longitude. The ancient Chamorros are the original inhabitants of the Mariana Islands, having settled on Guam about 4,000 years ago. These people are believed to have originated from Southeast Asia, arriving in the islands via Malaysia (Carano and Sanchez 1964). The Mariana Islands have had a long history involving Spanish and German colonial influences, as well as Japanese control prior to and during World War II. The indigenous language, Chamorro, is still spoken. The local people are a mixture of Chamorro, Spanish, Filipino, Carolinian, American, and many other nationalities (Carano and Sanchez 1964).

With over 2,000 islands and less than 2,000 square kilometers (772 square miles) of land, Micronesia's total landmass is smaller than the state of Rhode Island (Engbring and Pratt 1985; Engbring *et al.* 1986; NRC 1997). The Mariana archipelago is the northernmost Micronesian island group, lying roughly midway between Japan and New Guinea, and 2,600 kilometers (1,616 miles) east of the Philippines. The Mariana archipelago has 15 major islands (see Figure 1) of volcanic origin, decreasing in size from south to north, with a total land area of 1,020 square kilometers (394 square miles) (Bryan 1971). Guam is the largest (541 square kilometers, 209 square miles), most heavily populated (154,805 people; U.S. Census Bureau 2001a), and most developed of the Mariana Islands. Guam was seized by the United States over a century ago, being the first territorial conquest of the Spanish-American War. Rota and the other 13 northern islands are all members of the Commonwealth of the Northern Mariana Islands, which voted to join the United States in 1975 (Farrell 1991). In 2000, Saipan was the most populated island (62,392 people) in the Commonwealth of the Northern Mariana Islands followed by Tinian (3,540 people) and Rota (3,283 people) (U.S. Census Bureau 2001b). The remaining 10 most northerly islands are sparsely populated; in 2000, the estimated population size was a total of 6 people.

The Mariana Islands are warm and humid with little seasonal variation and an average mean temperature of 27° Celsius (80° Fahrenheit) (Eldredge 1983). An average of 250 centimeters (99 inches) of rain falls annually on Guam and marginally less falls on Rota; 75 percent of the annual rainfall occurs between July and November. Northeast tradewinds blow across the area, diminishing in strength during the wet season. The wet season also poses a one in three chance that either island will be affected by a typhoon. Supertyphoons, the strongest type of typhoon, have sustained wind strengths that exceed 240 kilometers (149 miles) per hour (Stone 1970; National Oceanic and Atmospheric Adminstration [NOAA] 1982; Engbring and Ramsey 1984; Engbring *et al.* 1986). Typhoon storms can cause widespread damage to crops, homes, infrastructure, and vegetation (NRC 1997).

Rota is the fourth largest island in the Mariana archipelago (85 square kilometers [33 square miles]), located 49 kilometers (30 miles) north of Guam. The central portion of the western half of the island, known as the Sabana, is an uplifted plateau, capped by a former mining and agricultural area that is now mostly grassland (Figure 4). The Sabana encompasses an area of 12 square kilometers (5 square miles) at an elevation of 450 meters (1,476 feet). Cliffs border the Sabana on all but the northeast side, where the plateau slopes down to the eastern part of the island, which has been covered in secondary growth forest intermingled with residential and agricultural lands since the 1930’s. Undeveloped land on Rota is held for agriculture, grazing, and potential ecotourism activities. The cliff lines surrounding the Sabana region remain primary forest due to their steepness. Although approximately 60 percent of Rota is now forested (Falanruw *et al.* 1989; Figure 5) much of the forest is of medium stature and is degraded by development activities, introduced plants and animals, logging

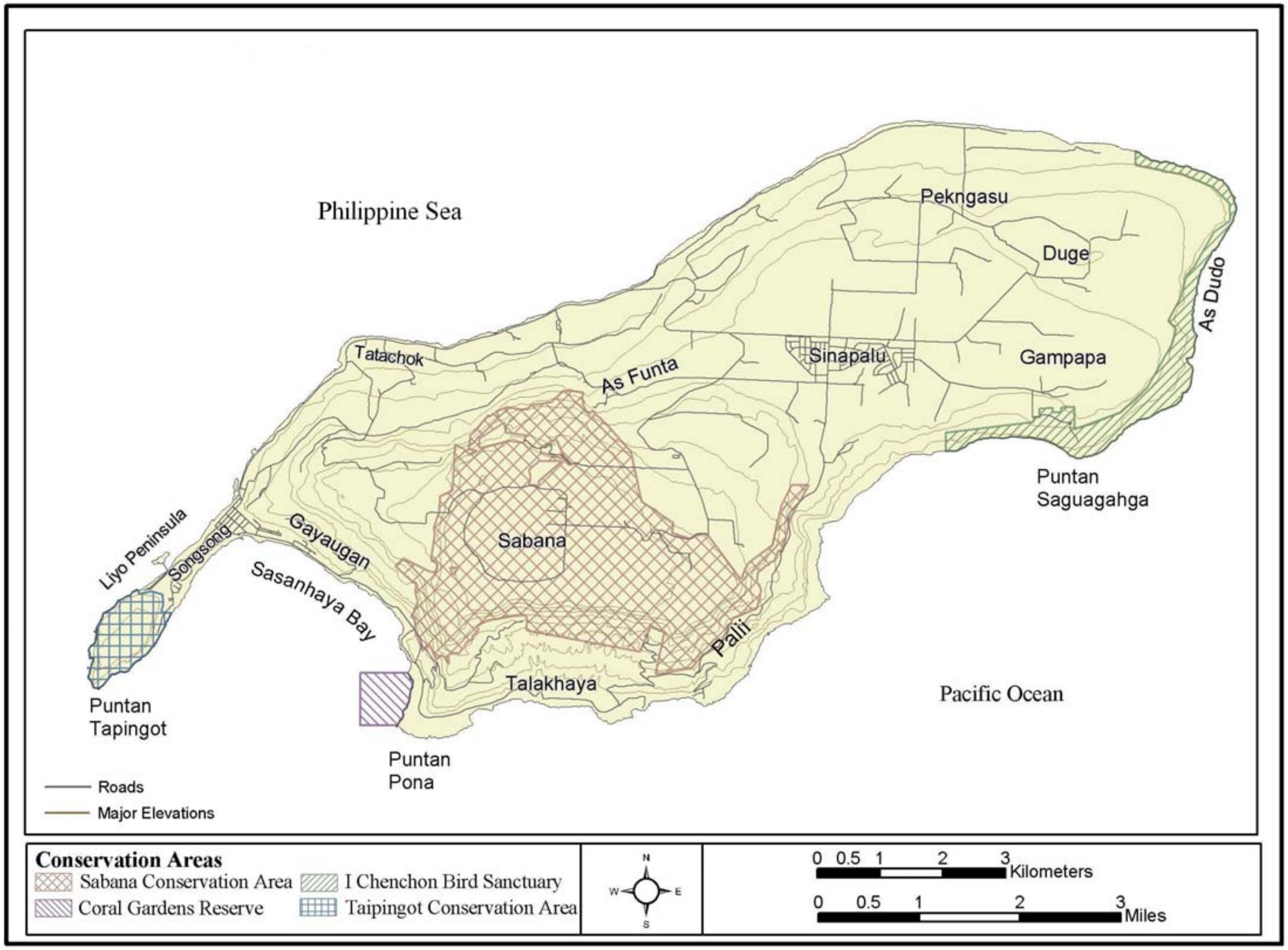

Figure 4. Island of Rota, Commonwealth of the Northern Mariana Islands.

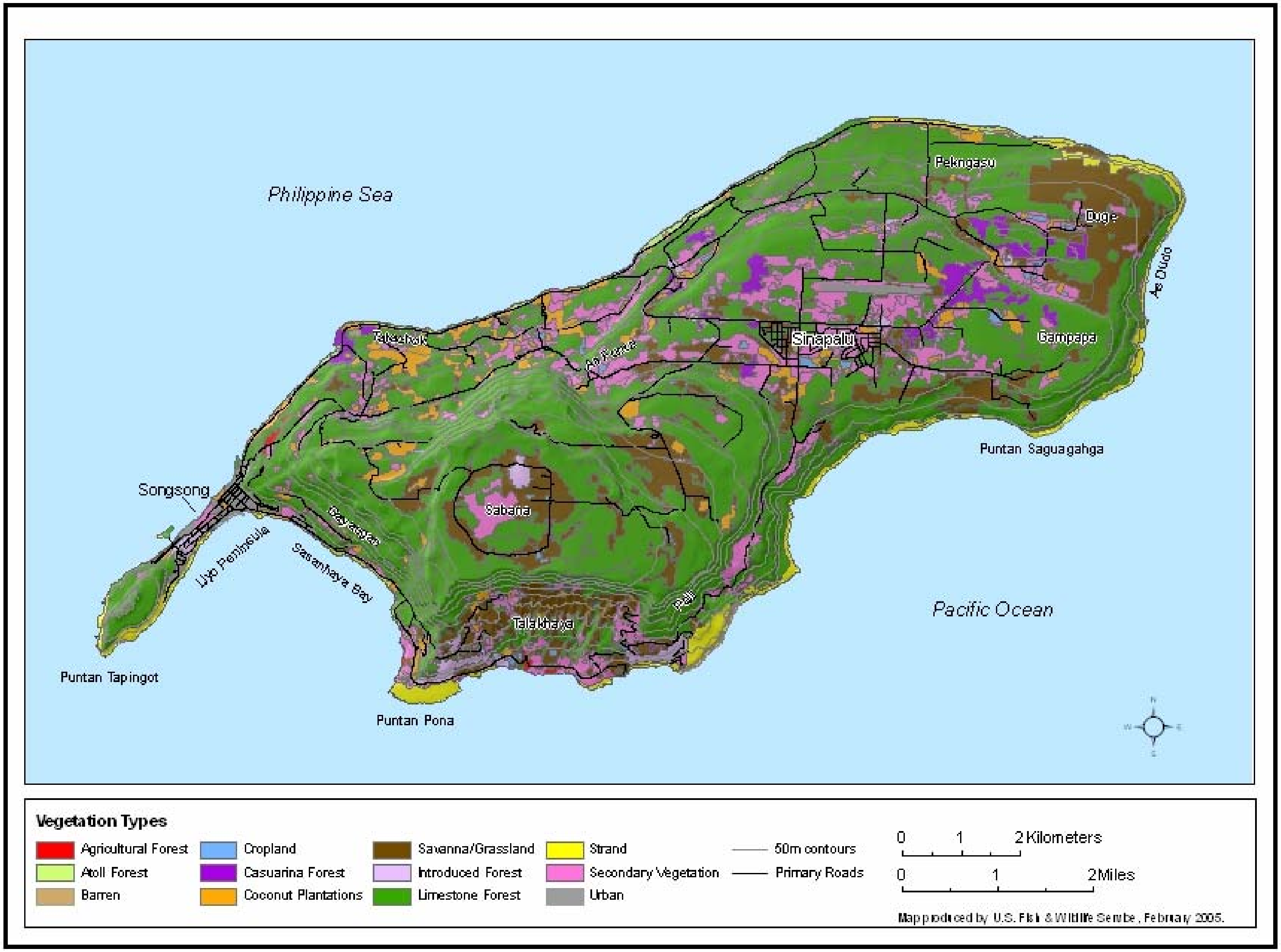

Figure 5. Vegetation types on the island of Rota, Commonwealth of the Northern Mariana Islands.

and the effects of warfare from World War II (Fosberg 1960; NRC 1997). Aerial photographs taken of Rota in 1945 indicate that many of the areas of current intact native forest were also intact when those pictures were taken. Approximately 50 percent of the island was forested in 1945 and many of the former fields and pastures are now secondary growth areas. Prior to human colonization, both Guam and Rota were most likely covered with forest and had similar vegetation and habitat types. However, the native vegetation on Rota has been less disturbed than on Guam (Fosberg 1960; Engbring *et al.* 1986; Mueller-Dombois and Fosberg 1998).

Guam can be divided into two main regions. The northern half of the island is an uplifted limestone plateau (100 to 200 meters [328 to 656 foot] elevation) with three small areas of volcanic origin (Mueller-Dombois and Fosberg 1998). The southern half of the island is mountainous, reaching 406 meters (1,330 feet) elevation, and is primarily of volcanic origin with some patches of limestone (Figure 6). The limestone plateau on the northern half of the island is dry and lacks permanent streams and marshes due to the porous coralline limestone substrate. In contrast, the southern half of the island contains numerous streams, a large river system (Talofofo River), and several marshes.

In 2002, Donnegan *et al.* (2004) completed a forest inventory and analysis for Guam. They estimated that approximately 48 percent (25,833 hectares [63,833 acres]) of the island was forested (Figure 7). Of the forested area, approximately (17,970 hectares [44,404 acres]) were classified as limestone forest, the majority of which was located in northern Guam, and approximately 7,741 hectares (19,129 acres) were classified as volcanic forest, primarily found in southern Guam. Of the remaining lands on Guam (29,068 hectares [71,827 acres]), 33 percent (17,991 hectares [44,455 acres]) was classified as savanna or fernland, 18 percent (9,695 hectares [23,956 acres]) was classified as urban, and the remaining 1 percent of the island was classified as either barren lands, water, or unclassified. For more detailed information about the vegetation on Guam, the reader is directed to Fosberg (1960), Stone (1970), and Mueller-Dombois and Fosberg (1998).

E. Aga Life History and Ecology

1. Habitat

Historically, aga distribution among habitats on Guam was similar to that on Rota. Although aga were known to utilize secondary forest, coastline forest, ravine forests, agricultural forest, and coconut plantations, all evidence suggests that aga were (and are) most abundant in primary or mature native limestone forests (Seale 1901; Stophlet 1946; Marshall 1949; Baker 1951; Jenkins 1983). The aga surviving in northern Guam used primary or mature limestone forest, nesting most frequently

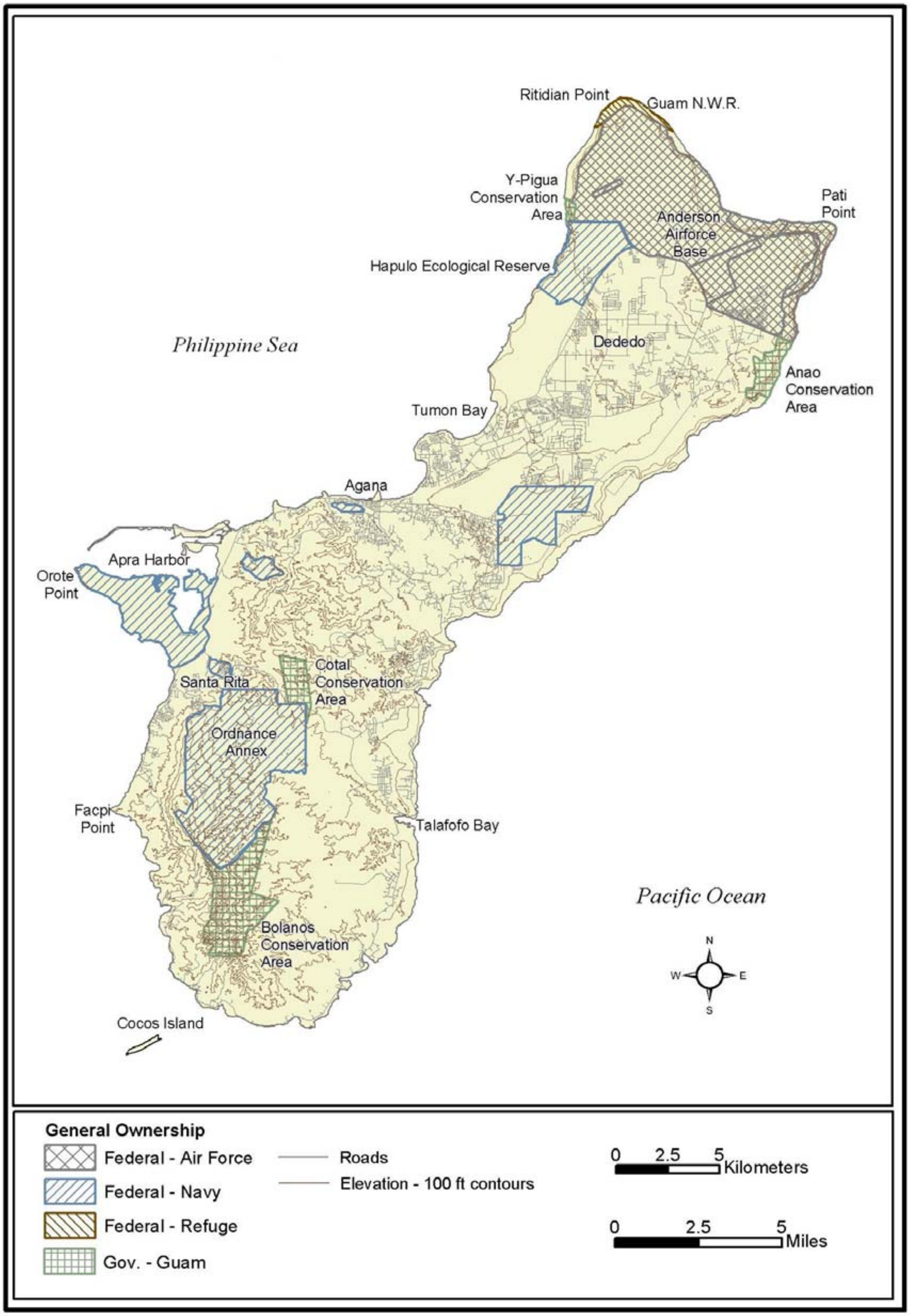

Figure 6. Territory of Guam.

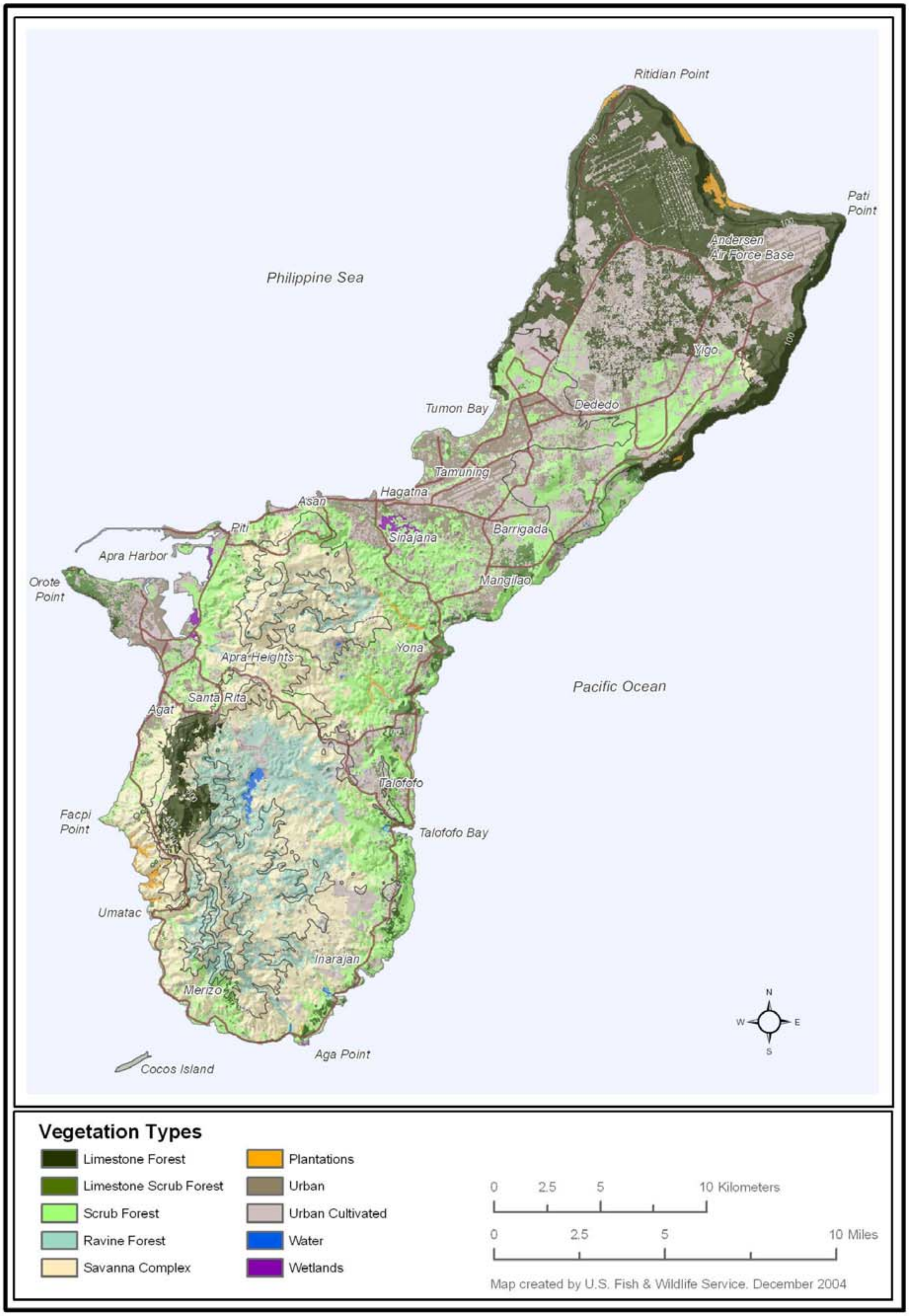

Figure 7. Vegetation types on the island of Guam.

in emergent *Ficus* spp. (fig) and *Elaeocarpus joga* (yoga) trees (Morton 1996). Nests have been found exclusively in native tree species on both Guam and Rota, and aga appear to forage primiarly in native trees as well (Table 3). On Rota, aga use both mature and secondary limestone forests (Morton *et al.* 1999), but not exclusively (M. Lusk and E. Taisacan, unpubl. data). Of 156 nest sites, 39 percent and 42 percent were in mature and secondary limestone forest, respectively (the remaining 19 percent were in coastal forest; Morton *et al.* 1999). Young aga may prefer immature limestone forest for foraging. Almost 61 percent of locations of banded, pre-dispersal juvenile resightings (n = 398) were associated with immature limestone forest; in contrast, only 49 percent of the study blocks were categorized as immature limestone forest (Morton *et al.* 1999), suggesting aga were selecting this habitat type. Between 1992 and 1994, 90 percent of perching observations on Rota (n = 115) were in native trees, primarily in mid- to low-heights of the canopy (M. Lusk and E. Taisacan, unpubl. data).

On Rota, Morton *et al.* (1999) found that breeding aga densities averaged one pair per 22 hectares (54 acres) of forested habitat (predominantly native forest) on their six study areas ranging from 50 to 130 hectares (124 to 321 acres) in size. Pair densities ranged from a low of one per 37 hectares (91 acres) on Duge, a relatively fragmented forest patch, to as high as one pair per 12 hectares (30 acres) along the coastal terrace above Puntan Saguagahga. Territories were aggressively defended from July through January, although established pairs occupied these areas throughout the year. Although 18 percent of the forested area of Rota is *Leucaena leucocephala* (tangantangan) or some other species of introduced tree (Falanruw *et al.* 1989), no aga nests have been found in anything other than a native tree on this island. Aga nested in 20 tree genera (Morton *et al.* 1999). Of 161 nest trees found during 1996 to 1999, 63 percent were of 4 species: *Neisosperma oppositifolia* (fagot), *Eugenia reinwardtiana* (a'abang), *Intsia bijuga* (ifit), and *Premna obtusifolia* (ahgao) (Morton *et al.* 1999). Individual nest trees averaged 16.9 centimeters (6.7 inches) diameter at breast height and 8.7 meters (28.5 feet) high. Canopy cover over nest sites averaged 93 percent and was never less than 79 percent.

Aga are generally less conspicuous on Rota than on Guam. Aga on Rota appear to avoid nesting in emergent trees, instead nesting and foraging within the canopy; they also do not fly high above the canopy as frequently as they do on Guam (USFWS 1981; M. Lusk and E. Taisacan, unpubl. data). This behavior led early researchers to believe that aga were not common on Rota (Morton 1996; NRC 1997). In contrast, wild aga on Guam were reported to nest primarily in emergent *Eleaocarpus joga* and *Ficus* spp. (Jenkins 1983; Morton 1996; C. Aguon, Guam Division of Aquatic and Wildlife

Table 3. Native and introduced tree genera utilized by foraging and nesting aga on Guam.

Tree Genera	Origin	Foraging		Nesting	
		Rota	Guam	Rota	Guam
Aglaia	Native	x[f]	x[e]		x[a]
Artocarpus	Native	x[d]	x[g]		
Barringtonia	Native			x[b]	
Calophyllum	Native			x[g]	
Cestrum	Introduced		x[e]		
Cocos	Introduced	x[d]	x[d,e]		
Cycas	Native	x[f]			
Cynometra	Native	x[f]		x[a,b]	
Delonix	Introduced	x[f]			
Drypetes	Native			x[a,b]	
Elaeocarpus	Native	x[f]	x[g]	x[b]	x[c]
Eugenia	Native			x[b]	
Ficus	Native	x[f]	x[e]	x[a,b]	x[g]
Geniostoma	Native	x[f]			
Glochidion	Native				x[g]
Guamia	Native	x[f]		x[b]	x[a]
Guettarda	Native	x[f]		x[a,b]	
Hernandia	Native	x[d]		x[d]	
Hibiscus	Native	x[f]	x[e]		
Intsia	Native	x[f]	x[g]	x[a,b]	x[g]
Leucaena	Introduced	x[f]	x[d]		
Macaranga	Native		x[g]	x[b]	x[g]
Mammea	Native	x[f]			
Maytenus	Native			x[b]	
Melanolepis	Native	x[f]			
Neisosperma	Native	x[f]	x[e]	x[b]	x[a]
Ochrosia	Native	x[f]	x[e]	x[a]	
Pandanus	Native	x[d]	x[d,e]		
Pisonia	Native	x[f]	x[g]	x[b]	
Pouteria	Native	x[f]		x[a,b]	
Premna	Native	x[f]	x[e]	x[a,b]	x[a]
Psychotria	Native	x[f]		x[b]	
Scaevola	Native	x[d]			
Triphasia	Introduced	x[f]			
Tristiropsis	Native		x[g]	x[b]	x[g]
Vitex	Native		x[g]		x[g]
Snags	Unknown	x[f]	x[g]		

[a] Morton 1996 [b] Morton *et al.* 1999 [c] Michael 1987 [d] Tomback 1986 [e] Jenkins 1983
[f] S. Plentovich, unpubl. data [g] C. Aguon, unpubl. data

Resources, pers. comm. 2001). The fact that aga chose to nest in emergent trees on Guam may be a response to snake predation (Morton 1996). Alternatively, avoidance of emergent trees on Rota may be a strategy to avoid mobbing by the black drongo (*Dicrurus macrocercus*) (R. Beck, Guam Division of Aquatic and Wildlife Resources, pers. comm. 1996), although aga on Rota have been observed to be mobbed almost as frequently by native Micronesian starlings (*Aplonis opaca*) as by drongos (M. Lusk and E. Taisacan, unpubl. data). Black drongos were introduced to Rota from Taiwan by the Japanese South Seas Development Company in the 1930's (Baker 1948), almost 30 years earlier than they were on Guam. According to data from avian surveys conducted in 1982, 1995 and 1999, drongos have become more widespread on Rota since the early 1980's (Plentovich *et al.*, unpubl. data).

2. Diet

Aga are omnivorous and their diet includes a wide variety of plants and animals. Aga have been observed foraging on several invertebrates, including Lepidopteran (butterfly and moth) larvae, grasshoppers, mole crickets, praying mantis, earwigs, and hermit crabs. Skinks, geckos, immature rats, and bird eggs are also a part of their diet (Beaty 1967; Jenkins 1983; Tomback 1986; Michael 1987; R. Beck, unpubl. data; M. Lusk and E. Taisacan, unpubl. data). They have also been observed foraging on the foliage, fruit, seeds, and buds of at least 26 different tree species (Table 3).

Aga have been observed to forage in the canopy, subcanopy, understory, in forest undergrowth, and on the ground (Jenkins 1983; Tomback 1986; M. Lusk and E. Taisacan, unpubl. data). On Rota, aga were found to forage at an average of 4.9 meters (16.1 feet) above the ground, significantly lower than the average canopy height (7.5 meters, 24.6 feet) of forests in which they were observed foraging (M. Lusk and E. Taisacan, unpubl. data). While foraging, aga will rustle through the leaf litter and tear at bark in search of insects (Tomback 1986; J. Morton and C. Aguon, unpubl. data).

3. Communication and Sociality

Aga make a variety of sounds. Communication alerts others to foraging opportunities and warns of predator presence. Pairs vocalize quietly at their nests with rambling dialogues (NRC 1997). Aga are typically found in families containing a monogamous pair and one to three offspring. During a 3-year period (1996 to 1999) on Rota, Morton *et al.* (1999) reported an average of 1.21 fledglings per nest (standard error [SE] = 0.07) for 33 successful aga nests. Sightings of large groups of aga have been reported on both Rota (E. Taisacan, Retired, Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife, pers. comm. 1999) and Guam, and were apparently common in the 1980's (Wiles 1998). Such groups typically appeared in late summer, prior to territory establishment for breeding. As many as 66 birds were observed roosting together on Guam during February of the 1984 breeding season, but this may have been a response to abnormally skewed sex ratios resulting from brown treesnake predation on nesting females (Wiles 1998). Large aggregations were not observed on Rota during the late 1990's (Morton *et al.* 1999); most recorded observations were attributable to brief mixing of family groups. Notable exceptions included observations of 16 aga in June 1989 in the Pekngasu region (D. Stinson, Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife [formerly], pers. comm. 1999), 9 aga in September 1997 in the Palii basin, and 7 aga near Puntan Saguagahga in February 1998 (Morton *et al.*, unpubl. data). Thus, social aggregations are occasionally observed, but the current frequency and causes of this behavior are not fully understood.

4. Reproduction

Aga likely breed year round on Rota. During a 3-year period (1996 to 1999), Morton and coworkers (1999) observed nest initiation as early as July 31 and fledging as late as May 22. June is the only month that active aga nests were not found. Peak nesting activity occurs from August through February, but the timing can vary considerably depending on typhoon activity during the previous breeding season (see section below on typhoons). In contrast, breeding activity in the remnant aga population on Guam was truncated, apparently due to nest predation, poor physiological vigor of the adults, and egg nonviability. In recent years (1998 to 2001), nesting by Guam aga was recorded only from October into mid-April (Morton 1996; C. Aguon, unpubl. data).

A minimum of 65 days is necessary to build the nest, incubate the eggs, and rear the brood through fledging (Morton *et al.* 1999). Both parents generally participate in all aspects of breeding, although the female incubates most of the time. Nest construction typically takes a week to complete by both parents and develops through three stages with progressively smaller-diameter nest materials: platform, cup, and nest lining (Morton 1996; Lusk and Taisacan 1996). The incubation period is 21 to 23 days and the nestling period is 36 to 39 days (Morton *et al.* 1999). Aga will often reinitiate the nest cycle within 2 weeks after abandoning an empty nest, and within 4 weeks after losing a clutch or brood (J. Morton, USFWS, pers. comm. 2001).

Over a 3-year period on Rota (1996 to 1999), the percentage of pairs that fledged young annually varied from 14 percent to 64 percent and averaged 44 percent (SE = 15.2, n = 3 years) (Morton *et al.* 1999). Clutch sizes ranged from one to four eggs (mean 2.31 ± 0.09, n = 87). For 50 occupied nests, the number of nestlings averaged 1.42 ± 0.08, but among 86 monitored territories, 88 completed nests produced only 71 chicks (mean 0.81 chicks per completed nest). Forty (56 percent) of the 71 chicks fledged. Large clutches (four eggs) have not been observed on Guam but were observed on Rota. This occurred most frequently (seven of eight observed nests) during the year immediately following Supertyphoon Paka (December 1997). During that year (1998), one female even deposited a second four-egg clutch immediately after losing her first clutch of four eggs (Morton *et al.* 1999).

Although aga generally produce no more than a single brood per year, nest failure and other factors lead to multiple nest attempts each breeding season. From 1996 to 1999, 32 aga pairs on Rota constructed a mean of 2.2 nests a year (SE = 0.14, n = 78), nesting as many as 7 times in one season (Morton *et al.* 1999). Not all nests resulted in egg laying, however. On average, Rota pairs produced about one nest per year that advanced to the level of egg deposition. Over a 3-year period, of 148 nests with known fates, 18 percent were only partially constructed, 13 percent were abandoned after completion, 4 percent had inviable clutches, 28 percent were depredated, and 16 percent were destroyed by typhoons (the remaining 22 percent fledged young; Morton *et al.* 1999). Similarly, on Guam, aga have been known to attempt nesting seven times in one season (Morton 1996). However, nest failures in more recent years have been attributed to premature abandonment (either as a result of predators or human-induced disturbance), interference by unmated males (due to skewed sex ratios), black drongo mobbing, and possibly senescence (*i.e.*, poor physiological vigor and infertility) (Morton 1996; NRC 1997).

After fledging, aga will typically remain in family groups until the following breeding season, a period that averaged 241 days (SE = 33, median 197 days) for 15 banded family groups (Morton *et al.* 1999). However, the period of parental attendance after fledging varies widely, from 99 to 537 days. Consequently, although aga typically produce from zero to one brood a year, exceptions have been documented. One pair on Rota successfully fledged and raised two broods of singletons in one breeding season; in contrast, another pair tended a single juvenile for 18 months, skipping an entire breeding season (Morton *et al.* 1999). This latter consequence of an extended parental attendance period is not uncommon in aga. Over a 3-year study period, 4 of 30 pairs were deemed nonbreeders during at least 1 year due to continued attendance of juveniles produced during the previous breeding season (Morton *et al.* 1999).

On Rota, the sex ratio of 57 fledglings during 1996 to 1999 was 1.48 females to 1 male (Morton *et al.* 1999). This skewed sex ratio continues through the post-fledging period. Of 30 aga banded as nestlings since 1992 and observed alive at least 100 days after fledging, 20 were female (Morton *et al.* 1999). Although similar data for fledglings are not available for Guam, the sex ratio of remnant aga adults was estimated to be skewed towards males (4 males:1 female) in the mid-1990's. This has been hypothesized to be a result of brown treesnake predation pressure on incubating females; however, definitive sex data on Guam aga do not exist (Morton 1996).

We know little about the age of first reproduction or length of reproductive life in aga. Aga are assumed to enter into the breeding cohort at 3.5 years of age, and the oldest known breeding bird was 6.6 years old (Morton *et al.* 1999). However, these estimates are based on samples of fewer than 10 birds. Although we do not have longevity data for aga, corvids in general are relatively long-lived passerines. The longevity record for the American crow (*Corvus brachyrhynchos*), for example, is 14 years, 7 months (USGS 2003).

Aga nests are large open cup nests typically composed of a nest platform and intermediate and inner cups. The nest platform is made principally of flexible *Jasminum marianum* (banago) vines and to a lesser extent of twigs from a few other species of trees (Lusk and Taisacan 1996; C. Aguon and J. Morton, pers. comm. 2001). The intermediate nest cup is usually composed of an interwoven mesh of small branches, *Ficus* spp. rootlets, vines of *J. marianum* and *Cocos nucifera* (coconut palm) fibers. The nest platform ranges in diameter from about 24 to 53 centimeters (9 to 21 inches) while the inner diameter of the nest may be about 15 centimeters (6 inches) (Lusk and Taisacan 1996). Nests on Guam are usually lined with fine fibers from *Flagellaria* spp. (C. Aguon, pers. comm. 2001).

Nest location and type of trees selected for nesting differs between Guam and Rota. Aga on Rota typically build their nests toward the inner part of the tree canopy. Morton and coworkers (1999) recorded aga nests in 20 species of native trees (Table 3). These trees are usually about the height of the forest canopy and sometimes shorter. In contrast, aga on Guam usually build their nests in the outer portions of the tree canopy and choose a small number of mainly emergent native tree species (Table 3; C. Aguon, pers. comm. 2001).

5. Recruitment and Survival

The post-fledging period of juvenile dependence may last from 3 to 18 months (Morton *et al.* 1999), and recruitment into the adult population is low. Of 19 aga that were banded as juveniles on Rota at least 3.5 years before the end of the study, 4 (21 percent) were known to be alive at age of entry into the adult cohort (3.5 years old). Assuming that all birds not resighted died, 1 in 4.8 fledglings made it into the adult cohort (Morton *et al.* 1999).

Adult survivorship can be indirectly quantified using territory turnover rates of change. On Guam, these data suggest that survival of females was approximately 71 percent per year while survival for both sexes was 75 percent per year (NRC 1997). On Rota, 4 of 64 adults were replaced over a 3-year period, suggesting annual adult survivorship might be as high as 97.9 percent (Morton *et al.* 1999). However, this is an optimistic estimate given that Morton and coworkers were studying a population of mostly unbanded adults (mate substitutions could have gone unnoticed) and had little knowledge about non-breeding adult "floaters."

For the 3 years of their observations on Rota, Morton and coworkers (1999) calculated the likelihood of an egg or chick being recruited into the breeding population. Thirty-five percent of 201 eggs hatched from 86 territories were monitored for one season. Fifty-six percent of these hatchlings fledged. Forty-six percent of 48 fledglings achieved independence. The survivorship of juveniles from independence to adulthood is unknown, however. If the 4 of 19 banded juveniles that reached age 3.5 years is taken as representative of cumulative survival from fledging to adulthood, about 4 percent of eggs will produce birds that survive to age 3.5 years (presumed age of first breeding). However, juveniles are banded at various ages prior to fledging and some of the loss of banded birds probably occurred prior to fledging. Thus the survivorship estimate based on the 19 banded birds (4 of 19 = 21 percent) overestimates losses from the post-fledging period, and the true proportion surviving from egg to adult is probably higher than 4 percent. The true proportion surviving to adulthood might have been higher prior to the introduction of predators on Rota.

6. *Response to Typhoons*

Morton and coworkers (1999) documented the response of nesting aga to four cyclonic events over a 3-year period. Typhoon Dale occurred on November 1, 1996, Supertyphoon Keith occurred on November 2, 1997, Supertyphoon Paka occurred on December 16, 1997, and Tropical Storm Alex occurred on October 11, 1998. Of 164 nests, 23 (14 percent) were destroyed or damaged by high winds associated with these events and, in one instance, winds caused premature fledging. Aga generally renested 2 weeks after these events, but the effects of Supertyphoon Paka were more severe. Paka had high sustained winds (265 kilometers [165 miles] per hour) and occurred during peak nesting in December 1997. This storm caused island-wide forest destruction and defoliation, catastrophic nest loss, a truncated breeding season, and mate replacement in two breeding pairs. Only 4 of 32 pairs fledged young during the year Paka hit (though Paka hit at midseason). In addition, as a result of Paka, at least 2 of 31 pairs on Rota lost one adult member, indicating that some adult mortality is also possible during major storms. On Guam, the four adult aga observed prior to Paka all survived.

During the breeding season following Supertyphoon Paka, however, the majority of aga pairs initiated nesting simultaneously. At least 75 percent of pairs initiated their first nests by September 1998. During the previous year, by contrast, less than 20 percent of studied pairs had initiated nests by this time. Aga were also more fecund in 1998. Whereas only one four-egg clutch had ever been recorded for aga prior to Paka, seven four-egg clutches were found during the following season. It appears that asynchrony in breeding, induced by random nest failures (including minor cyclonic events) and variable extended parental care, becomes accentuated with time after a major storm event. Major typhoons apparently synchronize the breeding aga population.

F. Factors in Decline and Current Threats

In determining whether to list, delist, or reclassify (change from endangered to threatened status, or *vice versa*) a taxon under the Endangered Species Act, we evaluate the role of five factors potentially affecting the species. These factors are:

A – the present or threatened destruction, modification, of curtailment of its habitat or range;

B - overutilization for commercial, recreational, scientific, or educational purposes;

C - disease or predation;

D – the inadequacy of existing regulatory mechanisms; and

E - other natural or manmade factors affecting its continued existence.

These factors are not always constant within or between populations as the status of the species changes through time. For example, when the aga was first listed as endangered in 1984, disease was believed to be the primary threat to the species on Guam (USFWS 1984). Since that time predation by the brown treesnake was found to be the primary threat (Savidge 1986, 1987). However, the potential spread of West Nile virus to Guam and Rota has once again raised concerns over the threat of an introduced disease on aga populations.

Factors that have impacted the aga are: habitat loss or degradation (Factor A), introduced predators such as cats, rats, monitor lizards (*Varanus indicus*), and brown treesnakes (Factor C), human persecution (Factor E), typhoons (Factor E), and reproductive and small population problems (Factor E) (USFWS 1984, 1990; NRC 1997). Factors that may have had an impact on aga are disease (Factor C), nutritional deficiencies (Factor E), contaminants (Factor E), harassment by black drongos (Factor E), and competition with introduced species (Factor E). Of these factors, brown treesnake predation is believed to be the overriding factor in the major decline of aga on Guam. The direct overutilization of aga for commercial, recreational, scientific, or educational purposes (Factor B) currently is not a significant threat. Existing regulatory mechanisms (Factor D) appear adequate, as the aga is currently listed by the Federal government as well as the government of the Territory of Guam and

Commonwealth of the Northern Mariana Islands.

1. Predation by Brown Treesnakes

The brown treesnake is native to coastal Australia, Papua New Guinea, and a large number of islands in northwestern Melanesia. These snakes are long and slender, ranging from 6 grams (0.2 ounces) in weight and a snout-vent length (SVL) of approximately 275 millimeters (11 inches) to 3,000 grams (6.6 pounds) in weight and a snout-vent length of approximately 2,700 millimeters (8.75 feet). Brown treesnakes are excellent climbers. They are active primarily at night and hide during the day in dark crevices and other unexposed areas. They prey on a wide variety of animals depending on the size of the individual snake. Brown treesnakes in captivity eat only geckos when they are first hatched (F. Qualls and C. Qualls, USGS/Colorado State University, pers. comm. 2001), but soon add skinks to their diet. Skinks form the bulk of the diet for snakes in the body size 600 to 1,000 millimeters snout-vent length (23 to 39 inches) (Rodda et al. 1999a). However, brown treesnakes add birds and mammals to their diet when they become reproductively mature (generally at a size of approximately 960 to 1,000 millimeters [37 to 39 inches] snout-vent length) (Savidge 1988).

Brown treesnakes probably arrived on Guam prior to 1950 as passive stowaways in materiel salvaged from an island near New Guinea (Manus) following World War II (Savidge 1987; Rodda et al. 1992). Available evidence suggests that brown treesnakes first colonized the Santa Rita/Ordnance Annex area, and then spread progressively across the island, reaching the northernmost point of the island (Ritidian Point) by 1968 (Savidge 1987). Within 20 years, the snake population had reached a peak density of 100 to 120 snakes per hectare (41 to 50 snakes per acre) on Guam. Such a high density of snakes is one to two orders of magnitude higher than would normally be expected for large snakes away from the concentrating effects of water or dens (Rodda *et al.* 1992).

The only native snake on the island of Guam is a tiny blind snake (*Ramphotyphlops braminus*) that burrows through the soil and feeds on the eggs, larvae and pupae of ants and termites. Guam's native birds were therefore particularly vulnerable to the exotic brown treesnake, as they had not evolved with any snake as a nest predator. By 1988, the brown treesnake had eliminated most of the native birds on the island (Savidge 1987), as well as many other native and exotic animal species (Fritts and Rodda 1998). All but two of Guam's native bird species (the yellow bittern [*Ixobrychus sinensis*] and Mariana swiftlet [*Aerodramus bartschi*]) have shown patterns of decline coinciding with the expansion of the snake's range across the island, indicating an inverse relationship between populations of snakes and birds (Savidge 1987), presumably due to nest predation by brown treesnakes. Conry (1988a) recorded daily egg and nestling mortality by brown treesnakes as high as 21.5 percent in Philippine turtle-doves (*Streptopelia bitorquata*) on Guam. The aga's decline followed the same pattern as other forest birds on Guam, kingfishers having been first extirpated in the southern and central portions of the island, where the snake first colonized.

Brown treesnake densities on Guam peaked in the mid-1980's and have since declined, but remain at levels that threaten the recovery of the aga. Current evidence suggests that snake populations in tangantangan (*Leucaena leucocephala*) habitat on Guam range from 20 to 60 snakes per hectare (9 to 26 snakes per acre) (counting only larger snakes over 800 millimeters [31 inches] snout-vent length), while snakes in this size class occur at lower densities (10 to 20 snakes per hectare (4 to 9 snakes per acre) in grassland, ravine forest, or native forest vegetation types (Rodda *et al.* 1999b). Historical fluctuations indicate that brown treesnake densities may recover following overpredation of its prey base and a crash in available food sources (Rodda *et al.* 1992). A population decline in brown treesnakes across Guam between 1985 and 1995 was attributed to the decimation of nearly all native fauna on the island (Rodda *et al.* 1992, 1999a; Fritts and Rodda 1998). The persistence of high densities of treesnakes is attributed to the continuing availability of several species of introduced lizards and rats as potential prey items (McCoid 1997; Rodda *et al.* 1999b). Other exotic avian and mammalian prey may also aid the snake's survival on Guam. Local residents have reported the loss of many domestic birds, as well as some pets, to the nocturnal snake (Fritts and McCoid 1991).

If the brown treesnake is introduced to Rota, declines in native bird populations, including the aga, are expected to occur in a similar manner to that observed on Guam. However, because Rota is smaller then Guam, the amount of time it takes for brown treesnakes to become established throughout the island is expected to be less than that observed on Guam. Currently, the bulk of Rota's human population is located near the geographic center of the island. Therefore, a likely site of accidental brown treesnake colonization is the village of Sinapalo, just south of the airport. If the brown treesnake colonizes Sinapalo and its spread is not significantly retarded by snake control actions (compared to Guam), colonization of the entire island of Rota would likely be complete in less than 10 years. This judgment is based on the rate of spread on Guam (about 2 kilometers [1.2 miles] per year) and the maximum distance from Sinapalo to the furthest point on Rota (a formation known as the "Wedding Cake" ["Tapingot" in Chamorro] extending off southwest Rota is about 14 kilometers [9 miles] from Sinapalo). If the snake were to become established in both of the two villages on Rota (accidental human transport would normally produce this result), the most remote spot (the top of the sabana) would be only 5 kilometers (3 miles) from an infestation, and would thus be vulnerable to colonization in less than 3 years. Note that the value of 2 kilometers (1.2 miles) per year requires that the snake average a net daily displacement of about 5.5 meters (18 feet) a day, which is well below the typical daily net displacement of about 60 meters (197 feet) a day (Wiles 1985, 1986, 1987; Santana-Bendix *et al.* 1994; Clark 1998; Tobin et al. 1999; Hetherington 2001). Accidental human transport or directional snake movement could undoubtedly increase the rate of population spread beyond the 2 kilometers (1.2 miles) a year average documented on Guam. Furthermore, this documented value is likely to be an underestimate, as no one purposefully investigated brown treesnake population expansion on Guam at the time it was occurring.

2. Other Predators

A study on Rota showed that in the year 1998, 40 percent of all aga nests failed due to predation, potentially by rats, monitor lizards, cats, and even other aga (Morton *et al.* 1999). In New Zealand and other Pacific Islands, rats have been found to be important predators of native birds, to the point where they are believed to have caused population declines or the extinction of native species (Atkinson 1985; Robertson *et al.* 1994). Rats were once thought to be a major nest predator of aga on the island of Rota (Morton *et al.* 1999), although the species of rat responsible for such predation had not been determined. Recently, however, Arjun Amar completed a 2-year study on Rota testing the hypothesis that introduced rats were responsible for the decline of aga there by assessing the correlation between rat density and aga nest success. Contrary to expectations, Amar's results indicated that aga were more likely to successfully produce young if they nested in areas with higher rat abundance; both hatch success and clutch success showed a positive relationship with rat density at the nest site (Amar 2004). These results do not necessarily suggest that predation by rats is not occurring, however; in fact, cameras set up on artificial nests showed multiple visits by rats (although they were apparently unsuccessful in opening the chicken eggs used in these trials). Instead, Amar suggests that possibly some common habitat factor may be favoring both rats and aga, such as food availability. Interestingly, Amar's cameras also recorded an incident of nest predation by another aga (Amar 2004).

The magnitude of the impact that introduced rats may have on the aga population on Rota requires further investigation. Rats have not been common on Guam since the irruption of the brown treesnake, but can be expected to become common in snake-reduced areas.

Monitor lizards, another introduced species, have been known to prey on eggs and young birds on Guam (Aguon and Henderson 1998) and undoubtedly do so on Rota as well. Monitor lizards may be at artificially high densities on Rota due to the ready availability of introduced rodents as prey. Feral house cats can exert a considerable negative impact on local bird populations (Veitch 1985; Churcher and Lawton 1987), and may also be artificially abundant on Rota due to the high densities of rats. Feral cats may also have an indirect impact through serving as a vector for the disease toxoplasmosis (a disease caused by the protozoan *Toxoplasma gondii*). Toxoplasmosis has been shown to affect captive-reared and released `alalā or Hawaiian crows (*Corvus hawaiiensis*), which apparently acquired the disease through contact with feral cat feces (Work *et al.* 2000).

The effects of these predators are probably not the primary reason for the general decline of birds on Guam. Because almost all bird species on Guam have been impacted by brown treesnake predation, the resulting decline in avian populations may have forced predators to switch from their preferred prey to species they would ordinarily forego eating (*i.e.*, the aga). On Rota, the aga may be more vulnerable to nonnative predators like rats because of other factors, including fragmentation of habitat and proximity to human settlements, each of which may boost populations of these exotic predator species.

3. Disease

Disease is not currently considered to be a significant factor in the decline of aga or any other forest birds on either Guam or Rota (USFWS 1990). However, a number of pathogens have been identified in endemic avifauna and should almost certainly be routinely screened for in captured aga. Avian pox (*Plasmodium* spp.) and *Haemoproteus* have been found in bridled white-eyes from Saipan (Savidge 1986). On Guam, *Salmonella newport, S. waycross, S. oranienburg, S. amager*, *Candida tropicalis*, Newcastle's disease, and influenza virus have been reported in both native and introduced bird species (Savidge *et al.* 1992). *Mycobacterium avium*, the cause of avian tuberculosis, was recently detected in fecal samples from backyard chickens on Guam (Silva-Krott *et al.* 1998). Nematode ova were also found in fecal samples collected from one aga and two Micronesian starlings on Guam (Savidge *et al.* 1992).

West Nile virus may pose a significant risk to aga if it reaches the Pacific Rim. The virus, introduced from Israel, has expanded from the original focus around New York City in 1999 to all but three states east of the Mississippi River (Washington, Alaska, and Hawai`i; USGS 2004). As of

August 2004, West Nile virus has been detected in 225 species of birds. Several members of the crow family, including the American crow (*Corvus brachyrhynchos*), fish crow (*C. ossifragus*), and blue jay (*Cyanocitta cristata*) have been the most susceptible species so far and are experiencing high mortality. Other corvids (crows, ravens, jays, and magpies) are also extremely susceptible. Experimental research conducted at the U.S. Geological Survey National Wildlife Health Center confirmed the high susceptibility of crows to West Nile virus infection, determined that crows were still competent reservoirs of West Nile virus to infect mosquitoes before they died from infection, and observed that crows could transmit West Nile virus directly between individuals without mosquitoes as intermediaries under confined laboratory conditions (USGS 2000). As of 2003, West Nile virus, RNA, or antigens have been detected in 43 mosquito species from 8 genera (*Aedes*, *Anopheles*, *Coquillettidia*, *Culex*, *Ochlerotatus*, *Orthopodomyia*, *Psorophora*, and *Uranotaenia*) (Centers for Disease Control and Prevention 2004). Three of these mosquito genera (*Aedes*, *Anopheles*, and *Culex*) were reported in the Mariana Islands (Swezey 1942; Bohart 1956; Savage *et al.* 1993). As the virus spreads to more locations along the Pacific Coast of North America, the threat to Pacific Island corvids grows.

4. Habitat Loss and Degradation

Most aga territories are associated with closed canopy forests (Morton *et al.* 1999). In the Marianas, some closed canopy forests appear to have been degraded by a combination of human-caused forest fragmentation and loss; alien weeds that irrupt in disturbed areas; suppression of forest regrowth by introduced ungulates such as deer (*Cervus mariannus*), pigs (*Sus scrofa*), and carabao (*Bubalus bubalis*); invasive vines that cover regenerating forest; and a possible increase in natural typhoon frequency (see Typhoons, below).

Human development and road building degrade forest quality over time. Mature forests and crow populations are not usually found near human habitation or in areas of high human activity. Due to increasing pressure for tourism, recreation, and the government practice of donating pubic land for homesteads on Rota, the loss or fragmentation of native forests will become an increasingly significant factor limiting aga population size and viability. Between 1945 and 1976 there was an approximate 10 percent increase in forest coverage on Rota (Plentovich *et al.*, unpubl. data). However, 5 to 10 percent of suitable forest habitat for aga was lost to development on Rota between 1982 and 1995 (Figure 8). Introduced ungulates alter forest community structure and composition by disturbing the soil, thereby promoting the spread of weeds. Besides competing for resources with native species, alien grasses and other weeds

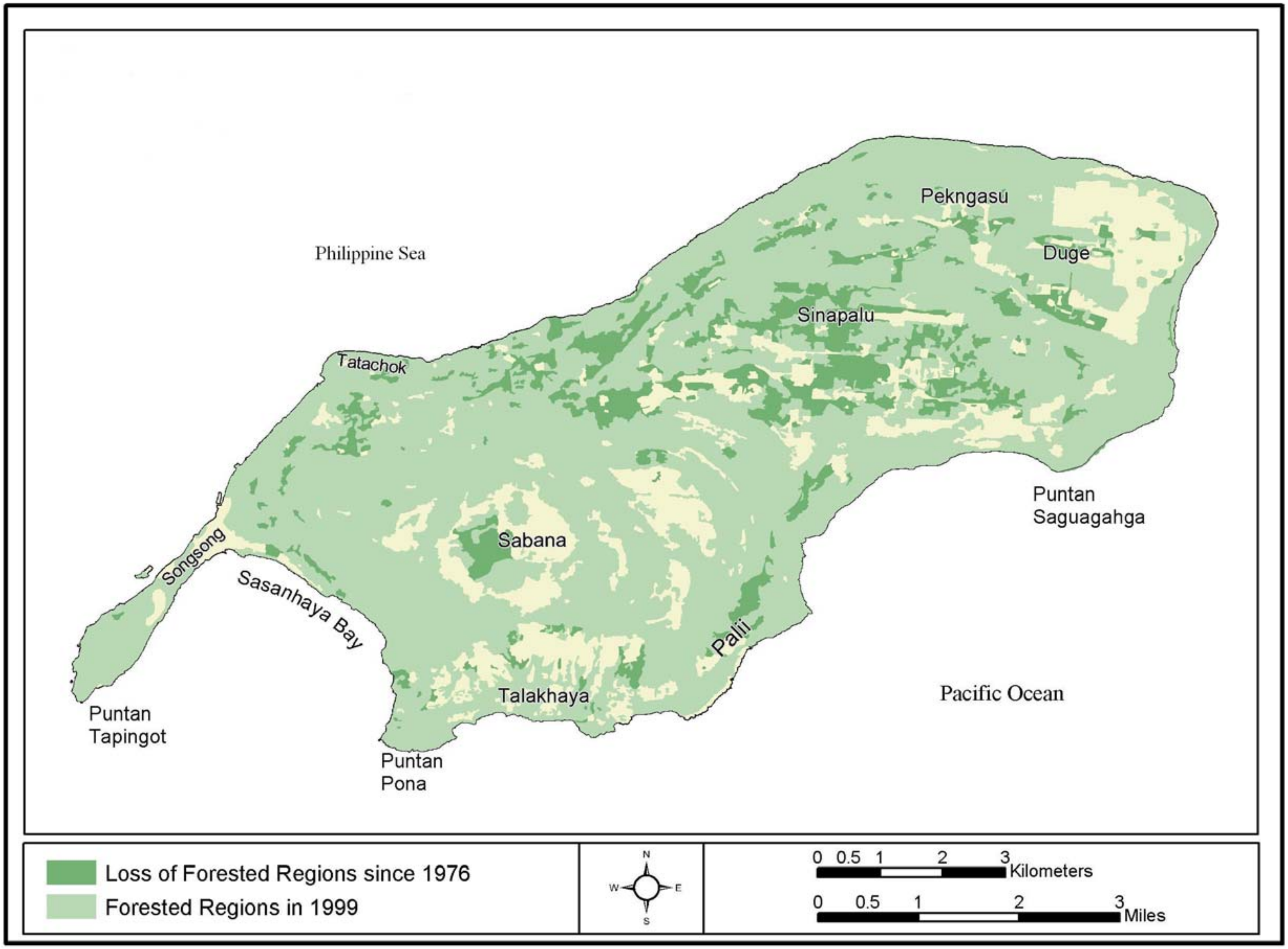

Figure 8. Distribution of native forests and areas of forest loss between 1976 and 1999, Island of Rota, Commonwealth of the Northern Mariana Islands.

also may change the fire regime, sometimes resulting in grass/fire cycles that eventually eliminate native vegetation (D'Antonio and Vitousek 1992; Mack and D'Antonio 1998). An example of fire-promoting vegetation is *Chromolaena odorata*, a shrub that is spreading in southern Guam and carries fire into native forest. Repeated burning has the potential to replace native forest with alien shrubland, thus reducing the availability of aga habitat. Regeneration of native trees is also harmed, especially on Guam, by ungulates that severely browse the tender shoots of regenerating trees or sprouting seeds. These plants did not evolve in the presence of browsing ungulates. Although they are subjected to insect herbivory, they probably have diminished chemical and physical defenses against browsing. Introduced rodents may also affect forest regeneration by feeding on the seeds of native trees. This effect (if it is significant) is likely to be more acute on Rota than Guam. Loss of native fruit bats, important pollinators and seed dispersers, is also likely to have severe long-term effects on forest composition and structure. Further study of these potential problems is needed to establish their significance in regard to habitat quality and quantity for the aga.

5. Harassment by Black Drongos

The black drongo is an introduced species of bird currently found on Guam and Rota. They were thought to have been deliberately introduced to Rota from Taiwan in 1935 by the Japanese South Seas Development Company to control insect pests (Baker 1948); they likely dispersed on their own to Guam in the 1960's from Rota (Jenkins 1983). Black drongos sometimes harass crows, perhaps to drive this potential predator from the vicinity of their nests or perches (Ali and Ripley 1972; Maben 1982). This harassment may force aga to avoid nesting in the open and choose nest sites within dense foliage. Perhaps due to the brown treesnake (or because black drongos were introduced to Rota three decades earlier than they were on Guam), black drongos are far more abundant on Rota (J. de Cruz, Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife, pers. obs. 2000), and therefore the demographic impact, if any, of the black drongo on aga is more likely to be important on Rota. It has been suggested that mobbing is less frequent in dense limestone forests, especially near cliff lines, and more frequent in secondary vegetation, pastures, and open areas (NRC 1997), perhaps because black drongos typically hawk insects from vantage points in open country and frequent cultivated areas (Grimmett *et al.* 1999). Although drongos are primarily insectivorous, they occasionally prey upon small passerines, including Rota bridled white-eyes (*Zosterops rotensis*), Eurasian tree sparrows (*Passer montanus*), rufous fantails (*Rhipidura rufifrons*), and Mariana swiftlets (Perez 1968; Drahos 1977; Maben 1982; Amidon 2000).

6. Competitors

Changes in the avifauna or food supply on Guam or Rota may have resulted in crucial food shortages or competition for food at particular times and places. For example, nestling aga have specific nutritional requirements and food shortages could episodically limit growth or survival. Introduced invertebrates, such as ants and spiders, and small alien vertebrates, such as rats, may also have significantly altered the availability of food for aga. On Guam, brown treesnakes have largely eliminated the smaller bird species that provided aga with food in the form of eggs and nestlings, a potentially important resource for reproducing aga. Thus the brown treesnake is not only an important predator, but also a potential competitor with the aga.

7. Human Impacts

The harvest of native birds has been outlawed on Guam since the turn of the century, but aga were not specifically protected until 1981 (Executive Order No. 61, Naval Governor of Guam, 1903). There are no reported problems with poachers capturing or killing aga on Guam. Therefore, direct human impacts, such as harvest of the aga, do not appear to be a major factor in their decline on Guam. On Rota, occasional persecution may be directed at aga, as the species is considered to impede and restrict land uses such as agriculture and development. One pair of nesting aga was killed on a forested site being cleared for development in 1995 (D. Grout testimony reported in NRC 1997). This is the only case where persecution was confirmed and documented (*i.e.*, two aga with bullet wounds were found under the nest they were attending), so its actual extent is unknown. The loss of adult aga is likely to have a more negative impact on Rota's aga population than the loss of subadults, juveniles or nestlings (see Appendix 4; Saether and Bakke 2000).

Aircraft noise may represent an indirect human effect. Anecdotal evidence suggests that especially loud or low-flying (under 305 meters [1,000 feet]) aircraft may disturb aga by disrupting communication and flushing nesting birds from their nests (Grout 1993; Morton 1996). The magnitude of impacts from aircraft on crow survival and fecundity have become important in light of the fact that aga now exist on Guam only within the boundaries of Andersen Air Force Base. Logistic regression modeling of aga distribution on Andersen Air Force Base suggested that aga were more affected by visible human disturbance than by auditory human disturbance (Morton 1996); therefore, roads, runways, and housing areas are more disturbing to aga populations than ambient noise from flyovers. This study was not complete in scope because it was impossible to observe the exact effects on nesting behavior (Morton 1996). On Rota, Morton and coworkers (1999) documented nesting by one aga pair in Tenetu, within 100 meters (328 feet) of two houses, and the nesting of a second pair within 150 meters (492 feet) of the Japanese Cave Museum outside of Songsong. Aga nesting near human habitation is likely the exception. Despite the fact that all of the six 1-square kilometer (0.386 square mile) areas studied by Morton and coworkers were at least partially bounded by roads, the mean distance from nests to the nearest road was 290 meters (950 feet) (SE = 38, n = 75). Morton and coworkers (1999) concluded that with high quality forest habitat, at least some pairs may be able to tolerate close proximity to human habitation (in the absence of persecution), albeit at lower densities.

8. Contaminants

Pesticides have been used extensively in the past for agriculture and disease vector control in the Mariana Islands. Following World War II and until the early 1970's, DDT (dichlorodiphenylytrichloroethane, an organochlorine pesticide now known to have adverse impacts on birds and other wildlife) was regularly applied by the military on Guam (Baker 1946; Maben 1980; Anderson 1981). In addition, Maben (1980) reported that the organophosphate insecticide malathion was applied by the military around beaches and buildings up to three times a week. Malathion was also aerially applied over approximately a third of the island of Guam over 4 days in 1975 to prevent the potential outbreak of dengue fever (Haddock *et al.* 1979). On Rota, malathion was used on to control insect pests in 1988 and 1989 (Engbring 1989). Researchers studying the impacts of pesticides on native forest birds in the 1980's did not believe that pesticides played a major role in the continuing decline of the aga and other endangered birds in the Mariana Islands (Grue 1985; Engbring 1989). However, Drahos (2002) believed that impacts of pesticides on native bird populations prior to the 1980's have been underestimated and that pesticide use may have played an important role in the decline of forest birds on Guam, especially southern Guam. Unfortunately, little data is available on forest bird populations in southern Guam and pesticide use during this time period to determine its role in the decline. Under current conditions, however, contaiminants are not considered a threat to the aga.

9. Low Egg Viability

Aside from potentially skewed sex ratios reducing pairing between male and female birds, other reproductive problems have been noted. In the 1990's, egg viability was low on Guam, probably due to the advanced age of most of the remaining birds (NRC 1997). For example, in the years 1994 to 1995, 3 pairs of aga were observed producing multiple clutches, but only 1 out of 12 eggs (8 percent) was fertile. In addition to infertility due to senescence, other possible causes for low egg viability include external environmental effects, stress hormone-related developmental failure of the egg, and parental abandonment of eggs due to human or other disturbances.

10. Small Population Problems

At very low population densities, chance variation in population attributes such as sex ratio can further lower effective population size and thereby depress population viability. In addition, natural behaviors may be inhibited by exceptionally low population density. A species such as the aga that forms long-term pair bonds often exhibits restrictive mate selection criteria, criteria that may be difficult or impossible to satisfy in sparse or fragmented populations. There are many other problems associated with extremely small populations as well. For example, information transfer (Wiles 1998) or social development of young birds may be facilitated by communal gatherings, which may diminish in frequency or cease to occur altogether at low population densities. A range-wide reduction in aga may lead to fragmentation of the population into smaller groups throughout their former range. This in turn may lead to inbreeding. Small populations are also particularly vulnerable to the catastrophic typhoons that regularly sweep the Mariana Islands.

11. Typhoons

Typhoons are a common occurrence in the Mariana Islands. Guam, for example, has been affected by typhoons in 37 of the last 50 years (based on records compiled by U.S. Navy, Joint Typhoon Warning Center). During the 1990's Guam experienced 20 typhoons, and supertyphoons[1] occur with regularity (about once every 5 to 10 years). There is some evidence that the frequency of severe storms[2] is increasing in the Mariana Islands. With reference to Guam, the historical record shows increasing numbers of mild[3] and severe storms over the last three centuries (Figure 9), as well as in just the last decade (Figure 10). While some underreporting of storms may have occurred in prior centuries, even mild storms were noticed in the colonial era because they destroyed the flimsy structures used for early housing. Furthermore, these data are consistent with trends expected on the basis of increasing sea surface temperatures that have been documented in recent years (*e.g.,* Strong *et al*. 1998; U.S. Department of State 1999).

Typhoons reduce annual reproduction and may lower adult survival as discussed above. Typhoons may also decrease juvenile survivorship because juveniles lack the survival skills of their adult counterparts. However, these effects on demography are unlikely to depress aga populations

[1] A "supertyphoon" is a category of severe storms, defined as having gusts exceeding 240 kilometers (150 miles) per hour.

[2] A severe storm has estimated gusts exceeding 160 kilometers (100 miles) per hour.

[3] A mild storm has estimated gusts in the range of 80 to 160 kilometers (50 to 100 miles) per hour.

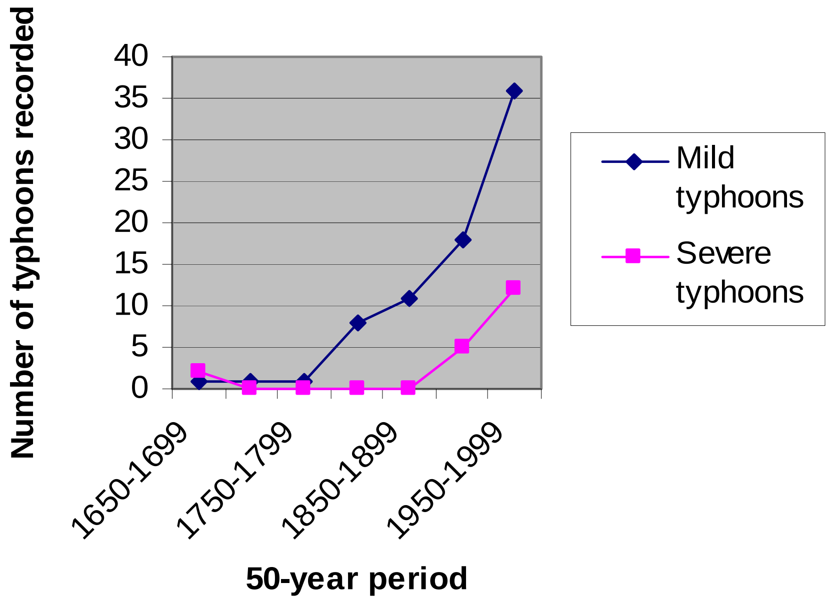

Figure 9. Historical record of mild typhoons (80 kph [50 mph] < estimated gusts < 160 kph [100 mph]) and severe (estimated gusts > 160 kph [100 mph]) typhoons recorded at the U. S. Navy Joint Typhoon Warning Center for Guam.

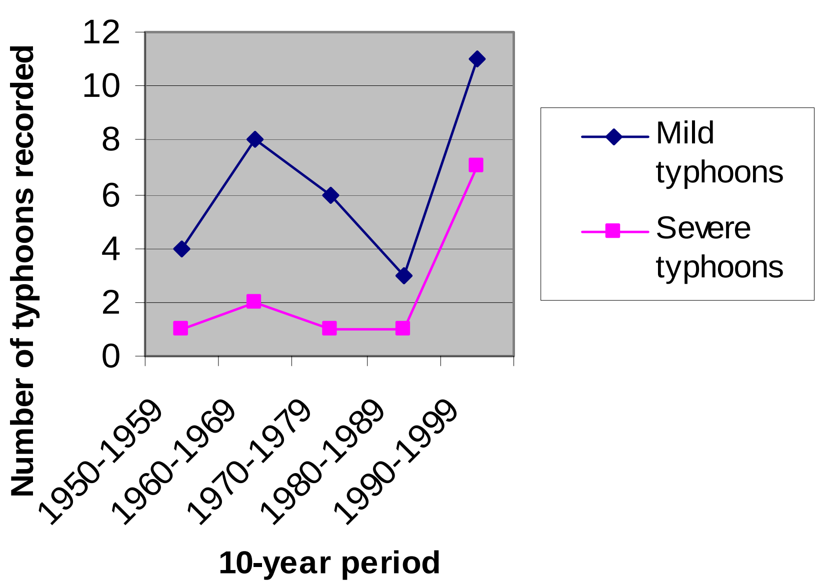

Figure 10. Mild typhoons (80 kph [50 mph] < estimated gusts < 160 kph [100 mph]) and severe (estimated gusts > 160 kph [100 mph]) typhoons recorded at 10-year increments at the U.S. Navy Joint Typhoon Warning Center for Guam from 1950 to 1999.

permanently, because few adults die and most breeders quickly renest.

The effects of increasingly common supertyphoons on habitat suitability may be more important to long-term aga viability. Supertyphoons fragment and decrease the suitability of existing habitat (documented following Roy in 1988 and Paka in 1997). An important way that habitat is degraded after major storms is by exacerbating the effects of introduced plants and ungulates. Following a major typhoon, forest canopies may be disrupted, facilitating the establishment or spread of introduced plants. Often these plants, especially rapid-growing vines, take advantage of typhoon-induced breaks in the forest canopy and grow over the top of regenerating native forest.

G. Critical Habitat

Critical habitat was designated on Guam and Rota for the aga and two other endangered species (the Guam Micronesian kingfisher [*Halcyon cinnamomina cinnamomina*] and fanihi or Mariana fruit bat [*Pteropus mariannus mariannus*]) in 2004 (USFWS 2004a; the fanihi was reclassified to threatened in 2005 [USFWS 2005]). For the aga, approximately 152 hectares (376 acres) were designated on Guam (Figure 11), and approximately 2,552 hectares (6,033 acres) were designated on Rota (Figure 12). On Guam, all three species share identical critical habitat boundaries. Critical habitat on Rota applies only to the aga.

H. Associated Species of Conservation Concern

Historically, 25 species of birds are known from Guam. Twelve of these were native forest birds, but most are now believed to be extinct or extirpated, most in association with the introduction of the brown treesnake (Savidge 1987; Engbring and Fritts 1988; Wiles *et al.* 2003). Thirteen bird species persist on the island of Guam, but nearly half of these (6 species) are introduced (Wiles *et al.* 2003). In addition to the aga, seven species of native birds from Guam are currently listed as endangered: the Guam Micronesian kingfisher (in captivity only), Mariana common moorhen (*Gallinula chloropus guami*), Guam rail (extirpated from the wild, but there is an experimental non-essential population introduced on Rota, as well as individuals in captivity), Mariana swiftlet, Micronesian megapode (*Megapodius laperouse laperouse*; believed extirpated), nightingale reed-warbler (*Acrocephalus luscinia*; believed extirpated), and Guam bridled white-eye (*Zosterops conspicillatus conspicillatus*; believed extirpated). Two species of fruit bats, the Mariana fruit bat or flying fox, and the little Mariana fruit bat (*Pteropus tokudae*), are also listed, the Mariana fruit bat as threatened and the little Mariana fruit bat as endangered, although the little Mariana fruit bat is possibly extinct. Overhunting was the most likely cause of historical declines for the fruit bats on Guam; habitat loss and predation by brown treesnakes are considered the key

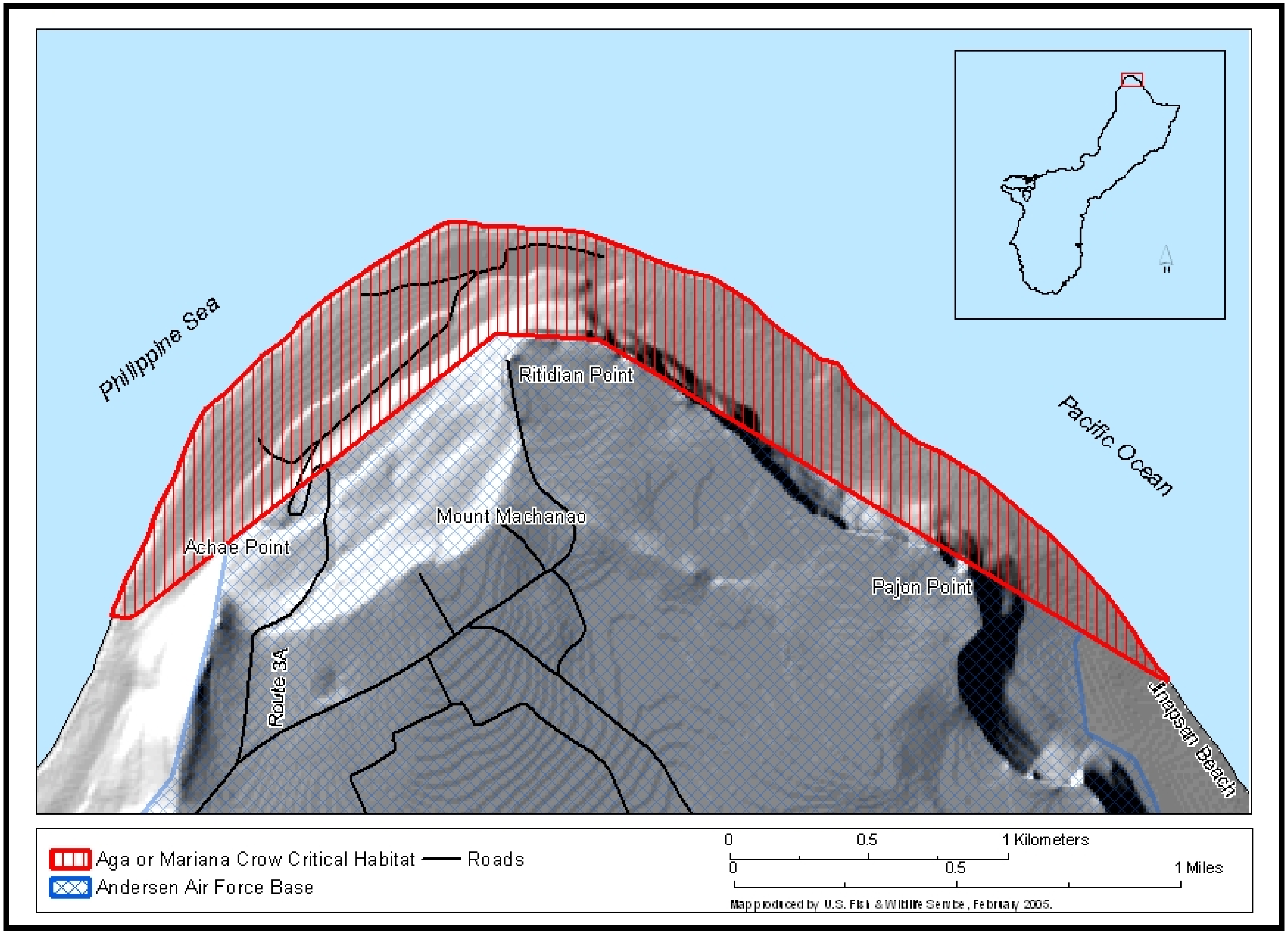

Figure 11. Designated critical habitat for aga, Territory of Guam.

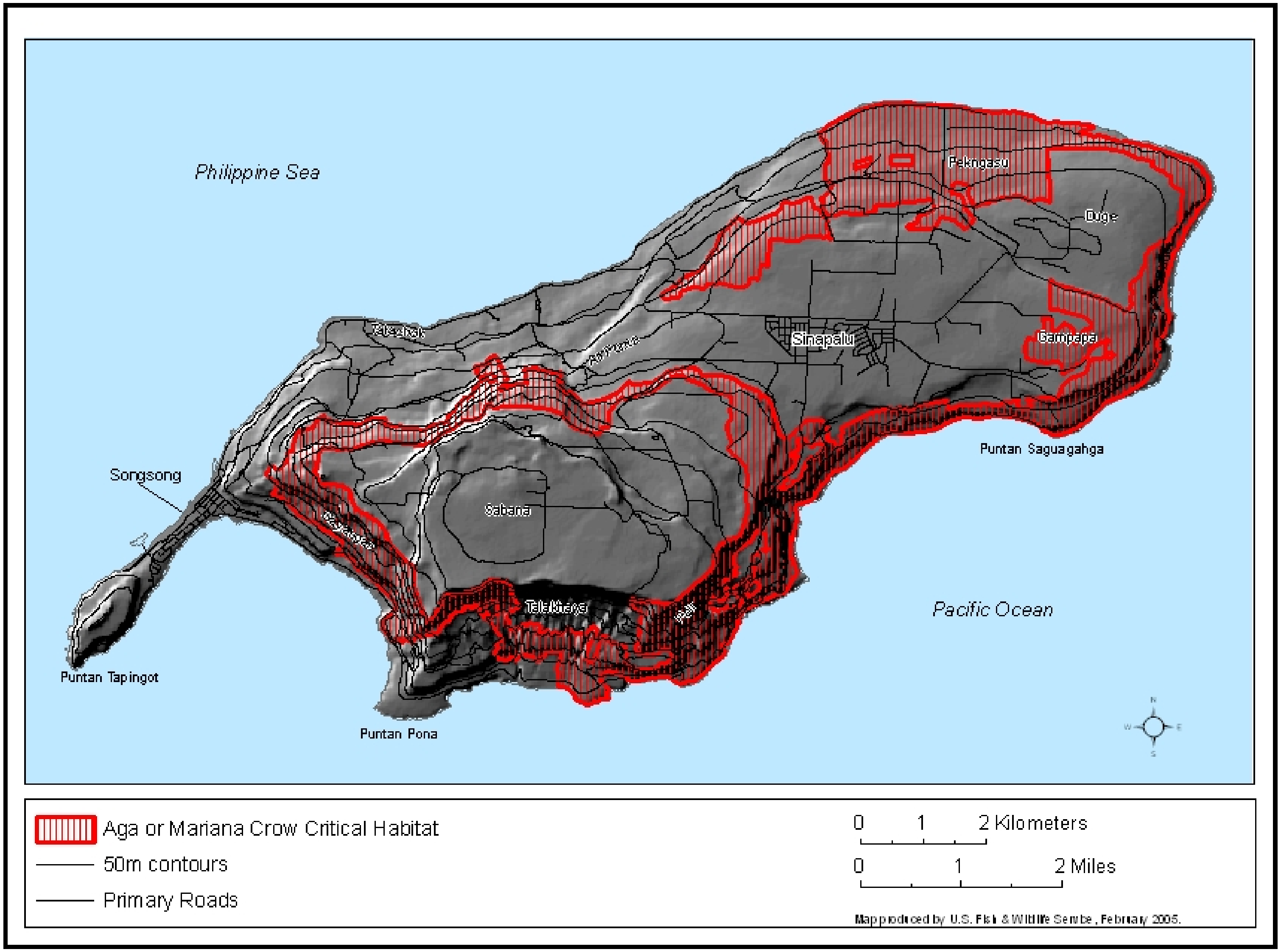

Figure 12. Designated critical habitat for aga, Island of Rota, Commonwealth of the Northern Mariana Islands.

threats to the Mariana fruit bat on Guama today (USFWS 2005). One tree species, *Serianthes nelsonii*, is listed as endangered. Browsing by introduced ungulates and infestation by herbivorous insects are the most likely factors in the decline of *Serianthes nelsonii* (USFWS 1987).

The island of Rota supported 10 species of native forest birds historically. Besides the aga, five other species of birds are listed as endangered: the Rota bridled white-eye, Guam rail (an introduced, experimental non-essential population), Mariana common moorhen, Mariana swiftlet (believed extirpated), and Micronesian megapode (believed extirpated). Of great concern is a recent study indicating that between the years 1982 and 2004, seven out of eight species of terrestrial birds on Rota showed significant declines in abundance, and five of these species had declined by more than 50 percent over that time period (Amar *et al*., in review; Table 4). Only one species, the Micronesian starling, had increased in abundance. Rota has not been impacted by the introduction of brown treesnakes, as on Guam, and the possible reason for such widespread avian declines on Rota is unknown. These pronounced negative trends indicate the immediate need for research on Rota to determine their root cause and to inform management actions that will prevent further extirpations or extinctions of the island's native avifauna.

In addition to listed bird species, the Mariana fruit bat is listed as threatened on Rota and the remainder of the Commonwealth of the Northern Mariana Islands. Overhunting and habitat loss are considered the key threats to this species on Rota (USFWS 2005). Three species of plants, *Serianthes nelsonii*, *Nesogenes rotensis*, and *Osmoxylon mariannense*, are also listed as endangered on Rota. Browsing by feral ungulates, habitat disturbance, and herbivorous insect infestations are thought to be factors in the decline of these three species (USFWS 1987, 2004b).

I. Conservation Efforts

Since the aga was listed in 1984, a wide range of recovery efforts have been implemented on both Rota and Guam. These efforts have included habitat restoration and protection, predator management and removal, captive propagation and translocation, research, and public outreach.

1. Habitat Restoration and Protection

a) Rota. The island of Rota is significantly less developed than Guam. Most of the land on Rota is publicly held in trust for people of island descent, and pressure to lease lands to foreign investors for economic development has waxed and waned since 1990, depending on the Asian economy. One resort has been established on Rota (The Rota Resort) and further development for resort properties has been proposed. In addition, 130 hectares (321 acres) of public lands have been permitted

Table 4. Long-term trends in the number of individuals counted per station along transects on the island of Rota between 1982 and 2004. Results based on generalized linear mixed models; all results significant at $P < 0.0001$. From Amar *et al*., in review.

Species		Change in abundance	Native (N) or Introduced (I)
Aga	*Corvus kubaryi*	-94%	N
Micronesian starling	*Aplonis opaca*	+54%	N
Black drongo	*Dicrurus macrocercus*	-30%	I
Micronesian honeyeater	*Myzomela rubratra*	-77%	N
Rufous fantail	*Rhipidura rufifrons*	-64%	N
Collared kingfisher	*Halcyon chloris*	-28%	N
Mariana fruit-dove	*Ptilinopus roseicapilla*	-72%	N
Philippine turtle-dove	*Streptopelia bitorquata*	-52%	I

or are scheduled to be permitted to Rotanese as part of the Agricultural Homestead Program.

There are four conservation areas on Rota (Figure 4). I Chenchon Bird Sanctuary (251 hectares [620 acres]) is a narrow strip of excellent aga breeding habitat (Morton *et al.* 1999) located along the southeast coast. The Sabana Conservation Area (1,472 hectares [3,637 acres]) is a multiple use area and the largest of the preserves located in the west central part of Rota; it offers good aga habitat at lower elevations and contains most of the significant Rota bridled white-eye habitat (Amidon 2000; Fancy and Snetsinger 2001). Taipingot Conservation Area (118 hectares [292 acres]) occupies the tip of the Liyo Peninsula on the southwest side of Rota. This area contains some good quality habitat, but aga have not been known to occupy the region. Coral Gardens Reserve, located at the eastern edge of the Sasanyaya Bay (63 hectares [156 acres]) is a marine sanctuary and provides no habitat for aga.

Efforts to establish an island-wide habitat conservation plan began in 1994, including plans to protect essential aga habitat. The habitat conservation plan process was initiated by the planned development of agricultural homestead sites in the Gampapa and Duge regions. These areas both contain aga breeding and foraging habitat. The island-wide habitat conservation plan was not completed; however, a habitat conservation plan specifically for the agricultural homestead sites is currently being considered. The Marianas Public Land Authority will apply for a section 10 (of the Endangered Species Act) permit, and has formally requested our assistance to develop a habitat conservation plan for these homestead sites. We awarded a grant to the Commonwealth of the Northern Mariana Islands in September 2002 for planning assistance on the homestead habitat conservation plan. In addition to the agricultural homesteads, the Historic Preservation Office of the Commonwealth of the Northern Mariana Islands government and the Mayor of Rota may apply for a separate section 10 permit to address development of the Mochong area as a cultural interpretive center for the island. The Mochong area contains aga habitat and three breeding pairs of aga.

b) Guam. Both northern and southern Guam maintain large tracts of forested lands that have been protected from development, agriculture, and public access since World War II as parts of Andersen Air Force Base and COMNAVMARIANAS (Commander Naval Forces Mariana Islands) (Figure 6). The latter includes the Communications Annex in northern Guam, and the Waterfront Annex (known as "Big Navy") and Ordnance Annex in southern Guam. Andersen Air Force Base and the Communications Annex contain large tracts of some of the best remaining limestone forest on northern Guam and are the sites of the extant aga population. The Munitions Storage Area, the hack site for recent aga translocations from Rota, and Area 50, the release site for captive-bred Guam rails, are both on Andersen Air Force Base. The Ordnance Annex contains excellent riparian forests in the watershed above the Fena Reservoir and, in particular, a *Merrilliodendron megacarpum* (faniok) forest near the base of Mount Almagosa.

In 1993, the U.S. Navy, U.S. Air Force, and U.S. Fish and Wildlife Service entered into a Memorandum of Understanding to create the Guam National Wildlife Refuge. As per the terms of that Memorandum, the two military branches entered into cooperative agreements with us to designate Department of Defense lands as overlay units of the refuge[4]. The Guam National Wildlife Refuge encompasses approximately 9,300 hectares (22,980 acres) of land owned by the U.S. Navy and U.S. Air Force. The cooperative agreements define the management and administrative roles and responsibilities of the two military branches and our agency. The primary use of the military lands designated as refuge overlay units is to meet the military mission of national defense.

[4] An "overlay refuge" refers to lands that are managed as a National Wildlife Refuge by the U.S. Fish and Wildlife Service, but that remain in the ownership of another party. In this case, most of the area designated as the Guam National Wildlife Refuge "overlays" lands administered by the U.S. Air Force and U.S. Navy.

Within the Guam National Wildlife Refuge, the U.S. Navy and U.S. Air Force have designated areas for special management consideration. These include the 281 hectare (694 acre) Pati Point Natural Area on Andersen Air Force Base that contains the primary roost site of the threatened Mariana fruit bat on Guam (Wiles *et al.* 1995) and maintained a nesting aga pair in 1994 (Morton 1996). The U.S. Navy has designated two Ecological Reserve Areas that include both terrestrial and marine habitats. The Haputo Ecological Reserve at the Communications Annex, Finnegayan includes 12 hectares (30 acres) of native limestone forest, and the Orote Peninsula Ecological Reserve at the Waterfront Annex includes 12 hectares (30 acres) of native limestone forest. On the Ordnance Annex, the Navy has established "No Disturbance" areas with respect to military training around Mount Almagosa (due to the unusual flora surrounding it) and Mahlac Cave (due to the presence of a Guam swiftlet colony) (U.S. Navy 2001).

Additionally, the Government of Guam has established four reserves (1,700 hectares [4,200 acres] total) for habitat protection (Figure 6). The Anao and Y-Pigua Conservation areas are located in the north and the Cotal and Bolanos Conservation areas are located in the south. These lands are under the jurisdiction of the Chamorro Land Trust Commission of the Government of Guam, an agency charged with supplying land to indigenous people. The Commission has the authority to change the status of these lands at any time.

2. Feral Ungulate Management and Removal

To date, there has been no large-scale control or removal of ungulates on Rota and Guam. Several attempts have been made to completely remove resident deer and feral pigs from Area 50, a 24-hectare (59-acre) patch of limestone forest surrounded by a chain-link fence on Andersen Air Force Base on Guam, but these have been unsuccessful (D. Vice, Guam Division of Aquatic and Wildlife Resources, pers. comm. 2002).

The U.S. Navy, in cooperation with the U.S. Fish and Wildlife Service and the Guam Division of Aquatic and Wildlife Resources, has been working to reduce the carabao (water buffalo) population on the Ordnance Annex in southern Guam. In 1996, they implemented an immunocontraception program to reduce the number of carabao and thereby reduce habitat degradation and erosion caused by the carabao population (U.S. Navy 2001). Currently the Navy is using immunocontraception along with the capture and relocation of young carabao and culling of adult carabao in a three-pronged approach to reduce the population. Over the last 2 years it is estimated that these efforts have reduced the carabao population on the Ordnance Annex by 60 percent (R. Wescom, U.S. Navy, pers. comm. 2004).

3. Predator Management and Removal

The management and removal of predators has primarily focused on control of brown treesnakes. These efforts have focused on preventing the introduction of brown treesnakes outside of Guam and on controlling brown treesnakes on Guam. Control of introduced animals such as rats, cats, and black drongos on Guam and Rota has received little attention to date.

a) Control of Brown Treesnakes in Transportation.

Keeping snakes out of the transportation network (cargo, cargo facilities, trucks moving cargo, ships, and planes traveling to Rota) is the baseline requirement for protecting the aga on Rota and was identified as a priority 1 recovery action in the 1990 recovery plan for this species (USFWS 1990). At present, snake interdiction in transportation facilities on Guam is the exclusive responsibility of the U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS) Wildlife Services, a Federal agency that is contracted to conduct snake control for the benefit of all United States lands (especially those affected by interstate transport; *e.g.*, Hawai`i and the Commonwealth of the Northern Mariana Islands). Rota is one beneficiary of this program, which is jointly funded by the Department of Defense and the Department of the Interior's Office of Insular Affairs. Since the brown treesnake threat was identified, a wide variety of techniques, including snake traps, barriers, snake detection dogs, and toxicants, has been developed for controlling brown treesnakes in transportation (see Appendix 5). Historically, visual searches, traps, and dog-aided searches have formed the backbone of Wildlife Services operations, although barriers and toxicants are being implemented. Prey reduction has been conducted in warehouses and at other key facilities throughout the program.

An effective snake control program for aga conservation also requires focused control efforts on Rota. A brown treesnake enclosure was built at the Rota port to hold cargo from Guam overnight to allow detection and capture of any snakes that might be present. This barrier has been taken down and a second barrier is planned to take its place. A snake detector-dog program is also expected to be implemented on Rota and plans are underway to build a new snake barrier around the cargo port. In addition, the following measures have been proposed (and implemented to some extent) for Rota: 1) increase inspection of cargo departing from Guam to Rota, especially by shippers that choose not to notify Wildlife Services; 2) expand the Rota barrier in off-loading areas; and 3) quarantine all high-risk cargo in the Rota port barrier. Unfortunately, funding, logistical, and personnel problems continue to plague control efforts on Rota. There have also been a series of problems with the operation of the Rota port snake enclosure which have compromised its effectiveness.

One favorable attribute of interdiction in transportation facilities is that *any* reduction in snake presence is beneficial. In contrast to snake reduction in aga habitat on Guam (which will be considered successful only if it reduces snake density to a level at which the aga populations can be sustained or increase), any incremental reduction in the number of snakes in transportation improves the chances that another year will pass without brown treesnakes colonizing Rota.

It is believed that the existing control efforts and techniques have achieved some success in reducing snake dispersal from Guam to Rota (BTSCC 1996). The efficacy of these efforts and their benefits relative to their costs have not been documented. Regardless of the efficacy of control in transportation, preventing the spread of brown treesnakes from Guam to other islands will be more cost effective than attempting control of the snake once it reaches another island (see Control for Endangered Species Conservation, below). Tools for enhancement of brown treesnake management efforts are suggested in sections of this plan, detailed in Appendix 5, and are also described in several publications provided in the references section of this document (BTSCC 1996; Rodda *et al.* 1998b; U.S. Department of Interior, Office of Insular Affairs 1997; Glass 2000).

b) Control of Brown Treesnakes for Endangered Species Conservation. Many of the techniques for control of brown treesnakes that have been developed are applicable to endangered species conservation efforts on Guam. Of the techniques available, the two most commonly utilized methods of control include snake trapping and snake exclusion barriers. Each of these techniques has their drawbacks (see Appendix 5 for details) but their application in endangered species conservation efforts has shown some success.

i. Large-scale brown treesnake trapping There have been several attempts to determine the effectiveness of trapping snakes out of large areas. Recently, trapping was attempted in a 42-hectare (104-acre) area of the Munitions Storage Area (approximately 580 hectares [1,433 acres]) on Andersen Air Force Base. Increasing numbers of traps have been set up in the Munitions Storage Area and trapping has occurred since 2000. The number of snakes captured declined rapidly, but snake capture continues. This is presumably due to immigration of snakes into the area or some other factor. There has also been ongoing trapping on the Ordnance Annex to protect swiftlets. Swiftlet numbers have increased since the trapping was begun.

ii. Electrical Barriers On Aga Nest Trees. Low-cost success has been reported in achieving brown treesnake control goals within individual nest trees. Electric and physical barrier construction, vegetation modification, and other nest protection techniques applied to aga nest trees were first used during the 1991 breeding season and continued over a 5-year study period (Aguon *et al.* 1999). Now known as the Aguon barrier, these electrical and hardware cloth barriers did not harm nest trees, successfully protected five of nine nests against predation beyond the incubation period, and resulted in production of three fledglings (Aguon *et al.* 1999, 2002). The barriers, which include the placement of snake traps in the nest tree, were also shown to reduce snake densities to very low values (Aguon *et al.* 1999). Despite the development of such egg protection techniques, fledging success remains poor, but because so few nests remain, few hypotheses have been adequately tested to determine the underlying reasons and results are inconclusive (NRC 1997).

There have also been some concerns raised regarding the large scale application of this technique. The largest cost in applying this technique is the labor costs associated with monitoring nesting aga to determine when to install the barrier. The costs will become prohibitive as the number of pairs of aga nesting on Guam increases through the recovery process. In addition, some trees cannot be barriered because of their architecture (*e.g.*, some fig trees have multiple trunks), extensive vegetative connections to the canopy of adjacent trees, or inaccessible location. Therefore, this technique may not be used on all aga nests.

iii. Landscape barriers. Permanent snake barriers could be used for endangered species conservation by preventing the immigration of snakes into snake-free areas. Currently, there has been only one attempt at using a barrier around a large area for conservation. A cyclone fence around Area 50, a 24-hectare (59 acre) limestone forest area in Northwest Field on Andersen Air Force Base, was retrofitted with a snake exclusion barrier in 1998 and the area was trapped for snakes. Results from this experiment suggest a substantial and sustained reduction in the number of snakes. Snake captures have continued at a low level, however, suggesting some possible combination of penetration of the barrier and/or the continuing presence of snakes that elude or avoid the traps. Unfortunately, the barrier utilized for the fence was not designed for long-term fence use and was not built to specifications. Therefore, some of the barrier's problems may be related to design issues. Currently there are plans underway for a large masonry barrier around the Munitions Storage Area and plans for a test version of this barrier around Area 50. The results of these experiments should provide the much-needed data to determine if trapping in conjunction with snake barriers is an effective conservation control.

c) Other Predators. Aga on the island of Rota experience significant predation effects despite the absence of brown treesnakes. For the 1998 breeding season, 44 percent of all aga nests failed due to predation, potentially by rats, monitor lizards, cats, or even other aga (Morton *et al.* 1999). Rat abundance on Rota does not seem to follow seasonal trends (Morton *et al.* 1999). Control measures to alleviate rat predation pressure and quantify rat density by habitat type may be important to future conservation of Rota and Guam aga. Registration of a rodenticide suitable for conservation uses is urgently needed for the Mariana Islands, and should be expedited for aga recovery. Monitor lizards and feral cats are also found on Rota, and may be significant predators. Control of these predators is possible with existing technology, but feasibility studies are needed to establish their cost-effectiveness. Black drongo control techniques have not been demonstrated; preliminary control attempts indicated that drongos have high aptitude for evading routine control measures (Lusk 1994; C. Kessler, USFWS, pers. comm. 2002). Further development of black drongo control methodologies is warranted.

3. Captive Propagation and Translocation

Despite efforts to control the brown treesnake on Guam during the 1990's, the aga population there continued to decline. Egg survivorship increased in snake-protected nests, but the advanced age of the remaining breeding pairs was apparently a problem, as only 1 of 12 eggs produced in 1994 to 1995 was fertile. Now that the native Guam aga are all gone, the restoration of a viable population of aga on Guam is entirely reliant upon the successful translocation or captive propagation of aga originating from Rota and an increase in effective area-wide control of brown treesnakes.

In 1993, the Marianas Archipelago and Rescue Survery Project was initiated to develop techniques for the capture, acclimation, transport, and propagation of aga, Rota bridled white-eyes, and Mariana fruit doves (*Ptilinopus roseicaplilla*). Participants in this program included the Philadelphia Zoological Garden, Houston Zoological Gardens, National Zoological Park, Louisville Zoological Garden, Memphis Zoological Garden and Aquarium, Honolulu Zoo, and North Carolina Zoological Park. As part of the project, 10 aga were captured on Rota between 1993 and 1995 and shipped to the National Zoological Park Conservation and Research Center in Front Royal, Virginia (4 pairs), and 1 pair was shipped to the Houston Zoo in Texas. During the 1994 to 1995 breeding season, the pair at the Houston Zoo produced two offspring, only one of which survived to adulthood. At the National Zoological Park, two pairs of aga nested; however, the first pair destroyed their clutch, and the eggs of the second pair were infertile. During the 1995 to 1996 breeding season, the Houston Zoo pair produced several clutches. The first clutch, consisting of three eggs, resulted in two destroyed eggs and one missing chick, presumably eaten by the parents. The eggs in the remaining clutches were either destroyed or disappeared.

In 1997, six of the aga from the mainland zoos were released on Guam based on the recommendation of the National Research Council (NRC 1997), and three remain in captivity (two at the Houston Zoo and one at the National Zoological Park Conservation and Research Center). The Houston Zoo pair continued producing unsuccessful clutches during the 1996 to 1997 and 1997 to 1998 breeding seasons, and laid no eggs during the 1998 to 1999 and 1999 to 2000 breeding seasons. During the 2000 to 2001 breeding season the Houston Zoo pair produced one fertile egg that was subsequently crushed on the day it was due to hatch.

In addition to these efforts, the Guam Division of Aquatic and Wildlife Resources implemented a small-scale aviculture intervention plan in 1994. The plan involved removing one egg out of each nest, artificially incubating the eggs, hand rearing the chicks, and returning the chicks early to the nest. The idea was to avoid predation of the eggs by brown treesnakes, but still allow for parent rearing of the chicks. After varying degrees of success in several trials, the Guam Division of Aquatic and Wildlife Resources concluded that the longer the egg was naturally incubated by its parents in the wild, the higher the survival rate, and a new approach to population augmentation was attempted.

In 1995, the Guam Division of Aquatic and Wildlife Resources submitted a proposal to translocate a chick from the Rota population to Guam to aid in the social development of the captive-reared chicks. It was further suggested to move individual nestlings from Rota to Guam in order to supplement the declining Guam population. During the 1994 to 1995 and 1995 to 1996 breeding seasons, the Guam Division of Aquatic and Wildlife Resources pulled 21 eggs from 12 clutches produced by active pairs on Guam. Of the 21 eggs, only 7 (33 percent) were fertile; 4 of these hatched in captivity. Two chicks successfully fledged, one nestling was malpositioned in the egg and died within 12 hours of hatching, and the fourth nestling was returned to the nest 2 days after hatching, but was found dead 2 days later. The necropsy report indicated the fourth chick was in very good medical health and the cause of death was most likely due to falling from the nest (K. Brock, formerly of Guam Division of Aquatic and Wildlife Resources, unpubl. data).

No nestlings or eggs were collected in 1997, however, eight captive aga were released into the wild on Guam.

Six of the individuals were captive pairs from Rota released from mainland zoos, while two were Guam aga, hand-raised at the Guam Division of Aquatic and Wildlife Resources aviculture facility. Five of the original eight from Rota cannot be located and are presumed dead (although some survived for several years), and three died within 13 to 219 days of release (Appendix 2).

In the 1997 to 1998 breeding season, a total of nine nests were located on Guam and three eggs were collected from two different clutches from the same breeding pair. These eggs proved inviable. Eggs in two other nests (without snake barriers) were predated and no offspring were produced for the second year in a row (Aguon 1997; Aguon and Henderson 1998). In the 1998 to 1999 breeding season, three pairs of aga (including two females of Rota origin) produced a total of six nests on Guam. However, only one pair produced an egg that later disappeared and all other nests were abandoned (Aguon and Henderson 1998; Aguon 1999a).

On January 7, 1999, and April 29, 1999, two chicks (named Una and Segundo) were taken from wild nests on Rota and transferred to Guam in order to augment the Guam population. At the time of transfer, the chicks were 17 and 21 days old. The chicks were hand-raised at the Guam Division of Aquatic and Wildlife Resources facility and were released after 4 months. They were kept in a hack box for 7 days prior to their release. One died 3 days after release, apparently due to asphyxiation, and the second died 10 days later of hepatitis.

In September 2000, seven aga were translocated from Rota to Guam and released in the Munitions Storage Area on Andersen Air Force Base. Of these seven, five were hand-reared juveniles, one was a wild juvenile, and one was a wild adult male. In May 2001, five more hand-reared aga were released in the same area, and another four were released in September 2003. As of January 2004, 10 of the aga from these releases continue to survive on Guam (Appendix 2).

4. Research

Since the aga was listed in 1984, some research has been conducted on the behavior and breeding biology of this species (*e.g.*, Tomback 1986; Michael 1987; Lusk and Taisacan 1996; Morton *et al.* 1999) as well as its threats (Grue 1985; Savidge 1987; Morton 1996). Research has also been done on the genetic variability and population differentiation of the aga on Rota and Guam (Tarr and Fleischer 1999). Extensive survey work has been done by the Guam Division of Aquatic and Wildlife Resources and the Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife, as well as the U.S. Fish and Wildlife Service, on both Rota and Guam. Currently, there are plans for a Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife biologist to work on aga nest predator identification and control as well as other aspects of aga biology. The Guam Department of Aquatic and Wildlife Resources is also continuing their research on the reproductive biology of aga on both Guam and Rota.

5. Public Outreach

A wide variety of outreach activities have been implemented by the Guam Division of Aquatic and Wildlife Resources and Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife that have focused on the conservation of native species and raising public awareness about brown treesnakes. All of these efforts directly or indirectly support aga conservation efforts. Outreach activities include wildlife posters, wildlife factsheets, curricula and presentations for school children, and public service announcements and newspaper articles. An informative video called “Rota- Our Island, Our Future” was also produced as part of the efforts to develop an island-wide habitat conservation plan on Rota. In 1999, the RARE program (“rare animal relief effort”) was also started on Rota. This community outreach program focused on the conservation of the Mariana fruit dove, but also covered basic conservation concepts that are applicable to the aga.

II. RECOVERY

A. Strategy

There are four essential elements to aga recovery. No element is more important than another, and all must be implemented for recovery to be achieved. These four elements are:

1. Provide the infrastructure necessary to achieve recovery;
2. Implement a habitat management program;
3. Implement an integrated program to identify and reduce limiting factors on Rota and Guam; and
4. Monitor, protect, and restore aga populations on both Rota and Guam.

B. Objectives

One of the primary goals of this recovery plan is to establish at least three viable, self-sustaining subpopulations of aga in the wild, two on Guam and one on Rota. In addition, the recovery program includes active research, habitat management, predator control, translocation, population monitoring, and community involvement. Currently, our emphasis is to: 1) maintain a stable or increasing population on Rota through habitat protection and predator reduction while conducting extensive research to identify and improve management tools; 2) evaluate the restoration potential of aga on northern Guam by detailed monitoring of translocations; and 3) prepare for full-scale restoration on Guam by developing area-wide predator control techniques. These primary components are laid out in detail in the recovery action outline and narrative that follows (Section III).

C. Recovery Criteria

In order to downlist (reclassify a species from endangered to threatened) or delist a listed species, we must go through a formal rulemaking process. The recovery criteria set forth in a recovery plan are intended to serve as objective, measurable guidelines to assist us in determining when a listed species has recovered to the point that the protections afforded by the Endangered Species Act are no longer necessary and such action may be warranted. In order to downlist or delist a species, we must first demonstrate that the threats to the species, as identified in the original "five factor analysis" [5] during the listing process, have been sufficiently controlled or eliminated. The recovery criteria presented here describe the conditions under which we believe such an analysis would lead to a subsequent regulatory rulemaking to downlist or delist the species.

The recovery criteria for downlisting and delisting the aga are based on reaching population goals to ensure long-term viability and removing or reducing the known threats to the species, as discussed earlier in this plan. However, new threats may arise as recovery efforts continue. These new threats will need to be monitored and addressed appropriately. If these new threats should become significant, the recovery criteria below will need to be revised to address these threats.

The population goals for the aga are to establish at least 3 stable populations consisting of a minimum of 75 territorial pairs at each of 3 sites: Rota, northern Guam, and southern Guam. These areas were selected because we believe it is unlikely that all three areas would simultaneously suffer the brunt of a major cyclonic event, disease outbreak, or other stochastic catastrophe. We also considered other Mariana Islands outside of the aga's historical range (Rota and Guam), but found them unsuitable as recovery areas for 3 reasons: 1) all are small (less than 720 hectares [1,779 acres]) or would support at most 40 breeding pairs; 2) all are inhabited by other smaller birds, reptiles, and invertebrates that might be impacted by the introduced aga; and 3) expansion of aga distribution beyond the historical range is undesirable. If,

[5] As described earlier, these five factors are:

A – the present or threatened destruction, modification, of curtailment of its habitat or range;

B - overutilization for commercial, recreational, scientific, or educational purposes;

C - disease or predation;

D – the inadequacy of existing regulatory mechanisms; and

E - other natural or manmade factors affecting its continued existence.

however, aga populations decline and limiting factors cannot be controlled on Guam and Rota, then these islands, mainland zoos, and other captive propagation centers may be considered suitable as short-term recovery areas.

The number of territorial pairs needed for each population was developed using a subjective method reliant on expert opinion. Three factors reinforce the sufficiency of this criterion: 1) long-lived, territorial birds, such as the aga, are characterized by stable numbers of breeders; thus abundance would not be expected to decline quickly or unexpectedly; 2) Rota and northern and southern Guam are relatively small areas that cannot support populations of aga much greater than this; and 3) obtaining a total population of 225 territorial pairs (our requirement for delisting) would double the current known aga breeding population, thus ensuring that the aga population would be substantially safer than at present. However, it should be noted that due to the extremely low number of aga on Guam, the successful recovery of the aga is almost entirely reliant upon the maintenance of a viable aga population on Rota. Therefore, more than 75 territorial aga pairs, the current population criterion for Rota, may be needed on Rota to ensure the stability of this population and to support efforts to reestablish viable aga populations on Guam.

Finally, determining a population's stability is not exact. Population stability can be estimated from annual reproductive success and age-specific survivorship data collected over a sufficient period of time (for a current example, see Appendix 4). These parameters must be collected on a random sample of approximately 35 pairs in each subpopulation (half the total population) to be representative. Determining when annual counts indicate population stability requires standardized survey protocols (see Appendix 3).

Specific downlisting and delisting criteria should be revisited as more is learned about wild aga populations. In the interim, we believe the recovery criteria detailed below are suitable and useful for guiding conservation efforts.

1. Downlisting Criteria. The aga may be considered for downlisting from endangered to threatened status when all of the following criteria are met:

Criterion 1: Aga occur in 2 populations, 1 on Rota consisting of a minimum of 75 territorial pairs, and 1 in northern Guam consisting of a minimum of 75 territorial pairs;

Criterion 2: Both populations are stable or increasing based on quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0 over a period of at least 10 consecutive years;

Criterion 3: Sufficient aga habitat, based on quantitative estimates of territory and home range size, is protected and managed to achieve criteria 1 and 2 above (Recovery Actions 2.1, 2.2, 2.3, 3.3.2);

Criterion 4: Brown treesnakes and other introduced predators found to be a threat to aga are controlled at a sufficient level to achieve criteria 1 and 2 above (Recovery Actions 3.1.2, 3.3.1.1, 3.3.1.3);

Criterion 5: Brown treesnake interdiction efforts are in place to prevent the establishment of brown treesnakes on Rota (Recovery Actions 3.1.1.1 through 3.1.1.4); and

Criterion 6: Efforts to resolve aga and landowner conflicts have been implemented (Recovery Actions 1.2.1.2.1 through 1.2.1.2.4, 1.2.2.5).

2. Delisting Criteria. The aga may be removed from the Federal list of threatened and endangered species when all of the following criteria are met:

Criterion 1: Aga occur in 3 populations, 1 on Rota consisting of a minimum of 75 territorial pairs, 1 on northern Guam consisting of a minimum of 75 territorial pairs, and 1 in southern Guam consisting of a minimum of 75 territorial pairs;

Criterion 2: All 3 populations are stable or increasing based on quantitative surveys or demographic monitoring that demonstrates an average intrinsic growth rate (λ) not less than 1.0 over a period of at least 10 consecutive years;

Criterion 3: Sufficient aga habitat, based on quantitative estimates of territory and home range size, is protected and managed to achieve criteria 1 and 2 above (Recovery Actions 2.1, 2.2, 2.3, 3.3.2);

Criterion 4: Brown treesnakes and other introduced predators are controlled at a sufficient level to achieve criteria 1 and 2 above (Recovery Actions 3.1.2, 3.3.1.1, 3.3.1.3);

Criterion 5: Brown treesnake interdiction efforts are in place to prevent the establishment of brown treesnakes on Rota (Recovery Actions 3.1.1.1 through 3.1.1.4);

Criterion 6: Efforts to resolve aga and landowner conflicts have been implemented (Recovery Actions 1.2.1.2.1 through 1.2.1.2.4, 1.2.2.5); and

Criterion 7: A monitoring plan has been developed and is ready for implementation, to cover a minimum of 5 years post-delisting, to ensure the ongoing recovery of the species and the continuing effectiveness of management actions.

D. Recovery Zones

We have identified various recovery zones for the aga, which we define as those areas that will allow for the long-term survival and recovery of the species. Areas identified as recovery zones contain habitat that is potentially important for the recovery of aga from a biological evaluation standpoint only; these recovery zones are intended to help focus and guide recovery efforts to emphasize those areas with the greatest potential to achieve recovery, and convey no legal obligation on the part of any entity to manage their lands for aga recovery. Implementation of the actions identified in the Recovery Action Outline (Section III) within the recovery zones identified on each island will address the threats to the species and allow for the aga's stabilization, recovery, and, ultimately, delisting. Recovery zones should not be confused with designated critical habitat (p. 34).

We have identified multiple recovery zones on Rota (Figure 13), northern Guam (Figure 14), and southern Guam (Figure 15). The biological determination of the recovery zones was based on the aga's ecology, conservation needs, current and former distribution, and recovery criteria of protecting and establishing viable populations. Within each area, these recovery zones are further ranked into tiers, based on the quality of the aga habitat, proximity to other forest areas, and degree of human disturbance. As the overall purpose of recovery zones is to guide efforts to stabilize and recover the aga, the identified areas include lands that currently provide habitat for existing populations, currently unoccupied areas that contain suitable habitat to provide for expansion of existing populations, and the establishment of new populations.

1. Rota

The six sites of highest priority for aga recovery on Rota are: 1) from I Batko to Puntan Fina Atkos (Mochong Unit); 2) the I Chenchon Bird Sanctuary along the eastern coastline to Puntan Fina Atkos (I Chenchon Unit); 3) from Taiapu to Alaguan Bay Scenic Overlook (Palii Unit); 4) from Matpo to As Pupuenge (Gayaugan Unit); 5) the "Golf Course Study Block" (Golf Course Unit) (Morton *et al*. 1999); and 6) from Sailigai Hulo to Manananana (Uyulan Hulo Unit) (Figure 13). Currently, these areas contain contiguous tracts of important aga habitat that harbor approximately 54 pairs of breeding aga.

The forest within the Mochong area contains unique coastal atoll forest. The expansion of the I Chenchon Bird Sanctuary would increase protection of the high quality breeding habitat on the eastern coastline, thus contributing to the future maintenance of a self-sustaining population. Currently, this area is not proposed for development, and as such, protecting this land should be of high priority.

Of secondary priority are: 1) from Alaguan to Taksunok (Alaguan Unit); 2) from Pona to Taiapu (Talakhaya Unit); 3) between Puntan Malilok and Puntan Haina (Agatasi Unit); and 3) a corridor of forest in Isang connecting the Matpo-As Pupuengi refuge to the Sailigai Hulo to Manananana refuge (Isang Unit).

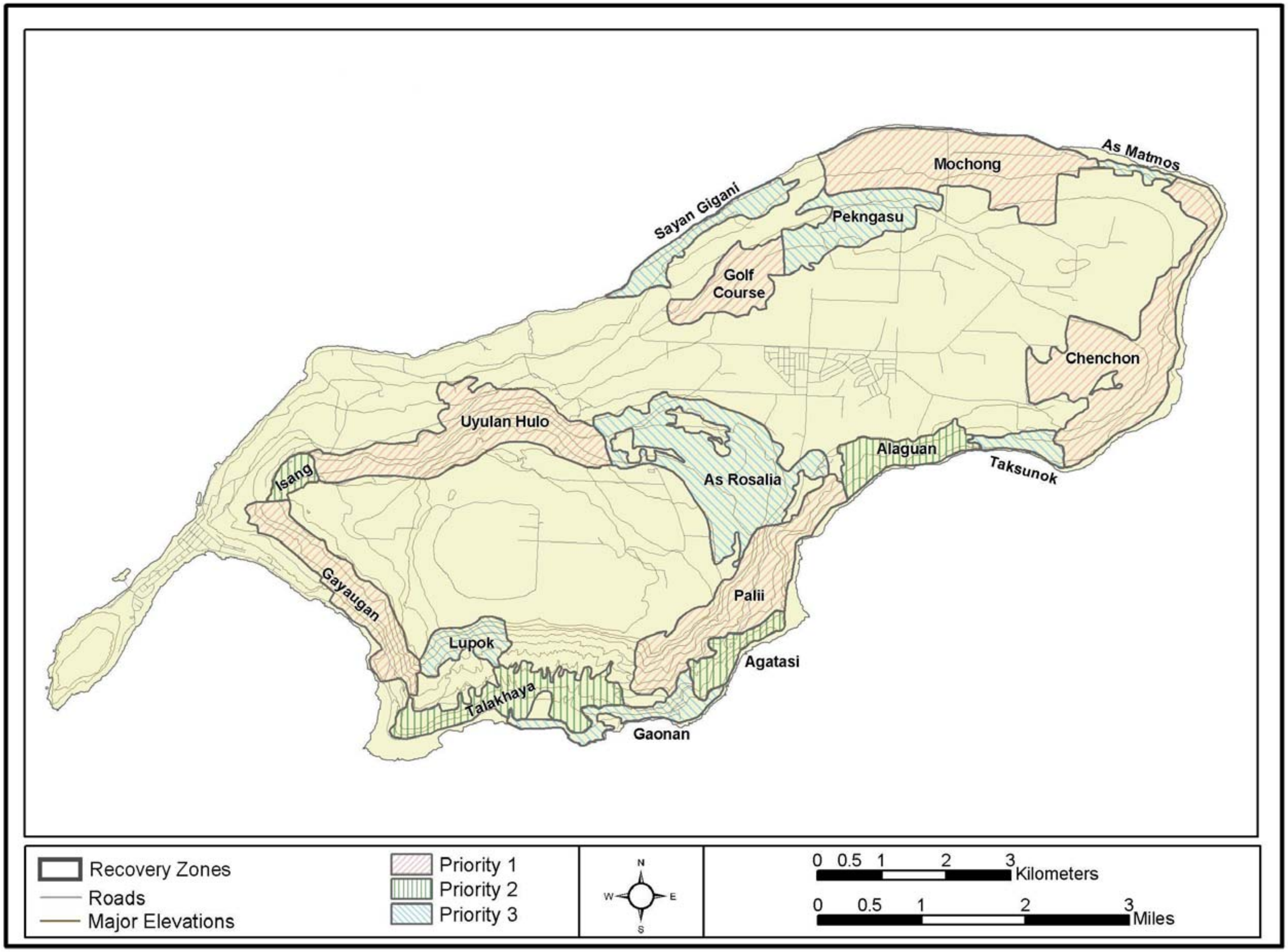

Figure 13. Aga recovery zones for the Island of Rota, Commonwealth of the Northern Mariana Islands.

Currently, these areas contain approximately five known breeding aga pairs and provide corridors between the high priority units. The carrying capacity of these areas could also be increased with appropriate habitat improvements.

Of tertiary priority are the forested areas connecting: 1) the Gayaugan and Talakhaya Units (Lupok Unit); 2) the Talakhaya, Palii, and Agatasi Units (Gaonan Unit); 3) the Alaguan and I Chenchon Units (Taksunok Unit); 4) the I Chenchon and Mochong Units (As Matmos Unit); 5) the Mochong and Golf Course Units (Pekngasu and Sayan Gigani Units); and 6) the Palii and Uyulan Hulo Units (as Rosalia Unit). Currently, these areas provide excellent travel corridors for aga between the various units and contain approximately 10 known breeding aga pairs. The carrying capacity of these areas could also be increased with appropriate habitat improvements.

2. Northern Guam

The highest priority sites for recovery of aga in northern Guam include the Tarague, Munitions Storage Area, and Lafac Units (Figure 14). Each of these units contains large, relatively undisturbed tracts of forest currently or historically utilized by aga and they are considered core areas for aga conservation in northern Guam. The Tarague Unit consists of mature and secondary limestone and strand forest and contains areas utilized by aga as recently as the 1990's. The Munitions Storage Area Unit is primarily composed of large tracts of mature and secondary limestone forest and contains the remaining aga population on Guam. The Lafac Unit is cliffline limestone forest and contains areas utilized by aga as recently as the early 1990's.

The secondary priority sites for recovery of aga include the Anao, Pipeline, Coconut plantation, and Finegayan Units. The Anao Unit contains relatively intact tracts of limestone forest and was utilized by aga as recently as the 1980's. However, development to the west is rapidly encroaching upon this area. The Pipeline Unit contains primarily secondary limestone forest that has been heavily disturbed. However, aga have utilized the area as recently as the1990's and with proper habitat management it would provide additional habitat to a recovering aga population. The Coconut Plantation Unit consists of large stands of coconut trees that were formally utilized for copra production. These coconut forests are not high quality aga breeding habitat but do provide good foraging habitat. The Finegayan Unit consists mostly of secondary forest with some mature limestone forest along the cliffiines. This area was utilized by aga as recently as the 1990's and with proper management could provide excellent habitat for an expanding aga population.

The lowest priority sites for aga recovery include the Pagat, Ague, Borrow Pit, and Northwest Field Units. Each of these areas is highly degraded

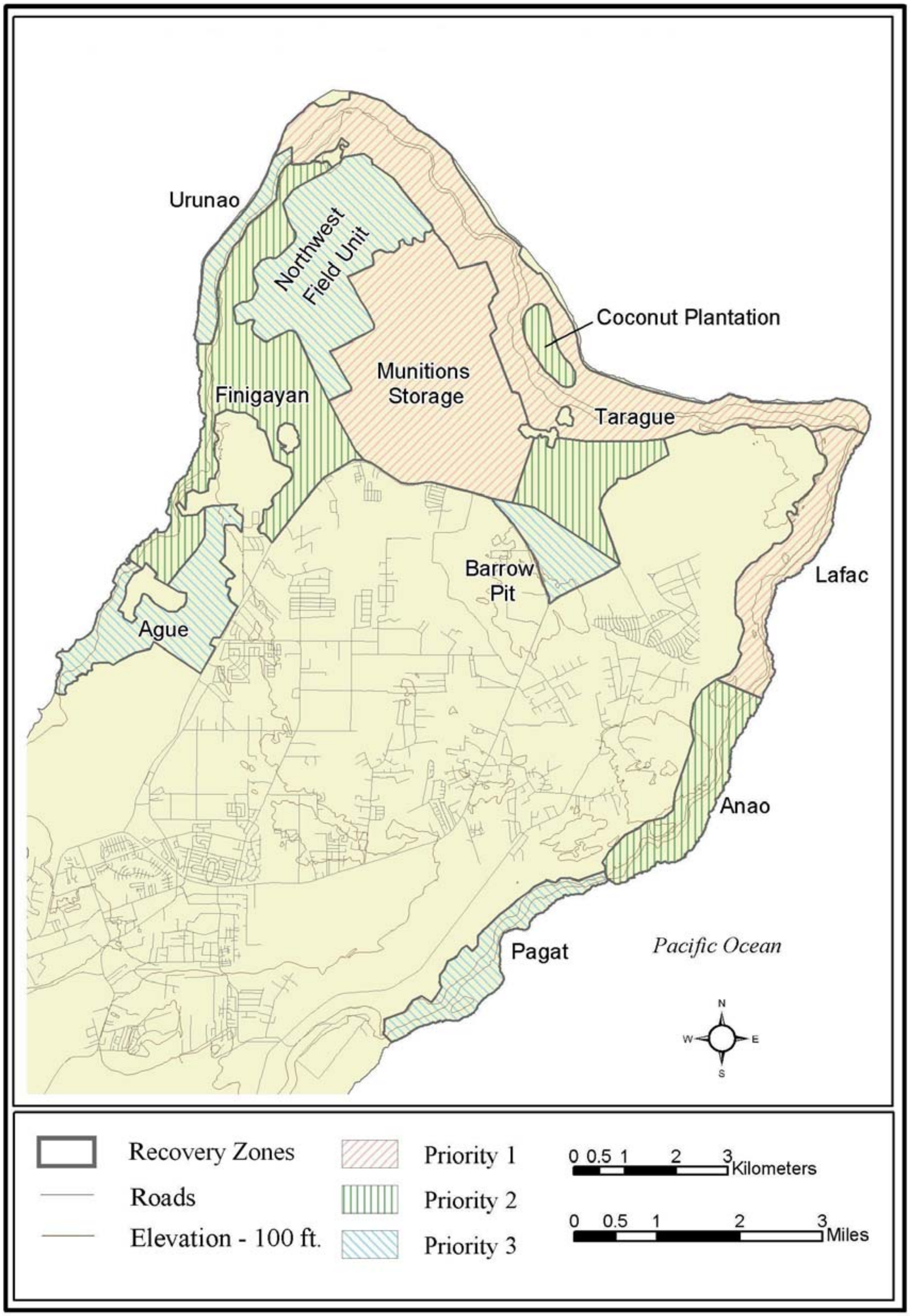

Figure 14. Aga recovery zones in northern Guam.

and primarily composed of secondary forest or other disturbed habitats that are not widely utilized by aga. However, these areas do contain some patches of good quality limestone forest and have recovery potential. With appropriate management and reforestation efforts, they would provide additional habitat for a recovering aga population in northern Guam.

3. Southern Guam

The highest priority sites for recovery of aga in southern Guam include the Almagosa, Ugum, and Talofofo Units (Figure 15). Each of these units contains large, relatively undisturbed tracts of forest that could be utilized by aga and are considered core areas for aga conservation in southern Guam. The Almagosa Unit consists of mature limestone forest and ravine forest and also contains the locations of the last known aga sightings in southern Guam in the 1960's. The Ugum Unit is primarily composed of relatively large tracts of ravine forest interspersed with agricultural lands and savanna. The Talofofo Unit is primarily ravine and wet forest interspersed with agricultural forest, savanna, and agricultural plots.

The secondary priority sites for recovery of aga include the Magazine, Umatac, Jalaojan, Ajayan, Tinechong, and Fena Units. Each of these sites contains some good quality forested habitat but they are either highly fragmented or are exposed to high levels of human disturbance. However, each of these areas provides connectivity between priority one sites and additional aga habitat that would be needed for recovery of aga in southern Guam.

The lowest priority sites for aga recovery include the Bolanos, Sinagoso, and Bubulao Units. Each of these areas is highly degraded and primarily composed of savanna or other disturbed habitats that are not widely utilized by aga. However, these areasdo have recovery potential; with appropriate management and reforestation efforts, they would provide additional habitat for aga recovery in southern Guam.

E. Recovery Actions

In this section we provide the outline and details for the actions required to accomplish each of the four broad elements comprising the aga recovery strategy. The Mariana Crow Recovery team's current assessment of priorities within these elements is provided in the Implementation Schedule that follows (Section III). The current priority areas include: 1) reduce the threat of brown treesnakes on Rota and Guam (Recovery Actions 3.1.1.1 through 3.1.1.4); 2) protect important habitat on Rota and Guam (Recovery Actions 2.1, 2.2.1, and 2.2.2); and 3) reestablish aga research on Rota led by an experienced scientist (Recovery Actions 1.1.1, 1.1.3, and 1.3) to determine the relative importance of limiting factors to survival and fecundity of aga on Rota (Recovery Actions 3.3.1.1, 3.3.1.3, and 3.3.2 through 5).

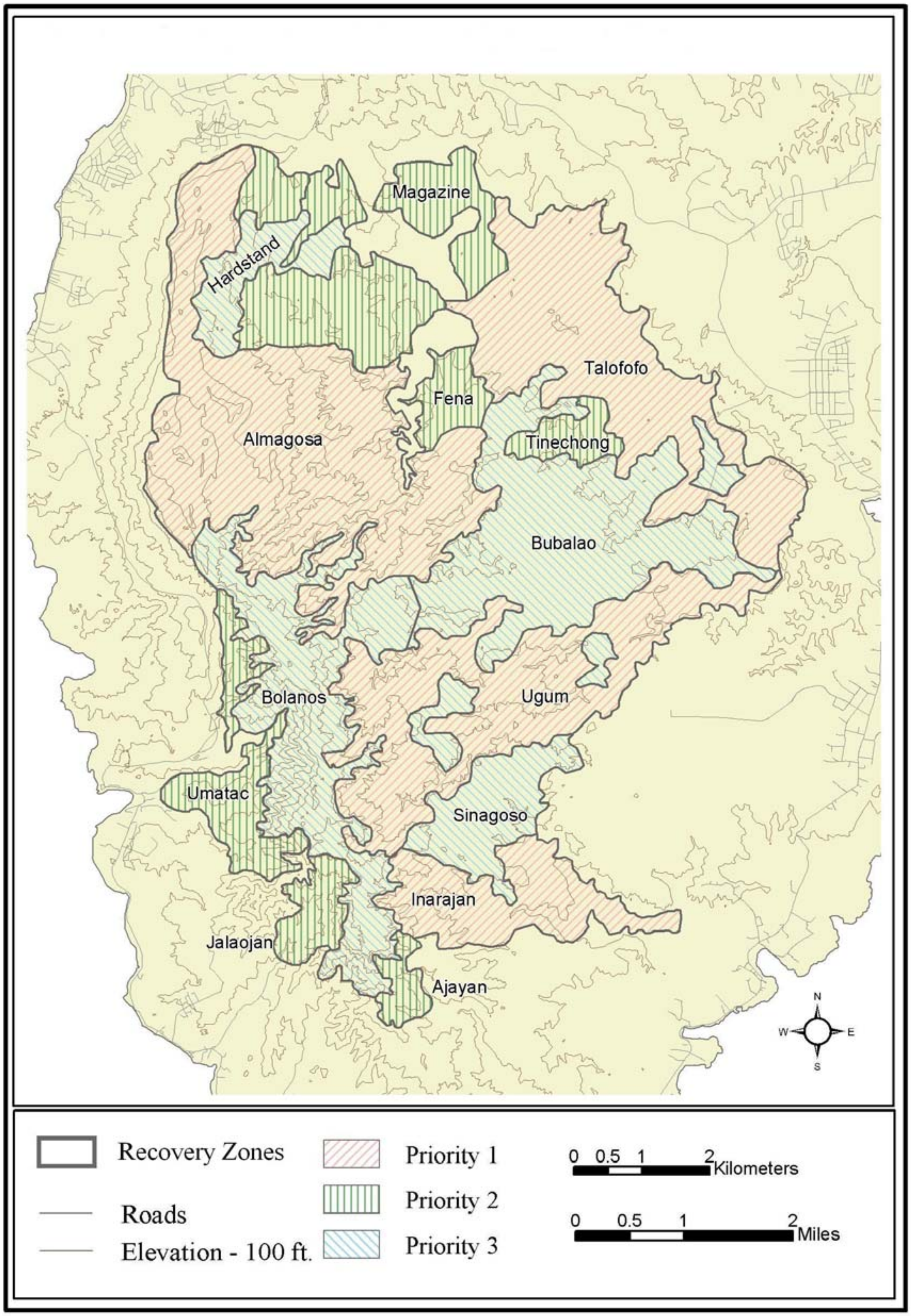

Figure 15. Aga recovery zones in southern Guam.

Step-Down Outline of Recovery Actions

1. Provide the infrastructure necessary to achieve recovery
    - 1.1 Maintain an active recovery team, as needed
        - 1.1.1 Oversee implementation of the recovery plan
        - 1.1.2 Coordinate recovery actions with other recovery and ecosystem management efforts
        - 1.1.3 Establish short-term (2 to 5 year) objectives for the recovery program, providing the rationale for each objective
        - 1.1.4 Periodically review the recovery plan and revise or update it as appropriate
        - 1.1.5 Establish and maintain an aga data center
    - 1.2 Engage stakeholders
        - 1.2.1 Plan for the specific information and involvement needs of stakeholders
            - 1.2.1.1 Engage agencies and recovery team members
            - 1.2.1.2 Engage people of Guam and Rota
                - 1.2.1.2.1 Interview and plan for information and involvement
                - 1.2.1.2.2 Address community organizations, island residents, schools, conservation groups, religious, cultural, and environmental groups
                - 1.2.1.2.3 Engage landowners and homesteaders
                - 1.2.1.2.4 Engage the legislature
        - 1.2.2 Establish interactions between the recovery team and other parties
            - 1.2.2.1 Increase funding agency interest in aga recovery
            - 1.2.2.2 Inform other recovery groups
            - 1.2.2.3 Develop partnerships with conservation groups
            - 1.2.2.4 Maintain respect for other management practices
            - 1.2.2.5 Develop relationships with landowners on Guam and Rota
                - 1.2.2.5.1 Consider safe harbor agreements
                - 1.2.2.5.2 Establish agreements that allow research to be conducted on lands that include aga habitat
                - 1.2.2.5.3 Establish an ambassador program
        - 1.2.3 Coordinate awareness and outreach efforts
    - 1.3 Hire a full-time experienced researcher dedicated to aga recovery on Rota
        - 1.3.1 Plan and conduct cooperative research at sites where aga exist on Rota and Guam
        - 1.3.2 Involve local residents in research to the extent practical
2. Implement a habitat management program
    - 2.1 Protect habitat in recovery zones on Rota

- 2.2 Maintain and/or protect habitat in recovery zones on Guam
  - 2.2.1 Maintain and/or protect habitat in recovery zones in northern Guam
  - 2.2.2 Maintain and/or protect habitat in recovery zones in southern Guam
- 2.3 Improve and manage habitat on Guam and Rota
  - 2.3.1 Minimize or eliminate ungulate impacts on aga habitat when appropriate
  - 2.3.2 Identify and eliminate invasive plant species
  - 2.3.3 Implement reforestation programs using native forest plant species to improve degraded areas within aga habitat
  - 2.3.4 Conduct vegetation assessments of all areas important to aga

3. Implement an integrated program to identify and reduce limiting factors on Rota and Guam
   - 3.1 Reduce brown treesnake threat
     - 3.1.1 Increase interdiction activities to stop brown treesnake movement to Rota
       - 3.1.1.1 Fund Wildlife Services to prioritize protection of Rota
       - 3.1.1.2 Reduce brown treesnake populations at ports and cargo holding areas on Guam
       - 3.1.1.3 Conduct research to increase detection of very small brown treesnake populations
       - 3.1.1.4 Initiate brown treesnake interdiction programs on Rota
     - 3.1.2 Control brown treesnakes over large areas on Guam
   - 3.2 Prevent establishment of new invasive predators on Rota
   - 3.3 Conduct essential research for effective management of wild aga
     - 3.3.1 Determine the importance of other predators on Guam and Rota and develop strategies and methods for their control
       - 3.3.1.1 Determine if rat control on Rota is necessary
       - 3.3.1.2 Pursue management registration of rodenticide
       - 3.3.1.3 Determine how black drongos affect aga
       - 3.3.1.4 Quantify the importance of human persecution of aga as a limiting factor
     - 3.3.2 Determine habitat use and requirements
       - 3.3.2.1 Determine if current habitat usage reflects factors limiting recovery
       - 3.3.2.2 Determine how size of territory varies with habitat quality (*i.e.*, vegetation characteristics and food resources) and what changes in habitat would likely lead to increased nesting density
     - 3.3.3 Collect demographic, breeding, and dispersal data
       - 3.3.3.1 Determine survivorship rates for three age classes
       - 3.3.3.2 Quantify the percentage of territorial birds that breed each year
       - 3.3.3.3 Determine reasons for abandonment of nests in wild populations

3.3.3.4 Determine nest site selection criteria and fidelity
3.3.3.5 Investigate effects of diet on productivity
3.3.3.6 Determine natal dispersal
3.3.3.7 Develop a spatially-explicit model of aga populations
3.3.4 Study aga behavioral ecology
3.3.4.1 Study the aga's social system
3.3.4.2 Determine behavior options that are pursued by pre-breeders
3.3.4.3 Investigate effects of egg removal on individual pairs
3.3.5 Increase knowledge of aga foraging ecology
3.3.5.1 Determine composition of diet
3.3.5.2 Conduct studies on foraging behavior and habitat use
3.3.6 Bank tissue samples for possible genetic analyses
3.3.7 Investigate possible disease transmission
3.3.7.1 Determine diseases found in wild populations
3.3.7.2 Specify diseases exclusive to Guam or Rota
3.3.7.3 Determine whether populations have different immunities to disease

4. Monitor, protect, and restore populations
4.1 Determine population size and trends in size
4.1.1 Obtain periodic estimates of the number of territorial aga pairs on Rota
4.1.2 Continue and expand the quarterly roadside counts
4.1.3 Consider repeating the offroad counts in 2008 and at 5-year intervals thereafter
4.2 Reestablish viable aga populations on Guam
4.2.1 Continue experimental translocations from Rota to northern Guam
4.2.1.1 Design translocations to determine what factors currently limit aga survivorship on Guam
4.2.1.2 Design translocations to determine if aga can breed successfully in the presence of snakes on Guam
4.2.1.3 Design translocations that do not introduce or exacerbate disease problems on Guam
4.2.2 Restore a viable population in northern Guam
4.2.2.1 Develop site-specific implementation plans for each release site
4.2.2.2 Release translocated birds from Rota
4.2.3 Restore aga to southern Guam
4.2.3.1 Remove limiting factors
4.2.3.2 Secure habitat in southern Guam
4.2.3.3 Translocate aga from northern Guam and/or Rota to southern Guam
4.3 Monitor the need for backup populations

4.3.1 Develop a captive breeding facility to support translocation efforts
- 4.3.1.1 Monitor the need to initiate captive breeding
- 4.3.1.2 Maintain contact with ongoing captive breeding efforts in the Pacific
- 4.3.1.3 Coordinate needs for captive breeding with other endangered species in the Mariana Islands

4.3.2 Establish captive populations in mainland zoos to prevent species extinction

4.3.3 Establish wild populations on other islands to prevent species extinction

Narrative Outline of Recovery Actions

1. Provide the infrastructure necessary to achieve recovery

1.1 Maintain an active recovery team, as needed

The recovery team will serve as the primary group providing recommendations and guidance to us regarding aga recovery. The team will serve as a forum in which issues affecting recovery are discussed and effective and coordinated recovery strategies are developed. The recovery team should include members with technical expertise useful in implementing the recovery plan and representatives of agencies and organizations that will participate in the recovery program. Technical disciplines that should be represented on the team include, but are not necessarily limited to: corvid biology, brown treesnake biology, wildlife biology, population biology, veterinary medicine, and habitat ecology. The team will also need access to specialists in related disciplines such as education and law. These specialists should be appointed as advisors to the team and should provide substantial input on these issues to the team when needed.

Several principles should guide the team's work. The team should maintain an awareness of all activities that have a major impact on aga recovery. The team should encourage peer review and publication of all scientific findings used in aga management. Management recommendations unsuitable for publication should nonetheless be subjected to independent peer review. The team should make substantial and continuing efforts to identify stakeholders in aga recovery and draw them into the recovery program to make meaningful contributions (Recovery Action 1.2). The team will promote effective outreach programs. It will advise outreach professionals of its decisions and assist in the development and implementation of outreach programs.

As it has done during recovery planning efforts, the team will continue to meet to oversee recovery implementation. The primary authors of this recovery plan (page ii) comprise the current Mariana Crow Recovery Team.

1.1.1 Oversee implementation of the recovery plan

The team will meet periodically to review past recovery activities, decide on the highest priorities for future work, and provide recommendations as requested by us and other groups interested in aga recovery, as appropriate. To document the team's progress and consensus, it will maintain minutes of each meeting, recording major issues considered and decisions made, and prepare periodic progress reports summarizing past recovery program activities, describing the current short-term goals and plans for achieving them, and identifying other issues that need attention from us and other interested parties. Bi-annual meetings may be necessary when the team is carrying out major actions such as revising the recovery plan or preparing recommendations on habitat conservation plans. At other times, the team may meet once a year or less frequently.

1.1.2 Coordinate recovery actions with other recovery and ecosystem management efforts

The team should coordinate its recommendations with other conservation initiatives on Guam and Rota. Particular attention should be given to coordination with us on efforts to prepare habitat conservation plans with the government of the Commonwealth of the Northern Mariana Islands and to reestablish other forest birds on Guam (*e.g.,* Guam Micronesian Kingfisher Recovery Committee).

1.1.3 Establish short-term (2 to 5 year) objectives for the recovery program, providing the rationale for each objective

The rationale should: (a) describe the objective, using quantitative terms whenever appropriate; (b) explain how achieving the objective will help meet the recovery program goals; (c) provide evidence that achieving the objective is feasible; (d) describe the funding and other resources needed; and (e) provide evidence that the resources to be committed are best used for the proposed activity rather than for some other aspect of aga recovery.

1.1.4 Periodically review the recovery plan and revise or update it as appropriate

The restoration of an endangered species is an uncertain science that requires continual critique and reevaluation of approach. A regularly updated recovery plan will assure all participants that recovery is being guided by the best available science and will be in keeping with our current guidance on recovery planning.

1.1.5 Establish and maintain an aga data center

We, the U.S. Fish and Wildlife Service, or our designee, will take responsibility for gathering, organizing, and maintaining an archive of aga data. Duplicates of each contribution will be deposited with the Guam Division of Aquatic and Wildlife Resources and the Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife. Agencies contributing to the preparation of this recovery plan (the U.S. Fish and Wildlife Service, the U.S. Geological Survey, Guam Division of Aquatic and Wildlife Resources, Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife, and U.S. Department of Defense) should agree to provide metadata and data derived from their aga activities in a timely manner, usually within 1 year of collection, or at the time of submission of a report or acceptance of publication. Agencies that submit data or metadata to the archive will have free access to the collections, with the understanding that use of the data for publication purposes will occur only with the consent of the original contributor, or after 5 years has elapsed since the data were submitted.

Users of the aga archives are strongly encouraged to communicate early and frequently with the data originator to avoid any misinterpretation of the data or misunderstanding concerning use of the data. Data contributors are strongly encouraged to submit at least one version each in hard copy and in electronic flat file form (ASCII characters, column delimited), though additional copies may be submitted in formats suitable for specific analytical software. Metadata will be provided in a form consistent with prevailing federal metadata standards; we, or our designee, will assist contributors with metadata preparation, including identifying the metadata fields appropriate for the type of data submitted. Geographic information systems (GIS) products such as maps and aerial photos, ordinary data sets (avicultural records, field observations, survey results), and relevant memos, reports, and publications dealing specifically with the aga should all be submitted to the aga data center, though all contributions relevant to the aga (*e.g.*

general geographic information systems layers dealing with aga habitat) will be accepted and archived.

Data collected as part of the actions specified in this recovery plan should always be archived in the aga data center. Researchers with common informational needs are encouraged to identify a common format for data collected by multiple sources. For example, it might be useful to select a common format for locality records of banded aga. Such formats will themselves be archived at the aga data center and contributors will be encouraged to use these formats to structure their submissions. We will post metadata on an internet web site (to be announced), which may also include postings of geographic information sytems products, ordinary data sets, and other submissions if such is acceptable to the submitter. If funding permits, we will archive the relevant data and compile comparable data in ways that will facilitate aga research and recovery. For example, observational records from different contributors on banded aga could be combined for greater statistical power and user convenience. The team has strongly recommended that we prepare or update metadata, and catalog and preserve aga data sets already in our possession. These include written records compiled for the National Research Council hearings, extant survey records and analyses, and relevant geographic information systems products.

1.2 <u>Engage stakeholders</u>

Identify stakeholder groups on Guam and Rota, and interested parties elsewhere. Determine the information and involvement needs of each group. Plan for meeting each group's needs, and for addressing the concerns, ideas and questions of each group.

1.2.1 <u>Plan for the specific information and involvement needs of stakeholders</u>

The specific needs of each interest group will vary depending on their interests, mandates and objectives. Also, the best mechanisms for information dissemination and program involvement may differ for each group.

1.2.1.1 Engage agencies and recovery team members

Field updates, research findings, team minutes and partnership meetings, mortality and necropsy reports, and other important information should be distributed on a regular and timely basis to all participants in the recovery program. An aga recovery website should provide most of this information and include contact information for all agency parties, team members, and local parties. For critical updates to biological information, the team leader or a Rota-based aga researcher can provide notification via e-mail, phone messages, or mail. For critical updates on endangered species policy information, our recovery team lead or the lead for local officials on Rota and Guam can provide notification.

1.2.1.2 Engage people of Guam and Rota

Solicit the participation and support of local leaders, landowners, homesteaders, and those whose lives may be directly or indirectly affected by the recovery program.

1.2.1.2.1 Interview and plan for information and involvement

Community leaders (*e.g.* legislators and other elected officials, editorial boards and other media managers, school leaders, military leaders, conservation leaders, business leaders and the heads of religious and cultural groups) and local residents should be interviewed to: 1) complete the list of stakeholders; 2) learn the best way to reach each group; 3) learn the most appropriate motivational mechanisms for engaging each group in the recovery effort; and 4) catalog a detailed list of concerns, issues and ideas. The team or its designee will be responsible for writing a detailed local information and involvement plan based on the interviews that is targeted to local people and their issues and concerns.

1.2.1.2.2 Address community organizations, island residents, schools, conservation groups, religious, cultural, and environmental groups

The information and involvement plan will include a description of the best mechanisms for providing general information and materials locally. It will also identify other funding mechanisms that could be used to assist in the development and dissemination of additional education materials. The plan will also include a description of how the opinions of the general population can be solicited, and criteria for when this should be done. The plan will include a detailed outline for the best ways to actively engage local residents in the recovery effort.

1.2.1.2.3 Engage landowners and homesteaders

The information and involvement plan will include mechanisms for providing incentives and recognition for landowners and homesteaders who participate in recovery, either through direct protection of aga or through reporting, research, etc. The plan will also include a detailed description for how information on potential or planned changes in local or Federal land management policies can be communicated promptly to all those with property enrolled in or potentially affected by the aga recovery program. The plan will include a process for gathering input from landowners and homesteaders before programmatic changes are made, and a plan for addressing any concerns before implementation.

1.2.1.2.4 Engage the legislature

Consistent with U.S. Fish and Wildlife Service policy, those with governing authority on both Rota and Guam should be regularly briefed on legislative initiatives they can undertake to support aga recovery, and made aware of recovery progress or lack of progress. Local legislators will be encouraged to be a part of the ambassador program (see Recovery Action 1.2.2.5.3).

1.2.2 Establish interactions between the team and other parties

Participants in the recovery effort should involve stakeholder groups. The team should work to establish frequent and productive interactions with other interested parties to integrate their actions, knowledge and support into the overall recovery effort.

1.2.2.1 Increase funding agency interest in aga recovery

Team members and those involved in recovery should encourage funding agencies to become engaged in the aga recovery program. The team should provide accurate and engaging technical information to all individuals, agencies and groups to help generate funding for aga recovery and related conservation actions. Supplemental funding for aga recovery initiatives should be sought actively from a variety of sources including the private and public sectors.

1.2.2.2 Inform other recovery groups

The team should communicate regularly and often with other recovery groups and scientists working on complementary efforts to avoid duplication of efforts and to maximize the efficient use of data, staff and funding, and encourage similar exchange with other recovery groups.

1.2.2.3 Develop partnerships with conservation groups

Solicit biological knowledge from local conservation group members, establish ongoing relationships, and encourage these groups to take part in appropriate recovery actions.

1.2.2.4 Demonstrate interest and respect for other management practices

Solicit information from local residents regarding historical land and management practices that support aga while allowing human use of the land. Incorporate these practices, whenever possible, into overall recovery efforts. This information can be solicited through a series of “teach us” or “tell us” workshops between the team, key agencies, and local residents.

1.2.2.5 Develop relationships with landowners on Guam and Rota

Work closely with landowners to resolve concerns and conflicts, establish cooperative relationships, and promote endangered species and habitat initiatives. An information and involvement plan will provide the basis for working with landowners on Guam and Rota. Use all available options for conflict resolution provided through policies and guidelines of Federal agencies implementing the Endangered Species Act.

1.2.2.5.1 Consider safe harbor agreements

Meet with landowners to discuss how safe harbor agreements could be established. Based on this meeting, establish and circulate a “template” or “model” safe harbor agreement, incorporating the ideas of local landowners.

1.2.2.5.2 Establish agreements that allow research to be conducted on lands that include aga habitat

Meet with landowners to discuss the needs for, and benefits of, research on public, private and leased (homestead) lands. Based on these consultations, team members should establish research protocols that include recognition and respect for the ideas and concerns of landowners. Whenever possible, local landowners and/or residents should be employed doing field research; other incentives should be established as well.

1.2.2.5.3 Establish an ambassador program

A team of landowners, scientists and agency personnel should meet with other landowners and homesteaders within areas frequented by aga on Guam and Rota to discuss aga recovery. These ambassadors should be prepared to discuss the causes of endangerment, findings to date, planned actions for achieving recovery, the ramifications of

Federal and local laws concerning endangered species, and the special needs and concerns of landowners and homesteaders.

1.2.3 Coordinate education and outreach

Individuals or organizations should be assigned to coordinate education efforts for particular stakeholder groups and target audiences. The members of the ambassador program (see Recovery Action 1.2.2.5.3) can be part of an outreach effort.

1.3 Hire a full-time experienced researcher dedicated to aga recovery on Rota

The aga population on Rota is in need of a full-time, experienced researcher to oversee research efforts and resolve the critical conservation issues on this island that will be the key to the recovery of the species (Guam Division of Aquatic and Wildlife Resources already has an aga biologist on that island). As recovery of the aga is now entirely dependent upon the Rota population, the need for a dedicated, experienced research scientist to determine the cause of the decline on that island is vitally important. This scientist will also be responsible for interpreting data and developing new recovery actions with the team. An annual research report, including a summary of findings and plans, should be presented to the team.

1.3.1 Plan and conduct cooperative research at sites where aga exist on Rota and Guam

The research leader will be responsible for initiating cooperative research involving relevant Guam and Rota agencies. A serious effort will be made to coordinate efforts between the two islands in order to standardize research protocols, to keep all agencies apprised of aga status, and to avoid interagency and agency-team conflict.

1.3.2 Involve local residents in research to the extent practical

Researchers will assess the feasibility of involving local people in the data gathering process, with special emphasis on school groups. Potential involvement programs will focus on creating a wider understanding and appreciation for the aga as well as increasing human resources available to study the aga.

2. Implement a habitat management program

Aga recovery requires that habitat of sufficient size and quality be protected on Rota and Guam for the long-term survival of the species.

2.1 Protect habitat in recovery zones on Rota

Currently, the Sabana Conservation Area and I Chenchon Bird Sanctuary both contain some excellent aga habitat and should be protected as permanent conservation areas. Additional habitat should be protected in areas identified as recovery zones (Figure 13) to augment wild aga populations to meet recovery goals. These areas could be protected through conservation easements, partnership agreements, safe harbor agreements, change in land use designation, lease, or purchase from a willing seller. In addition, innovative funding mechanisms should be explored to manage reserves.

2.2 Maintain and/or protect habitat in recovery zones on Guam

Currently, all wild aga on Guam are located within the Guam National Wildlife Refuge overlay lands on Andersen Air Force Base. In order to increase the aga population on Guam, good quality habitat must be protected and managed in northern and southern Guam to meet recovery goals.

2.2.1 Maintain and/or protect habitat in recovery zones in northern Guam

Guam National Wildlife Refuge overlay lands on Andersen Air Force Base and the Navy’s Communications Annex along with the Anao Conservation Area all contain aga habitat that should be maintained. Additional habitat should be protected in areas identified as recovery zones (Figure 14) to augment wild aga populations to meet recovery goals. These areas could be protected through conservation easements, partnership agreements, safe harbor agreements, change in land use designation, lease, or purchase from a willing seller. In addition, innovative funding mechanisms should be explored to manage reserves.

2.2.2 Maintain and/or protect habitat in recovery zones in southern Guam

Guam National Wildlife Refuge overlay lands on the Navy’s Ordnance Annex along with the government of Guam’s Bolanos Conservation Area all contain aga habitat that should be maintained. Additional habitat should be protected in areas identified as recovery zones (Figure 15) to augment wild aga populations to meet recovery goals. These areas could be protected through conservation easements, partnership agreements, safe harbor agreements, change in land use designation, lease, or purchase from a willing seller. In addition, innovative funding mechanisms should be explored to manage reserves.

2.3 Improve and manage habitat on Guam and Rota

The maintenance of good habitat and improvement of marginal habitat can be achieved by identifying and eliminating factors compromising quality aga habitat.

2.3.1 Minimize or eliminate ungulate impacts on aga habitat when appropriate

By browsing on the tender shoots of plants that have evolved in the Mariana Islands (*i.e.*, in the absence of grazing/browsing animals), introduced ungulates (*e.g.*, Philippine deer, feral pigs, carabao, and cattle) appear to be transforming the vegetative composition of forests on Guam and Rota. It is likely that aga depend on some of the plants that are now rare or missing. In selected cases, it may be necessary to remove the invading animals to protect the aga and other indigenous animals.

2.3.2 Identify and eliminate invasive plant species

Invasive plants are displacing native plants in some areas of the Mariana Islands. Control of these plants may be needed in selected areas to maintain the native plants upon which the aga depend.

2.3.3 Implement reforestation programs using native forest plant species to improve degraded areas within aga habitat

Maintenance or restoration of important ecosystem services such as pollination and seed dispersal (*e.g.*, Mariana fruit bats, Micronesian honeyeaters, Mariana fruit dove, etc.) depends on native forest tree species. Planting of nonnative tree species (*e.g.*, eucalyptus) within aga reserve areas should be stopped, and removal of exotics followed by replanting of native trees should be initiated.

2.3.4 Conduct vegetation assessments of all areas important to aga

Managers on Rota and Guam should determine what, if any, vegetative elements need augmentation, rehabilitation, encouragement, or restoration within important aga landscapes. Additionally, invasive vegetation determined to be detrimental to aga habitat quality should be identified and removed (see Recovery Action 2.3.3).

3. Implement an integrated program to identify and reduce limiting factors on Rota and Guam

Aga recovery must be guided by research that identifies and investigates the factors limiting population recovery, and by management that sustains habitat source areas. Monitoring is needed to adjust or refine management, provide research data, and validate research results and assumptions. Research, management, and monitoring should be integrated to ensure that recovery outcomes are achieved efficiently, and that the reasons for success or failure are understood. The threat to aga posed by the brown treesnake has been well established and vigorous management action is warranted, although additional research and management are necessary to determine the extent to which snakes and aga might coexist. In addition, aga ecology must be further investigated to identify other important factors limiting their recovery, particularly on Rota where treesnakes are not established. When other unnatural factors limiting recovery have been identified, cost-effective management techniques must be developed and implemented to control these factors.

3.1 Reduce brown treesnake threat

3.1.1 Increase interdiction activities to stop brown treesnake movement to Rota

Keeping Rota free of invasive predators, especially brown treesnakes, is essential to the survival of aga. Current efforts need to be increased to stop brown treesnake movement to Rota.

3.1.1.1 Fund Wildlife Services to prioritize protection of Rota

Interdiction of brown treesnakes moving from Guam to Rota is primarily the responsibility of Wildlife Services, a branch of the U.S. Department of Agriculture. Wildlife Services does not fund interdiction activities, but carries out interdiction activities funded by others. At the present time, funding for these interdiction activities is provided by the U.S. Department of Defense and U.S. Department of the Interior's Office of Insular Affairs through its technical assistance program. Neither funding source is dedicated to protecting wildlife. Therefore, the protection of aga on Rota occurs only incidentally to other responsibilities. Within that constraint Wildlife Services has done an excellent job protecting the natural resources of Rota. Nonetheless, financial support for Wildlife Services' interdiction activities related directly to Rota's wildlife would insure that the highest level of protection would be achieved and sustained. In particular, there have been times in the recent past when shippers moving cargo to Rota have done so without the protection afforded by Wildlife Services' dog detection and inspection program. In addition, non-commercial shippers probably often travel between Guam and Rota without the benefits of Wildlife Services' inspection. With funds dedicated to protecting Rota's wildlife, more effort could be put into identifying such noncovered shipments and extending interdiction activities to include them.

3.1.1.2 <u>Reduce brown treesnake populations at ports and cargo holding areas on Guam</u>

In addition to direct inspection of cargo, additional brown treesnake protection for aga (and all other wildlife on Rota) could be afforded by new or additional brown treesnake population reduction in areas of Guam through which Rota-bound shipments pass. Such sites would include all ports from which Rota-bound cargo passes (Agana Boat Basin, Sumay Marina, Agat Small-boat Basin, Cabras Island, and Won Pat International Airport), as well as all sites that are used for staging cargo (Harmon Consolidators, as well as non-Harmon sites). This population reduction could be accomplished with snake traps, visual searches, snake toxicants, and any other successful techniques that prove to be cost-effective (see Appendix 5).

3.1.1.3 <u>Conduct research to increase detection of very small brown treesnake populations</u>

One problem that especially affects the interdiction of snakes moving from Guam to Rota is the challenge of detecting or controlling snakes at very low population densities. Areas subject to heavy snake trapping on Guam may still contain low densities of snakes if the snakes are either too small for the attractant being used or otherwise of an unsuitable size or behavior for trapping or poisoning. Similarly, an incipient snake colonization on Rota would be difficult to detect or control if techniques suitable for controlling and detecting snakes at low density do not exist. Current techniques may be relatively ineffective in areas such as Rota that have high "natural" prey densities. For example, due to the abundance of rats on Rota, a free-ranging snake there might be reluctant to enter a trap to get close to a rodent used as an attractant. Research into matters such as size selectivity in control techniques, attractant success (some individuals may be unwilling to take baits or enter traps), and trap or toxicant capture in the face of high prey densities may identify alternative or additional tools that would be of great value in controlling the spread or colonization of snakes moving from Guam to Rota. Support for such research would benefit the aga, as well as all the other species of native wildlife vulnerable to brown treesnakes on Rota.

3.1.1.4 Initiate brown treesnake interdiction programs on Rota

In addition to interdicting snakes leaving Guam for Rota, it may be prudent to add a layer of protection by also interdicting snakes arriving on Rota from Guam and Saipan. For example, Engeman *et al.* (1998b, 2002) compiled evidence indicating that about 62 percent of brown treesnakes purposely planted in cargo leaving Guam as a test are detected by the Wildlife Services dog detection program. If the success rate of naturally dispersing snakes is comparable, this means that about 38 percent of the snakes that may be present in cargo are leaving Guam undetected. Many of these could be intercepted by an additional dog detection program on Rota. Other activities (outlined below) could be initiated or bolstered to further reduce the likelihood of brown treesnake colonization of Rota. We recommend that discussions be initiated about transferring brown treesnake interdiction activities on Rota to Wildlife Services. Wildlife Services should consider using local residents on Rota as employees to the maximum extent practicable. Wildlife Services possesses the needed technical expertise, and the agency's presence on Rota might facilitate the availability of additional funding for this effort.

Additional Rota-based interdiction activities might include: a) a requirement that all cargo be inspected on Guam (see Recovery Action 3.1.1.1); b) where possible, transoceanic shipments should be routed through Saipan rather than Guam (as long as Saipan remains relatively snake-free); c) fumigation should be required for the highest risk cargos once a replacement for methyl bromide is licensed; d) brown treesnake enclosures could be operated at portside locations, such that inbound cargo are held overnight to encourage brown treesnakes to escape into the enclosure (such enclosures must be snakeproofed and include effective traps to capture any such snakes); e) a rapid response team should be assembled, trained, and equipped to eliminate any incipient colonizations detected on Rota; and f) public awareness efforts should be supported on Rota, such that all residents will assist in the detection and elimination of brown treesnakes (citizen efforts have been responsible for all brown treesnakes captured on Saipan). For example, large multilingual signs at key sites (*e.g.*, airport, port) should proudly proclaim that Rota is snake-free. Such signs should provide a 24-hour phone number that could be used for reporting snake sightings.

3.1.2 Control brown treesnakes over large areas on Guam

For aga to be recovered on Guam we must develop and implement effective tools for snake control over large areas. Existing technology can and should be harnessed for this action. In particular, financial support should be given to the most cost-effective techniques available for area snake control. At the present time this means a combination of snake trapping and snake barriers (Rodda *et al.* 1999a). The current snake control project for the Munitions Storage Area should be supported. In the near future, approved toxicants and their delivery systems, *e.g.*, acetaminophen-tainted baits, may augment or replace the snake trapping component of large-area snake control (Savarie *et al.* 2001). In certain circumstances the most effective tool may be single-tree nest barriers (Aguon *et al.* 1999). Development of these and other nascent snake control technologies should be supported. Specific actions that would improve the cost effectiveness of existing large-area brown treesnake control technologies include:

- develop traps to capture a wider range of snake sizes;
- determine if a significant fraction of brown treesnakes avoid trap entry, and if so, identify what trap alterations can be done to minimize the number of untrappable snakes;
- develop toxicant delivery systems that are harmless to aga and other native wildlife, specifically toxicants that do not enter the native wildlife food chain by nontarget poisoning or secondary ingestion; and
- develop methods for accurately quantifying the density of brown treesnakes in snake-reduced areas of Guam.

To extend large-area brown treesnake control on Guam, several additional developments are needed:

- develop brown treesnake barriers that are suitable for terrain that includes cliffs and streams (stream crossing barriers will be essential for restoring the crow population on southern Guam);
- reduce the initial costs of brown treesnake barriers;

- develop tools or strategies for sequentially eliminating brown treesnakes from large exclosures, as proposed for the Munitions Storage Area (it will be very expensive and/or difficult to eradicate brown treesnakes from the 500-hectare [1,235-acre] Munitions Storage Area all at once; sequential elimination may be more cost-effective, but tools to keep snakes from escaping from treated to nontreated portions of an exclosure need to be developed);
- develop inanimate attractants so that snake trapping and snake toxicants are not dependent on mice for their effectiveness;
- identify more "permissive" snake trap entrances so that a greater fraction of the snakes visiting a trap or bait station enter the trap/bait station (current flap entrances exclude a significant fraction of the snakes that visit);
- develop multi-species barriers so that costs can be reduced where there are a variety of introduced species that should be excluded (cat, rat, and monitor lizard exclusion devices can sometimes be cost-effectively combined with brown treesnake barriers); and
- large-area exclosures need to be designed and implemented for areas on northern Guam in addition to the Munitions Storage Area.

A third tier of assistance for protecting aga and other native species on Guam from brown treesnakes will rely on additional actions. Some of the better prospects include:

- more exotic (i.e., non-traditional) brown treesnake control technologies such as biocontrol;
- development of a "reproduction" trap that would target gravid females (who might find the traps especially suitable for oviposition sites) or newborn hatchlings;
- develop refugium traps to increase detection or capture of snakes that might not enter food-based traps or bait stations; and
- implement large area brown treesnake exclosures on southern Guam.

3.2 <u>Prevent establishment of new invasive predators on Rota</u>

New procedures need to be implemented to keep novel invasive predators (in addition to brown treesnakes) from becoming established on Rota. Obvious targets would include mammalian predators such as mongooses, weasels, and rodents; avian predators or competitors; and potential toxic prey items such as poisonous frogs (dendrobatids) and invertebrates (ants, slugs). At present there does not seem to be a well-developed regulatory mechanism for keeping harmful invasive species from arriving on Rota; this can be rectified by changing regulatory requirements and improving cargo handling procedures.

3.3 Conduct essential research for effective management of wild aga

Many aspects of the aga's ecology remain unknown. A solid scientific program needs to continue on Rota and Guam to research the ecology of the aga and aid in determining further recovery actions. The priority topics for research revolve around the determination of limiting factors, and basic research still needs to be conducted on the demography, ecology, and behavior of the aga. Where feasible, carefully controlled experiments should be conducted to provide a sound basis for recovery actions and management activities.

3.3.1 Determine the importance of other predators on Guam and Rota and develop strategies and methods for their control

The impact of predators other than brown treesnakes on aga is unclear. Research is needed to better understand the role of other predators in limiting aga recovery, if any, and the possibility of controlling them, if needed, in a cost-effective way.

3.3.1.1 Determine if rat control on Rota is necessary

In the case of introduced rats there is a special need to provide quantification of their importance to aga populations. The biogeographic and historical evidence for the negative impacts of introduced rats is quite strong for some bird species, yet perpetual rat control incurs a staggering cost, and a recent study on Rota has raised some question as to the influence of rats on the aga population there. Therefore, a logical action would be to further test the importance of rat populations on the aga experimentally. This experiment would need to be planned by an expert in this field, but should include paired control and treatment plots of a size sufficient to obtain meaningful quantification of aga reproduction. Each condition should be replicated. The treatment plots should be subjected to sufficient rat reduction that significant change in rat-induced nest loss should occur. In addition, rat density should be monitored to provide independent confirmation that significant rat population reduction occurred during the test. In addition to monitoring the effects of rat reduction on aga reproduction, the experiment should provide for monitoring other wildlife species that are likely to benefit from rat reduction. The rationale for including this additional step is that the cost of perpetual rat control is likely to be very high, and quantification of the full suite of benefits is likely to be necessary to justify the rat management costs on an operational basis.

If assessment of rat reduction indicates that control can be cost-effective for promoting the recovery of the aga, such control should be undertaken. However, as part of the adaptive management of any such control program, a long-term monitoring program should be instituted to assess the role of rats both on Rota and in snake-reduced areas of Guam. A monitoring program may identify rat irruptions before they have time to seriously reduce the survival prospects of the crow population. This benefit accrues to a rat monitoring program on both islands, even if not paired with an ongoing rat control effort.

3.3.1.2 <u>Pursue management registration of rodenticide</u>

The application of rodenticides for the control or eradication of rats has produced measurable increases in the populations of declining island avifaunas (*e.g.*, Taylor and Thomas 1993; Robertson *et al.* 1994; VanderWerf and Smith 2002). In addition, because rodents provide an important prey base for the brown treesnake, rodent control may be essential for effective brown treesnake control (G. Rodda, USFWS, pers. comm. 2001). An Environmental Protection Agency registration for at least one diphacinone rodenticide product for use in bait stations is needed for Guam and the Commonwealth of the Northern Mariana Islands. A registration for hand and aerial broadcast could be pursued in the future, once this use pattern has been successfully established in Hawai`i.

3.3.1.3 <u>Determine how black drongos affect aga</u>

The potential effects of black drongos on aga should be investigated in an experiment analogous to that outlined above for rats. However, it may be that perpetual lethal control of drongos is unsustainable, in which case it may be more cost effective to control drongos by depriving them of the disturbed habitats they favor. Habitat restoration may be directly favorable to aga as well. A full factorial experiment including both direct and indirect drongo control, as well as habitats that have been restored (by weed control, and reseeding of native trees) and left unmanipulated, would be highly desirable. Rigorous cost accounting is needed for each treatment, such that preliminary cost-effectiveness figures can be obtained. If such a test indicates that either direct or indirect drongo control is likely to be cost-effective for restoration of the aga, such control should be undertaken.

3.3.1.4 Quantify the importance of human persecution of aga as a limiting factor

Research should be undertaken to attempt to develop physical methods (*e.g.*, study of aga flight distances, or perhaps remote monitoring methods, *e.g.*, cameras) of quantifying human persecution of aga on Rota. The objective of such research should be to replace heresay as a source of information on the amount of human persecution to which the aga population is subject.

3.3.2 Determine habitat use and requirements

To designate appropriate management strategies and conservation measures, researchers must determine the habitat characteristics required by aga to promote their survival and productivity. It should be noted that habitats currently occupied and used may not necessarily be optimal habitats. Habitat requirements should be examined in the context of reproduction, foraging, roosting, and dispersal across age and breeding classes. Long-term studies are needed to determine changes in survivorship, productivity, and population density in relation to habitat characteristics.

3.3.2.1 Determine if current habitat use reflects factors limiting recovery

Research shows that aga do not occupy all wildlife conservation areas currently established on Rota, even though those areas provide what appears to be suitable habitat. Researchers need to determine the factors excluding aga from available habitat, and determine if the habitat currently occupied is detrimental to the recovery of the population ("sink" habitat).

3.3.2.2 Determine how size of territory varies with habitat quality (*i.e.*, vegetation characteristics and food resources) and what changes in habitat would likely lead to increased nesting density

The density of aga in native forest on Rota is known to vary widely, and the factors contributing to the variability in territory size are not well understood. Vegetative species composition, seral stage, canopy closure, canopy height, patchiness, and topography probably affect aga density. Aga nests have never been found in nonnative trees on either Rota or Guam. Access to regularly-replenished food resources in the tidal zone and associated strand vegetation may be important during periods of drought and other food stresses (*e.g.*, post-typhoon). Anecdotal reports indicate that crops and fruit trees on agricultural homesteads may attract aga, though human persecution may limit current use. There is good evidence to suggest that some human disturbance (*e.g.*, roads, aircraft) may negatively impact breeding behavior and nest site selection. The relationship between habitat structure and predator densities also needs exploration.

3.3.3 Collect demographic, breeding, and dispersal data

Existing knowledge of aga biological requirements and life history traits needs to be expanded using larger sample sizes and data from consistent, long-term studies. Banding and radio-tagging techniques should be employed. As information accumulates on annual survivorship and reproductive performance of the aga, it becomes increasingly possible to model an age-specific life table for the species. To allow accurate projections of extinction probabilities, demographic parameters should be calculated separately for each distinct population of aga. The demographic parameters of released captive-reared and wild-hatched individuals should be compared.

3.3.3.1 Determine survivorship rates for three age classes

The accurate determination of survivorship rates among age-classes is vital for the development of life tables and subsequent modeling of extinction probabilities. It also can provide useful information about the age class for which conservation efforts will be most effective. Researchers need to determine survivorship rates specific to juveniles because this is the group on Rota that will provide most of the individuals for translocation to Guam in future projects. For accurate, complete life tables, it is vital that researchers determine adolescent survivorship. The accurate determination of adult survivorship is crucial for guiding effective management because analysis suggests that adult survivorship drives aga population viability (Appendix 4).

3.3.3.2 Quantify the percentage of territorial birds that breed each year

To accurately monitor the stability of the wild population we need to know why some aga pairs breed and others do not in any given year. Annual modulation in breeding activity often provides clues as to the factors limiting recruitment, and understanding these factors may point to human-caused impacts that can be mitigated or eliminated.

3.3.3.3 Determine reasons for abandonment of nests in wild populations

Abandonment constitutes 17 percent of known nest failures. In order to increase productivity, it is necessary to understand the underlying causes of this behavior. All cases of known abandonment should be documented, including the following information when possible: amount of time spent incubating/brooding before abandonment, a description of any observed interactions with any other aga or other species (including humans), habitat quality, nest parasites, diet, an examination of any abandoned eggs or nestlings obtainable, examination of previous nesting history, and observation of future nesting attempts.

3.3.3.4 Determine nest site selection criteria and fidelity

Nest placement often determines vulnerability to nest predators and therefore nesting success in birds (Marzluff 1988). Therefore, to better understand why habitats, or specific trees, may vary in suitability to breeding aga, nest placement and its relationship to nesting success should be recorded and analyzed.

3.3.3.5 Investigate effects of diet on productivity

Studies to determine the effects of foraging rate and diet on productivity should be done in both a captive setting and through long-term comparison of birds in habitats of varying qualities.

3.3.3.6 Determine natal dispersal

Male and female aga should be radio-tagged as juveniles and followed through their nonbreeding years until they settle on territories as breeders. During this time, researchers should determine habitat-specific settlement, survival, and use of space by dispersing aga. Probabilities of 1) successful assimilation into the breeding population, and 2) movement between specific habitats can be used to model population structure and viability.

3.3.3.7 Develop a spatially-explicit model of aga populations

To summarize what is known about aga populations and project their future changes, a spatially-explicit model of population structure and function should be developed. This model should be updated annually as demographic and dispersal data are refined. The modeling effort will be useful for synthesizing what is known about aga habitat-specific survival, reproduction, and dispersal.

3.3.4 Study aga behavioral ecology

3.3.4.1 Study the aga's social system

It is essential to establish a working knowledge of the aga social system in order to manage for increased survival and productivity. Management techniques that promote the preservation of social system integrity should be developed.

3.3.4.2 Determine behavior options that are pursued by pre-breeders

Virtually nothing is known about the pre-breeding segment of aga populations. Radio telemetry and direct observation of color-banded individuals should be used to determine their dispersal (see above), seasonal movement patterns, foraging behavior, and social interactions. These observations could answer questions such as: Do pre-breeders get extra-pair copulations? Do pre-breeders facilitate or disrupt breeding by territory holders? What cues are used by pre-breeders to select mates or territories? Can habitat restoration increase the entry of pre-breeders into the breeding population?

3.3.4.3 Investigate effects of egg removal on individual pairs

An important management option is the removal of eggs and chicks. However, to be successful, this strategy assumes pairs will re-lay and fledge young at the same rate as unmanipulated pairs. Additionally, the productivity of pairs should decline minimally during the long-term if only first clutches are removed. These effects need to be researched in conjunction with experimental translocation efforts (Recovery Action 4.2.1).

3.3.5 Increase knowledge of aga foraging ecology

Researchers should work to expand existing knowledge of aga foraging habitat, and to determine its spatial and qualitative overlap with other essential habitats (*e.g.*, breeding and roosting).

3.3.5.1 Determine composition of diet

It is important to know what aga eat. This can be studied with a variety of techniques including, but not limited to, direct observation, stable isotopes, and fecal analysis. Fecal samples should be collected in order to reveal any foods that are not identified from direct observations (Sakai and Ralph 1980; Sakai *et al.* 1986).

3.3.5.2 Conduct studies on foraging behavior and habitat use

The foraging behavior of present-day aga on Rota and Guam should be further researched and described in detail, including any seasonal shifts in food choice and/or foraging rate. Food choice should be compared with independently gathered information on food availability, especially with respect to native diet requirements and their relative nutritional value. Together with information on food plant dispersion these studies could potentially reveal shortages of important food plants within existing habitat. Such studies of animal prey items would be similarly informative.

3.3.6 Bank tissue samples for possible genetic analyses

Whenever wild individuals are captured for banding, study, or translocation, at least a feather sample should be taken. These samples could be used for a variety of important future investigations including study of extra-pair copulations, contaminants, and genetic composition of recovering and recovered subpopulations.

3.3.7 Investigate possible disease transmission

Disease is often not a source of direct mortality but may hinder productivity and/or expose individuals to other sources of mortality. Nutritional stress may predispose individuals to disease (and *vice versa*). Researchers need to assess the impacts disease and parasites have on wild aga and monitor their spread and baseline levels within populations. In addition, investigation into and preparation for possible epidemics of pathogens brought in from other countries should be instigated.

3.3.7.1 Determine diseases found in wild populations

Researchers should catalog all known pathogens and parasites found in wild aga populations. Studies to determine pathogen/parasite transmission, virulence, and distribution should be initiated. The ecology of nonnative pathogens should be compared between land of origin and Guam and/or Rota.

3.3.7.2 Specify diseases exclusive to Guam or Rota

Identify and describe any diseases or parasites of aga unique to Guam or Rota, if any. Determine what potential diseases most threaten aga (*e.g.*, avian malaria, pox, or a suitable vector for these diseases).

4. Monitor, protect, and restore populations

Aga populations on Guam can be recovered only by reintroduction and intensive management, whereas the Rota population can likely be maintained and enhanced by protecting habitat and reducing predators and other limiting factors. Protecting and restoring populations on both islands requires monitoring to determine how these populations respond to management. Depending on the progress of recovery on Guam and Rota, it may become necessary to establish backup populations in captivity.

4.1 Determine population size and trends in size

4.1.1 Obtain periodic estimates of the number of territorial aga pairs on Rota

Results from the intensive research program, supplemented by additional work as needed, should be used to estimate the number of territorial pairs of aga at least every 5 years and preferably more often, as feasible. It may be possible to directly count all of the pairs, and this approach is favored because it should yield the most accurate estimate. Other sampling approaches, for example based on capture-recapture or telemetry, may also be worth considering. Point estimates should be accompanied by an interval estimate, and methods used to obtain the point and interval estimates should be documented in detail. The method of population estimation should be standardized to allow for comparisons between surveys.

4.1.2 Continue and expand the quarterly roadside counts

The quarterly roadside counts should be continued, and modifications should be made to increase the number of aga detected. The following changes are suggested: record all species, not just aga (to potentially identify any parallel populations trends in other bird species); distinguish between individuals detected closer to, and farther than, 50 meters (164 feet) from the observer; continue the 2-minute playbacks initiated recently; continue recording all species (with distance category) during these 2 minutes and tally individuals first detected during the initial 3 minutes separately from individuals first detected during the last 2 minutes. The recovery team also recommends adding about 50 count stations, mainly along roads but also along three trails (no clearing needed) that would be surveyed once per year (or twice per year if needed due to phenological differences between species).

4.1.3 Consider repeating the offroad counts in 2008 and at 5-year intervals thereafter

We are uncertain at present whether repeating the offroad counts will be needed for reliable estimates of change in population size among species other than aga. Such estimates will be valuable in interpreting aga trend data (as well as for goals related to other species) but sufficient data may be provided by the expanded onroad counts. This issue should be reconsidered in 2008.

4.2 Reestablish viable aga populations on Guam

Recovery of the aga on Guam requires the establishment of two large self-sustaining populations, one in northern and one in southern Guam. Reestablishment of aga on Guam is a three-phase process. First, experimental reintroduction of aga to protected areas where brown treesnake populations have been reduced in northern Guam will be continued. Second, as area-wide snake control proceeds (see Recovery Action 3.1.2.), aga should be translocated from Rota to northern Guam in a full-fledged restoration effort provided that experimental translocations are shown to not negatively impact the Rota population. Lastly, after limiting factors in southern Guam have been removed and the northern Guam population is self-sustaining, aga should be translocated from Rota (and perhaps northern Guam) to southern Guam. Reintroducing aga to southern Guam will be more feasible after the most difficult lessons have been learned while restoring the northern population.

4.2.1 Continue experimental translocations from Rota to northern Guam

Since 1997, 26 aga have been released on Guam by Division of Aquatic and Wildlife Resources personnel, 6 adults from mainland zoos, and 20 individuals that were taken primarily from Rota as eggs or chicks. Ten of the birds released thus far are surviving in the wild. These efforts have increased our understanding of translocation techniques (including methods for collecting, transporting, and hatching eggs; rearing chicks; and releasing young birds), produced insights into factors currently limiting recovery, and provided vital feedback about the efficacy of habitat management efforts and needs. Determinations of what may be suitable habitat are purely hypothetical in the absence of aga to serve as a direct indicator of habitat quality.

4.2.1.1 Design translocations to determine what factors currently limit aga survivorship on Guam

Although the decline of the aga and other species of native Guam birds corresponds closely to the spread of the brown treesnake, to date, predation of aga by brown treesnakes has not been documented. Other potential predators (cats, monitor lizards), parasites, toxins, and diseases may be important limiting factors for the aga as well. The hypothesis that the brown treesnake is the only serious impediment to the successful reestablishment of aga on Guam needs to be tested.

4.2.1.2 Design translocations to determine if aga can breed successfully in the presence of snakes on Guam

It is unlikely that Guam will ever be free of snakes in the near or distant future, and there is a real danger of snakes colonizing Rota. It is critically important to develop methods for reducing snake populations and experimentation with snake-reduction techniques should continue. Protection of individual nest trees is feasible, but as more and more aga breed on Guam these efforts will become logistically difficult, and it also does not provide a practical long-term strategy for sustaining aga populations. Area-wide trapping as currently conducted near release sites provides an alternative that should be investigated. Translocations should test the hypothesis that aga populations can presently persist on Guam in areas where the brown treesnake has been reduced through control efforts that could be applied over wide areas at a reasonable cost.

4.2.1.3 Design translocations that do not introduce or exacerbate disease problems on Guam

Nestlings, fledglings, or adults brought from Rota to Guam should be carefully screened for disease in consultation with qualified avian or wildlife veterinarians.

4.2.2 Restore a viable population in northern Guam

Aga must be restored on Guam to reduce extinction threats resulting from, among other things, the impact of stochastic events on the one remaining population on Rota. When limiting factors in northern Guam are sufficiently reduced, and experimental translocations of aga result in successful reproduction and recruitment, the numbers of eggs and chicks collected from first nesting attempts on Rota should be increased up to the maximum rate of removal deemed tolerable for viability of the Rota population and continued until 75 territorial pairs are maintaining a viable population in northern Guam.

4.2.2.1 Develop site-specific implementation plans for each release site

Site-specific implementation plans will need to be developed for each reintroduction site on Guam. These must incorporate plans for habitat management (*i.e.*, predator control, abundance and composition of food resources), reintroduction, and population monitoring. Cooperative relationships with landowners, Andersen Air Force Base, and provincial government agencies must be a central element of these plans. An overall assessment of the effectiveness of these plans and the ongoing reestablishment program at each site should be undertaken yearly.

4.2.2.2 Release translocated birds from Rota

We anticipate that up to 20 fledglings will need to be translocated each year for 5 to 10 years to establish a viable population on northern Guam. However, due to the apparent sensitivity of the Rota population to adult survival and the uncertainty surrounding the pre-breeding cohort, only eggs and chicks should be translocated. Additionally, we should take advantage of any opportunities to salvage birds or nest contents on Rota. It is unlikely that such removals will endanger the Rota population (Appendix 4).

4.2.3 Restore aga to southern Guam

Full recovery of the species requires that a self-sustaining population eventually be established in southern Guam.

4.2.3.1 Remove limiting factors

Accomplishment of Recovery Actions 3.1.2 and 3.3.1 may produce areas suitable for translocation and successful reestablishment of aga in southern Guam.

4.2.3.2 Secure habitat in southern Guam

Accomplishment of Recovery Action 2.2 would assure that habitat is available for the duration of translocation efforts.

4.2.3.3 Translocate aga from northern Guam and/or Rota to southern Guam

Once limiting factors have been removed, habitat is secured, and the northern Guam and Rota populations are self-sustaining, full-scale reintroduction to southern Guam would be possible. Specific techniques to accomplish this will depend on how translocation techniques have evolved during their use to restore the population in northern Guam.

4.3 Monitor the need for backup populations

It may be necessary to establish a captive breeding program or backup populations in captivity or, in extreme circumstances, on other islands if the Rota population declines, restoration on Guam falters, or threats to the species increase.

4.3.1 Develop a captive breeding facility to support translocation efforts

4.3.1.1 Monitor the need to initiate captive breeding

It is possible that successful restoration of aga to northern and southern Guam will require a self-sustaining, highly productive captive population. This may become a necessity within years, or may never be needed. At this time we do not believe captive breeding is necessary to support restoration of aga to Guam. Captive breeding is extremely expensive and should be a last resort for restoration (Snyder *et al.* 1996). However, this decision should be revisited annually or whenever the biology of the wild Rota population or politics of the region dictate. In particular, we should be prepared to rapidly commit to captive breeding if: a) new and significant threats to the viability of the Rota population are discovered, such as colonization of the island by brown treesnakes; b) we determine that the Rota population can no longer sustain harvest of eggs and young for expanded translocation efforts; c) translocation from Rota is no longer feasible politically; or d) the number of pairs in population estimates on Rota falls below 75. If captive breeding efforts should begin, a genetics management plan and a studbook should be developed to ensure effective management of the captive aga population.

4.3.1.2 <u>Maintain contact with ongoing captive breeding efforts in the Pacific</u>

Significant efforts are being made on Guam and especially Hawai`i to breed endangered birds for reintroduction. Information and data regarding avicultural advancements made at these facilities should be made available so that if captive breeding is needed for aga the best techniques can be rapidly implemented.

4.3.1.3 <u>Coordinate needs for captive breeding with other endangered species in the Mariana Islands</u>

A major cost of captive breeding programs is the initial investment in facilities. If captive breeding facilities are planned for other species in the Mariana Islands, the needs of aga should be considered. Relatively little additional resources would be required to expand such plans to allow for aga to be bred there, if the need arises.

4.3.2 Establish captive populations in mainland zoos to prevent species extinction

It may be necessary to establish additional populations to prevent species extinction if the Rota population declines significantly (*e.g.*, more than 10 percent per year for more than 3 years) and causes of the decline are not understood or cannot be controlled.

4.3.3 Consider establishing wild populations on other islands to prevent species extinction

Although it is not desirable to establish populations outside of the natural range of the species, it may be necessary to consider establishing aga populations on other islands if management to stop the decline of the Rota population fails and restoration of the Guam population becomes implausible. Any such action could not be undertaken without first analyzing and considering the potential environmental impacts, as per the National Environmental Policy Act, as well as providing the opportunity for public comment.

III. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated costs for the recovery program for the aga. It is a guide for meeting the recovery goals outlined in this plan. This schedule indicates the action priorities, identifies and describes the actions as per the Recovery Action Outline in Section II-E, estimates the costs and duration of those actions, identifies the parties responsible for actions (either funding or carrying out), and identifies the listing factors (threats) that will be addressed by the action.

Definition of Action Priorities

Priorities in the Implementation Schedule are ranked according to the following definitions for recovery actions:

Priority 1 — An action that must be taken to prevent extinction or prevent the species from declining irreversibly in the foreseeable future.

Priority 2 — An action that must be taken to prevent a significant decline in the population, habitat quality, or some other significant negative impact short of extinction.

Priority 3 — All other actions necessary to meet the recovery objectives.

In addition, the recovery action priority rankings are further subdivided into four tiers or levels of descending priority. All actions with the same priority number ranking are of approximately equal priority, but Tier 1 actions are of greater importance than Tier 2 actions, and so on within the same priority rank. Where possible, actions are ordered in descending priority tiers, at least in the sense that one or more actions may have to be started or completed before another action can be accomplished. However, no linear hierarchy can suitably express the complex interrelationships between actions. To accomplish the goal of recovering the aga, all actions identified must be successfully executed.

Threat Categories

The Listing Factor column indicates which of the five listing/delisting factors the recovery action addresses to reach the recovery goals and criteria for the aga, as described in Section I-F, Reasons for Decline and Current Threats. The majority of the recovery actions in this plan address the threat of predation by the brown treesnake (Factor C), habitat loss or degradation (Factor A), and human persecution (Factor E).

Definition of Action Durations

The estimated time to completion of each recovery action is presented, where possible, or may be defined as follows:

Continual — An action that will be implemented on a routine basis once begun.

Ongoing — An action that is currently being implemented and will continue until action is no longer necessary.

Unknown — Either the action duration or associated costs cannot be realistically estimated at this time.

Parties Responsible for Action Implementation

We have the statutory responsibility for implementing this recovery plan. Only Federal agencies are mandated to take part in the effort. However, species recovery will require the involvement of the full range of Federal, Territorial, Commonwealth, private, and local interests. The expertise and contributions of additional agencies and interested parties will be needed to implement recovery actions and to accomplish public awareness and outreach objectives. For each recovery action described in the Implementation Schedule, the column titled "Responsible Parties" lists the primary Federal and local agencies we have identified as having the authority, responsibility, or expressed interest to implement a specific recovery action. When more than one party has been identified, the proposed lead party is indicated by an asterisk (*). No lead was designated if the action spanned the two islands of Rota and Guam with separate agencies or landowners involved. The listing of a party in the Implementation Schedule does not require the identified party to implement the action(s) or to secure funding for implementing the action(s).

Key to Acronyms used in the Implementation Schedule

CNMI	Commonwealth of the Northern Mariana Islands
DAWR	Guam Division of Aquatic and Wildlife Resources
DFW	Division of Fish and Wildlife, Commonwealth of the Northern Mariana Islands
GNWR	Guam National Wildlife Refuge
MCRT	Mariana Crow Recovery Team
USAF	U.S. Air Force
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USN	U.S. Navy
WS	Wildlife Services, U.S. Department of Agriculture Animal and Plant Health Inspection Service

Implementation Schedule for the Draft Revised Recovery Plan for the Aga or Mariana Crow • May 2005

Priority Number	Priority Tier	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Cost Estimate (in $10,000 units)						
							Total Costs	FY 05	FY 06	FY 07	FY 08	FY 09	5-Year Costs
1	1	3.1.1.2	C	Reduce brown treesnake populations at ports and cargo holding areas on Guam	Continuous	WS	9,000	500	500	500	500	500	2,500
1	1	3.1.1.4	C	Initiate brown treesnake interdiction programs on Rota	Continuous	DFW* WS	750	20	15	15	15	15	80
1	1	2.1	A	Protect recovery habitat on Rota	10 years	USFWS	200	20	20	20	20	20	100
1	2	1.3	A, C, E	Hire full-time experienced researcher dedicated to determining why the aga population on Rota is declining	10 years	DFW* USFWS	50	5	5	5	5	5	25
1	2	2.2.1	A	Maintain and protect recovery habitat on Northern Guam	15 years	USAF USN USFWS	7,500	500	500	500	500	500	2,500
1	2	3.1.1.3	C	Conduct research to increase detection of very small brown treesnake populations	10 years	WS USGS*	1,000	100	100	100	100	100	500
1	2	4.1.2	A, C, E	Continue and expand quarterly roadside count	50 years	DFW	150	3	3	3	3	3	15
1	2	4.1.1	A, C, E	Obtain periodic estimate of number of territorial pairs on Rota	50 years	DFW* USFWS	160	10	-	-	10	-	20
1	3	3.1.2	C	Control brown treesnakes over large areas on Guam	Ongoing; 30 years	USN USAF WS USFWS	12,500	500	500	500	500	500	2,500
1	3	3.3.3.1	C	Determine juvenile, pre-breeder, and adult survivorship	5 years	DFW* USFWS	100	20	20	20	20	20	100

Implementation Schedule for the Draft Revised Recovery Plan for the Aga or Mariana Crow • May 2005

Priority Number	Priority Tier	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Cost Estimate (in $10,000 units)						
							Total Costs	FY 05	FY 06	FY 07	FY 08	FY 09	5-Year Costs
1	4	3.2	C	Keep new invasive predators, besides brown treesnakes, from being established on Rota	50 years	DFW WS	755	20	15	15	15	15	80
1	4	3.3.1.3	C	Quantify importance of human persecution on aga	5 years	DFW* USFWS	100	20	20	20	20	20	100
2	1	1.1.5	A, C, E	Develop and maintain aga data center	50 years	USFWS	52	3	1	1	1	1	7
2	1	1.2.1.2	A, E	Engage people of Guam and Rota	50 years	DFW USFWS	250	5	5	5	5	5	25
2	1	1.2.2.5.1	A	Consider safe harbor agreements	10 years	USFWS	50	5	5	5	5	5	25
2	1	1.2.2.5.2	A, C, E	Establish agreements that allow research to be conducted on lands that include aga habitat	10 years	DFW USFWS	50	5	5	5	5	5	25
2	1	2.2.2	A	Maintain and protect recovery habitat on Southern Guam	15 years	USN* USFWS	7,500	500	500	500	500	500	2,500
2	1	3.3.1.1	C	Determine if rat control on Rota is necessary	3 years	DFW* USFWS	60	20	20	20	-	-	60
2	1	3.3.1.2	C	Pursue management registration of rodenticide	4 years	USFWS* WS	40	10	10	10	10	-	40
2	1	3.3.1.3	C	Determine how black drongos affect aga	3 years	DFW* USFWS	60	20	20	20	-	-	60
2	1	3.3.4.3	E	Investigate effects of egg removal on individual pairs	5 years	DFW USFWS DAWR*	10	2	2	2	2	2	10
2	1	4.1.3	A, C, E	Consider repeating the offroad counts in 2008 and at 5-year intervals	50 years	DFW* USFWS	50	-	-	-	5	-	5

Priority Number	Priority Tier	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Cost Estimate (in $10,000 units)						
							Total Costs	FY 05	FY 06	FY 07	FY 08	FY 09	5-Year Costs
2	1	4.2.1	C	Continue experimental translocations from Rota to northern Guam	Ongoing; 20 years	DFW USFWS DAWR	400	20	20	20	20	20	100
2	1	4.2.1.1	C	Design translocation studies determining factors limiting aga survivorship on Guam	1 year	DAWR* USFWS	10	10	-	-	-	-	10
2	1	4.2.1.2	C	Design translocation studies to determine aga breeding success in presence of snakes on Guam	1 year	DAWR* USFWS	10	10	-	-	-	-	10
2	1	4.2.2.1	C	Develop site-specific implementation plans for each release site	1 year	DAWR* USFWS	10	10	-	-	-	-	10
2	2	3.3.3.3	C, E	Determine reasons for nest abandonment	3 years	DFW* USFWS	60	20	20	20	-	-	60
2	2	4.3.1.1	A, C, E	Monitor need to initiate captive breeding	20 years	DAWR DFW MCRT USFWS*	20	1	1	1	1	1	5
2	3	3.3.2.2	A	Determine how territory size varies with habitat quality	3 years	DFW* USFWS	60	20	20	20	-	-	60
2	4	1.2.3	A, C, E	Coordinate education and outreach	50 years	DAWR DFW USFWS	50	1	1	1	1	1	5
2	4	2.3.4	A	Conduct vegetation assessment of all areas important to aga	3 years	DFW* USFWS	60	20	20	20	-	-	60
2	4	3.3.2.1	C, E	Determine if current habitat is occupied to escape limiting factors	3 years	DFW* USFWS	60	20	20	20	-	-	60

Implementation Schedule for the Draft Revised Recovery Plan for the Aga or Mariana Crow • May 2005

Priority Number	Priority Tier	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Cost Estimate (in $10,000 units)						
							Total Costs	FY 05	FY 06	FY 07	FY 08	FY 09	5-Year Costs
2	4	3.3.3.2	A, C, E	Quantify percentage of territorial birds breeding each year	10 years	DFW* USFWS	100	10	10	10	10	10	50
3	1	1.1	A, C, E	Maintain an active recovery team	Ongoing; 50 years	USFWS	50	1	1	1	1	1	50
3	1	1.1.3	A, C, E	Establish short-term objectives for the recovery program	Ongoing; 50 years	MCRT USFWS*	50	1	1	1	1	1	50
3	1	1.1.4	A, C, E	Review recovery plan every 5 years or as needed, and revise and update it as appropriate	50 years	MCRT USFWS*	10	-	-	-	-	1	1
3	1	1.2.2.1	A, C, E	Increase funding agency interest in aga recovery	50 years	MCRT	50	1	1	1	1	1	5
3	1	1.2.2.2	A, C, E	Inform other recovery groups	50 years	MCRT	50	1	1	1	1	1	5
3	1	1.2.2.3	A, C, E	Develop partnerships with conservation groups	50 years	MCRT USFWS*	50	1	1	1	1	1	5
3	1	1.2.2.4	A, C, E	Demonstrate interest and respect for other management practices	50 years	DFW DAWR USFWS MCRT	50	1	1	1	1	1	5
3	1	1.3.2	A, C, E	Involve local residents in research to the extent practical	50 years	DAWR DFW	400	8	8	8	8	8	40
3	1	2.3.1	A	Minimize or eliminate ungulate impacts on aga habitat when appropriate	20 years	DAWR DFW USN USAF USFWS WS	200	20	20	20	20	20	100

Implementation Schedule for the Draft Revised Recovery Plan for the Aga or Mariana Crow • May 2005

Priority Number	Priority Tier	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Cost Estimate (in $10,000 units)						
							Total Costs	FY 05	FY 06	FY 07	FY 08	FY 09	5-Year Costs
3	1	2.3.2	A	Identify and eliminate invasive plant species	30 years	DAWR DFW USN USAF USFWS	600	20	20	20	20	20	100
3	1	3.3.6	E	Bank tissue samples for possible genetic analyses	30 years	USFWS	30	1	1	1	1	1	5
3	1	3.3.7.1	C	Determine diseases found in wild populations	3 years	DAWR DFW USFWS	60	20	20	20	-	-	60
3	1	3.3.7.2	C	Specify diseases exclusive to Guam and Rota	3 years	DAWR DFW USFWS	60	20	20	20	-	-	60
3	1	4.2.1.3	C	Design translocations that do not introduce or exacerbate disease problems on Guam	1 year	DAWR* USFWS	10	10	-	-	-	-	10
3	1	4.2.3.1	A, C, E	Remove limiting factors for aga in southern Guam	30 years	DAWR USN USFWS WS	12,500	500	500	500	500	500	2,500
3	1	4.2.3.3	E	Translocate aga from northern Guam and/or Rota to southern Guam	20 years	DAWR* DFW USFWS	1,000	50	50	50	50	50	250
3	1	4.3.1.2	A, C, E	Maintain contact with ongoing captive breeding efforts in Pacific	20 years	DAWR MCRT USFWS	20	1	1	1	1	1	5
3	1	4.3.3	A, C, E	Establish wild populations on other island to prevent species extinction	20 years	DFW USFWS	1000	50	50	50	50	50	250

Implementation Schedule for the Draft Revised Recovery Plan for the Aga or Mariana Crow • May 2005

Priority Number	Priority Tier	Action Number	Listing Factor	Action Description	Action Duration	Responsible Parties	Cost Estimate (in $10,000 units)						
							Total Costs	FY 05	FY 06	FY 07	FY 08	FY 09	5-Year Costs
3	2	1.3.1	A, C, E	Plan and conduct cooperative research at sites where aga exist on Rota and Guam	20 years	DAWR DFW MCRT USFWS	400	20	20	20	20	20	100
3	2	2.3.3	A	Implement reforestation programs using native forest plant species to improve degraded areas with aga habitat	30 years	USAF USN DAWR DFW USFWS	7,500	250	250	250	250	250	1,250
3	2	3.3.3.4	A	Determine nest site selection criteria & fidelity	3 years	DFW* USFWS	60	20	20	20	-	-	60
3	2	3.3.3.6	E	Determine natal dispersal	3 years	DFW* USFWS	60	20	20	20	-	-	60
3	2	4.3.1.3	A, C, E	Coordinate needs for captive breeding with other endangered species in Marianas	20 years	DAWR DFW MCRT USFWS*	20	1	1	1	1	1	5
3	2	4.3.2	A, C, E	Establish captive populations in mainland zoos to prevent species extinction	10 years	USFWS	500	50	50	50	50	50	250
3	3	3.3.3.7	A, C, E	Develop spatially-explicit model of aga populations	1 year	DFW* USFWS	5	-	-	-	-	5	5
3	3	3.3.4.1	E	Study aga social system	3 years	DFW* USFWS	60	20	20	20	-	-	60
3	3	3.3.4.2	E	Determine behavior options that are pursued by pre-breeders	3 years	DFW* USFWS	60	20	20	20	-	-	60
3	3	3.3.5.2	A	Conduct studies on foraging behavior and habitat use	3 years	DFW* USFWS	60	20	20	20	-	-	60
						TOTALS	66,142						17,118

IV. REFERENCES

Aguon, C.F. 1990. The current distribution and abundance of the Mariana crow, *Corvus kubaryi*, on Guam. Pages 129-135 *in* Annual Report Fiscal Year 1990 (Andersen, R.D., G.W. Davis, L.L. Mariano, T.J. Pitlik, and G.J. Wiles, eds.). Guam Division of Aquatic and Wildlife Resources. Guam Departmetn of Agriculture, Marngilao, Guam.

Aguon, C.F. 1997. Survey for Mariana crow and their nests. Pages 98-113 *in* Annual Report, Fiscal Year 1997 (R.D. Anderson, G.W. Davis, L.L. Mariano, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Aguon, C.F. 1999a. Reproductive biology of the Mariana crow and other endangered species. Pages 110-122 *in* Annual Report, Fiscal Year 1999 (G.W. Davis, L.L. Mariano, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Aguon, C.F. 1999b. Translocation of Mariana Crows. Pages 139-142 *in* Annual Report Fiscal Year 1999 (G.W. Davis, L.L. Mariano, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Aguon, C.F. and L. Henderson. 1998. Reproductive biology of the Mariana crow and other endangered species. Pages 94-109 and 128-136 *in* Annual Report, Fiscal Year 1998 (R.D. Anderson, G.W. Davis, L.L. Mariano, T.J. Pitlik, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Aguon, C.F., and L. Henderson. 1999. Survey for Mariana crows and their nest sites on Guam and Rota. Pages 104-109 *in* Annual Report Fiscal Year 1999 (G.W. Davis, L.L. Mariano, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Aguon, C.F. and G.J. Wiles. 1991. Survey and inventory of non-game birds. Pages 106-119 *in* Annual Report, Fiscal Year 1991 (R.D. Anderson, G.W. Davis, L.L. Mariano, and G. J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Aguon, C.F. and G.J. Wiles. 1992. Survey and inventory of non-game birds. Pages 84-92 *in* Annual Report, Fiscal Year 1992 (R.D. Anderson, G.W. Davis, L.L. Mariano, T.J. Pitlik, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Aguon, C.F., R.E. Beck, Jr., and M.W. Ritter. 1999. A method for protecting nests of the Mariana crow from brown treesnake predation. Pages 460-467 *in* Problem snake management: the Habu and the Brown Treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Aguon, C.F., E.W. Campbell, III, and J.M. Morton. 2002. The efficacy of electrical barriers used to protect Mariana crow nests. Wildlife Society Bulletin 30:703-708.

Aguon, C.F., G.J. Wiles, and T.L. Larscheid. 1994. Survey and inventory of non-game birds. Pages 79-89 *in* Annual Report Fiscal Year 1994 (R.D. Andersen, G.W. Davis, L.L. Mariano, T.J. Pitlik, and G.J. Wiles, eds.). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Akcakaya, H.R. 1999. RAMAS GIS. Linking landscape data with population viability analysis. Applied Biomathematics. Setauket, New York.

Ali, S. and S.D. Ripley. 1972. Handbook of the Birds of India and Pakistan, Volume 5. Oxford University Press, London.

Altizer, S. and Dobson, A.P. 2000. Progress report to the USGS Biological Resources Division, National Wildlife Health Center, Madison, Wisconsin. Report by the Department of Ecology and Evolutionary Biology, Princeton University, Princeton, New Jersey.

Amar, A. 2004. Mariana Crow Research Project Report, 2003-2004. Unpublished report submitted to the Division of Fish and Wildlife, Commonwealth of the Northern Mariana Islands.

Amar, A., F. Amidon, B. Arroyo, J. Esselstyn, and A. Marshall. In review. Population trends of the forest bird community on the Pacific island of Rota, Mariana Islands. Submitted to *Condor*.

Amidon, F.A. 2000. Habitat relationships and life history of the Rota bridled white-eye (*Zosterops rotensis*). M.S. thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Anderson, R.D. 1981. Impact of environmental contaminants on native forest bird populations. Pages 177-178 <u>in</u> Annual Report, Fiscal Year 1981. (R.D. Anderson and A. Hosmer, editors) Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Atkinson, I.A.E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. Pages 35-81 *in* Conservation of island birds (P.J. Moors, editor). Technical Publication Number 3. International Council for Bird Preservation, Cambridge, England.

Baker, R.H. 1946. Some effects of the war on the wildlife of Micronesia. Transactions of the North American Wildlife Conference 11:205-213.

Baker, R.H. 1948. Report on the collections of birds made by United States Naval Medical Research Unit No. 2 in the Pacific war area. Smithsonian Miscellaneous Collection 107:1-74.

Baker, R.H. 1951. The avifauna of Micronesia, its origin, evolution, and distribution. University of Kansas Publications 3:1-359.

Beaty, J.J. 1967. Guam's remarkable birds. South Pacific Bulletin 17:37-40.

Bohart, R.M. 1956. Insects of Micronesia. Diptera: Culicidae. Bernice.P. Bishop Museum Bulletin12:1-85.

[BTSCC] The Brown Tree Snake Control Committee. 1996. The Brown Tree Snake control plan. U.S. Fish and Wildlife Service, Aquatic Nuisance Species Action Force, Honolulu, Hawai`i.

Bryan, E.H., Jr. 1971. Guide to place names in the Trust Territory of the Pacific Islands. Pacific Science Information Center, Bernice P. Bishop Museum. Honolulu, Hawai`i.

Bykovskii, V.A., and N.V. Kandybin. 1988. Biological principles, development, and perspectives of the use of bacteria and viruses. Pages 377-389 *in* Rodent pest management. CRC Press, Boca Raton, Florida.

Campbell, E.W., III. 1996. The effect of Brown Tree Snake (*Boiga irregularis*) predation on the island of Guam's extant lizard assemblages. Ph.D. dissertation, Ohio State University, Columbus, Ohio.

Campbell, E.W., III, G.H. Rodda, T.H. Fritts, and R.L. Bruggers. 1999. An integrated management plan for the Brown Treesnake (*Boiga irregularis*) on Pacific islands. Pages. 423-435 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Carano, P. and P.C. Sanchez. 1964. A complete history of Guam. Charles E. Tuttle, Inc., Rutland, Vermont.

Centers for Disease Control and Prevention. 2004. Web site of the Centers for Disease Control and Prevention, U.S. Department of Health and Human Services, available at <http://www.cdc.gov/ncidod/dvbid/westnile/mosquitoSpecies.htm>. Accessed August 2004.

Chiszar, D. 1990. The behavior of the Brown Tree Snake, *Boiga irregularis*: a study in applied comparative psychology. Pages 101-123 *in* Contemporary issues in comparative psychology (D. Dewsbury, editor). Sinauer Associates, Sunderland, Massachusetts.

Churcher, P.B. and J.H. Lawton. 1987. Predation by domestic cats in an English village. Journal of Zoology 212:439-456.

Clark, C.S. 1998. Activity patterns and microhabitat use of the Brown Treesnake, *Boiga irregularis*. M.S. thesis, Ohio State University, Columbus, Ohio.

Conry, P.J. 1988. High nest predation by brown tree snakes on Guam. Condor 90:478-82.

D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass-fire cycle, and global change. Annual Review of Ecology and Systematics 23:63-87.

Davis, D.E., K. Myers, and J.B. Hoy. 1976. Biological control among vertebrates. Pages 501-519 *in* Theory and practice of biological control (C.B. Huffaker and P.S. Messenger, editors). Academic Press, New York.

[DAWR] Division of Aquatic and Wildlife Resources. 2002. Endangered species recovery report for the aga, *Corvus kubaryi*, on Guam: Subpermit TE-032209-05 activities, 2001-2002 breeding season, for period through 4 April 2002. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam.

[DAWR] Division of Aquatic and Wildlife Resources. 2003. Endangered species recovery report for the aga, *Corvus kubaryi*, on Guam: Subpermit TE-032209-06 activities, 2002-2003 breeding season, for period through December 2003. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam.

[DAWR] Division of Aquatic and Wildlife Resources. 2004. Endangered species recovery report for the aga, *Corvus kubaryi*, on Guam: Subpermit TE-032209-05 activities, 2003-2004 breeding season, for period through January 2004. Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam.

Donnegan, J.A., S.L. Butler, W. Grabowiecki, B.A. Hiserote, and D. Limtiaco. In press. Guam's forest resources, 2002. Resource Bulletin PNW-RB-XXX. U.S. Department of Agriculture, Pacific Northwest Research Station, Portland, Oregon.

Drahos, N. 1977. Population dynamics of Guam birds. Unpublished report submitted to Division of Aquatic and Wildlife Resources, Guam Department of Agriculture, Mangilao, Guam.

Drahos, N. 2002. The mysteries and histories of Guam's birds. Published by Nick Drahos, Aurora, New York.

Eldredge, L.G. 1983. Summary of the environmental and fishing information of Guam and the Commonwealth of the Northern Mariana Islands. Historical background, description of the islands, and review of climate, oceanography, and submarine topography. NOAA [National Ocean and Atmospheric Administration] Technical Memorandum NMFS 40.

Engbring, J. 1989. Fluctuations in bird populations on the island of Rota as related to an experimental program to control the Melon Fly. Unpublished report submitted to U.S. Fish and Wildlife Service, Honolulu, Hawai`i.

Enbring, J., and T.H. Fritts. 1988. Demise of an insular avifauna: the brown tree snake on Guam. Transactions of the Western Section of the Wildlife Society 24:31-37.

Engbring, J. and F.L. Ramsey. 1984. Distribution and abundance of forest birds of Guam: Results of a 1981 survey. U.S. Fish and Wildlife Service, Washington, D.C.; Contract no. FWS-OBS-84/20.

Engbring, J. and H.D. Pratt. 1985. Endangered birds in Micronesia: Their history, status, and future prospects. Bird Conservation 2:71-105.

Engbring, J., F.L. Ramsey, and V.J. Wildman. 1986. Micronesian forest bird survey, 1982: Saipan, Tinian, Agiguan, and Rota. U.S. Fish and Wildlife Service Special Publication, Honolulu, Hawai`i.

Engeman, R.M. and M.A. Linnell. 1998. Trapping strategies for deterring the spread of brown tree snakes from Guam. Pacific Conservation Biology 4:348-353.

Engeman, R.M., M.A. Linnell, P.A. Pochop, and J. Gamboa. 1998a. Substantial reductions of Brown Tree Snake (*Boiga irregularis*) populations in blocks of land on Guam through operational trapping. International Biodeterioration and Biodegradation 42:167-171.

Engeman, R.M., M.A. Linnell, D.S. Vice, and M.E. Pitzler. 1998b. Efficacy of the methods used in an integrated program to deter the spread of brown tree snakes from Guam. Proceedings from the Australian Vertebrate Pest Conference 11:435-440.

Engeman, R.M., D.V. Rodriguez, M.A. Linnell, and M.E. Pitzler. 1998c. A review of the case histories of the brown tree snakes (*Boiga irregularis*) located by detector dogs on Guam. International Biodeterioration and Biodegradation 42:161-165.

Engeman, R.M., S. Sayama, and M.A. Linnell. 1998d. Operational utility of perimeter trapping for removing brown tree snakes (*Boiga irregularis*) from a defined area. The Snake 28:19-22.

Engeman, R.M., D.S. Vice, D.V. Rodriquez, K.S. Gruver, W.S. Santos, and M.E. Pitzler. 1998e. Effectiveness of detector dogs used for deterring the dispersal of brown tree snakes. Pacific Conservation Biology 4:348-353.

Engeman, R.M., D.S. Vice, G. Nelson, and E. Muña. 2000. brown tree snakes effectively removed from a large plot of land on Guam by perimeter trapping. International Biodeterioration and Biodegradation 45:139-142.

Engeman, R.M., D.S. Vice, D. York, and K.S. Gruver. 2002. Sustained evaluation of the effectiveness of detector dogs for locating brown tree snakes in cargo outbound from Guam. International Biodeterioration and Biodegradation 49:101-106.

Falanruw, M.C., T.G. Cole, and A.H. Ambacher. 1989. Vegetation survey of Rota, Tinian, Saipan, Commonwealth of the Northern Marianas. U.S. Department of Agriculture Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California. Resource Bulletin PSW-27.

Fancy, S.G. 1997. A new approach for analyzing bird densities from variable circular-plot counts. Pacific Science 51:107-114.

Fancy, S.G. and T.J. Snetsinger. 2001. What caused the population decline of the bridled white-eye population on Rota, Mariana Islands. Studies in Avian Biology 22:274-280.

Fancy, S.G., M.R. Lusk, and D.J. Grout. 1999. Status of the Mariana crow population on Rota, Mariana Islands. Micronesica 32:3-10.

Farrell, D.A. 1991. History of the Northern Mariana Islands. Public School System of the CNMI (Commonwealth of the Northern Mariana Islands), Saipan, MP.

Fenner, F. 1983. Biological control, as exemplified by smallpox eradication and myxomatosis. Proceedings of the Royal Society of London B, Biological Sciences 218:259-285.

Fosberg, F.R. 1960. The vegetation of Micronesia. Bulletin of the American Museum of Natural History 119:1-75.

Fritts, T.H. 2000. Problems and innovations in controlling Brown Treesnakes on Guam. Aquatic Nuisance Species Digest 4:1-4.

Fritts, T.H. and M.J. McCoid. 1991. Predation by the Brown Tree Snake on poultry and other domesticated animals in Guam. The Snake 23:75-80.

Fritts, T.H. and G.H. Rodda. 1998. The role of introduced species in the degradation of island ecosystems: a case history of Guam. Annual Review of Ecology and Systematics 29:113-140.

Fritts, T.H., M.J. McCoid, and D.M. Gomez. 1999. Dispersal of snakes to extralimital islands: incidents of the Brown Treesnake, *Boiga irregularis*, dispersing to islands in ships and aircraft. Pages 209-223 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Glass, P.O. 2000. Overview of the Brown Tree Snake interdiction program in the Mariana Islands with respect to cargo movements, 1999. Draft report by U. S. Fish and Wildlife Service, Houston, Texas.

Grimmett, R., C. Inskipp, and T. Inskipp. 1999. A guide to the birds of India, Pakistan, Nepal, Bangladesh, Bhutan, Sri Lanka, and the Maldives. Princeton University Press, Princeton, New Jersey.

Grout, D.J. 1993. An investigation into the effects of VRC-50 squadron overflights on federally endangered Mariana crows and Mariana fruit bats in Pati Point area of Andersen Air Force Base, Guam. Unpublished report submitted to the U.S. Fish and Wildlife Service, Honolulu, Hawai`i.

Grue, C.E. 1985. Pesticides and the decline of Guam's native birds. Nature 316:301.

Gustafson, L. and T. Part. 1990. Acceleration of senescence in the collared flycatcher, *Ficedula albicollis*, by reproductive costs. Nature 347:279-281.

Haddock, R. L., R. A. Mackie, and K. Cruz. 1979. Dengue control in Guam. South Pacific Bulletin 2:16-24.

Hetherington, T.E. 2001. Project summary: ecological physiology of the Brown Treesnake (*Boiga irregularis*). Unpublished report submitted to the U.S. Geological Survey by Ohio State University, Columbus, Ohio.

Holmes, J.C. 1982. Impact of infectious disease agents on the population growth and geographical distribution of animals. Pages 37-51 *in* Population biology of infectious diseases (R.M. Anderson and R.M. Mar, editors). Springer-Verlag, Berlin.

Howarth, F.G. 1999. Environmental risks of biological control of vertebrates. Pages 399-410 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Imamura, C.K. 1993. Use of dogs in the interdiction and containment of the Brown Tree Snake in transportation networks in the Pacific: a preliminary examination. Pacific Basin Development Council, Honolulu, Hawai`i.

Imamura, C.K. 1999. A preliminary examination of public policy issues in the use of canine detection of Brown Treesnakes. Pages 353-362 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Jackson, K. and G. Perry. 2000. Changes in intestinal morphology following feeding in the Brown Treesnake, *Boiga irregularis*. Journal of Herpetology 34:459-462.

Jenkins, J.H. 1983. The native forest birds of Guam. Ornithological Monographs 31:1-61.

Linnell, M.A., R.M. Engeman, M.E. Pitzler, M.O. Watten, G.F. Whitehead, and R.C. Miller. 1998. An evaluation of two designs of stamped metal trap flaps for use in operational trapping of brown tree snakes (*Boiga irregularis*). The Snake 28:14-18.

Lusk, M. 1994. Rota bridled white-eye/black drongo research. Pages 18-20 *in* Division of Fish and Wildlife, Wildlife Research and Management Program: 1993 Annual Report. Commonwealth of the Northern Mariana Islands Division of Fish and Wildlife, Lower Base, Saipan, MP.

Lusk, M.R. and E. Taisacan. 1996. Dimensions and composition of Mariana crow nests on Rota, Mariana Islands. Micronesica 29:299-304.

Maben, A.F. 1980. Development of a study to determine the past and present impact of pesticides on Guam's wildlife populations. Pages 326-329 *in* Annual Report, Fiscal Year 1980 (R.D. Anderson, A. Hosmer, D. Morris, and J. Beaver, editors). Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Maben, A.F. 1982. The feeding ecology of the black drongo (*Dicrurus macrocercus*) on Guam. M.S. thesis. California State University, Long Beach; Long Beach, California.

Mack, M.C. and C.M. D'Antonio. 1998. Impacts of biological invasions on disturbance regimes. Trends in Ecology and Evolution 13:195-198.

Marshall, J.T. Jr. 1949. The endemic avifauna of Saipan, Tinian, Guam, and Palau. Condor 51:200-21.

Marzluff, J.M. 1988. Vocal recognition of mates by breeding pinyon jays, *Gymnorhinus cyanocephalus*. Animal Behaviour 36:296-298.

McCoid, M.J. 1997. Interactions of *Carlia cf. fusca* (Scincidae) with the herpetofauna of Guam. M.S. thesis, Texas A&M University, Kingsville; Kingsville, Texas.

McDonald, D.B, J.W. Fitzpatrick, and G.E. Woolfenden. 1996. Actuarial senescence and demographic heterogeneity in the Florida Scrub Jay. Ecology 77:2372-2381.

Michael, G.A. 1987. Notes on the breeding biology and ecology of the Mariana or Guam crow. Aviculture Magazine 93:73-82.

Morton, J. 1996. The effects of aircraft overflights on endangered Mariana crows and Mariana fruit bats at Andersen Air Force Base, Guam. Pearl Harbor: Department of the Navy, Pacific Division, Naval Facilities Engineering Command.

Morton, J.M., S. Plentovich, and T. Sharp. 1999. Reproduction and juvenile dispersal of Mariana Crows (*Corvus kubaryi*) on Rota 1996-1999. Unpublished report submitted to the U.S. Fish and Wildlife Service, Honolulu, Hawai`i.

Mueller-Dombois, D. and F.R. Fosberg. 1998. Vegetation of the tropical pacific islands. Ecological Studies, Volume 132. Springer, New York, New York.

Nakamoto, E., H. Fukushima, and Y. Sawai. 1981. Longevity of Habu (*Trimeresurus flavoviridis*) maintained in a hungry condition [in Japanese w/Eng. summary]. The Snake 13:61-62.

Nichols, D.K. 2000. Project title: Pathogenesis of *Ophidian paramyxovirus* infection in the Brown Tree Snake (*Boiga irregularis*). Final report for the Office of Insular Affairs, Department of the Interior, September 30, 2000. Unpublished report submitted to the U.S. Department of the Interior Office of Insular Affairs, Washington, D.C.

[NOAA] National Oceanic and Atmospheric Administration. 1982. Local climatological data, annual summary with comparative data, Guam, Pacific. Asheville National Climatic Data Center, Asheville, North Carolina.

Nokes, D.J. 1992. Microparasites: viruses and bacteria. Pages 349-374 *in* Natural enemies: the population biology of predators, parasites and diseases (M. J. Crawley, editor). Blackwell Science, Oxford, England.

[NRC] National Research Council. 1997. The scientific bases for preservation of the Mariana Crow. National Academy Press, Washington, D.C.

Perez, G. 1968. Relative status and ecological notes of some Guam birds. Unpublished report submitted to the Division of Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Perry, G. 1999. Digestion in the Brown Treesnake, *Boiga irregularis*. Page 181 *in* Program book and abstracts: American Society of Ichthyology and Herpetology, American Elasmobranch Society, Herpetology League, Society for the Study of Amphibians and Reptiles, State College, Pennsylvania.

Perry, G., G.H. Rodda, T.H. Fritts, and M.W. Doles. 1996. Experimental research on snake control conducted using Legacy funding-a preliminary report on barrier technology and related work. Unpublished report by Ohio State University, Columbus, Ohio.

Perry, G., G.H. Rodda, T.H. Fritts, and S.J. Kit. 1997. Use of temporary barriers to block dispersal of brown tree snakes (*Boiga irregularis*) during military exercises. (Final report to Andersen Air Force Base). Unpublished report by Ohio State University, Columbus, Ohio.

Perry, G., E.W. Campbell, III, G.H. Rodda, and T.H. Fritts. 1998. Managing island biotas: brown treesnake control using barrier technology. Pages 138-143 *in* Proceedings of the 18th Vertebrate Pest Conference (R. O. Baker and A. C. Crab, editors). University of California, Davis; Davis, California.

Perry, G., Rodda, G.H., Fritts, T.H., and Qualls, F.J. 2001. Snake control using barrier technology: a final report on studies to develop temporary and permanent barriers for blocking movement of Brown Treesnakes (*Boiga irregularis*). Report submitted to the U.S. Department of the Interior, Washington, D.C.

Plentovich, S., J.M. Morton, J. Bart, R.J. Camp, M. Lusk, N. Johnson, and E.VanderWerf. In review. Current and historical population status of the Mariana Crow (*Corvus kubaryi*) on Rota, Commonwealth of the Northern Mariana Islands. Submitted to Bird Conservation.

Pratt H.D., P.L. Bruner, and D.G. Barrett. 1979. America’s unknown avifauna: the birds of the Mariana Islands. American Birds 33:227-235.

Qualls, F.J., and C.P. Qualls. 2002. A simple methods of sterilizing male snakes: a potential aid in the preventing the spread of brown treesnakes (*Boiga irregularis*) from Guam. Herpetology Review 33:185-187.

Reynolds, R.T., J.M. Scott, and R.A. Nassau. 1980. A variable circular-plot method for estimating bird numbers. Condor 82:309-313.

Robertson, H.A., J.R. Hay, E.K. Saul, and G.V McCormack. 1994. Recovery of the Kakerori: an endangered forest bird of the Cook Islands. Conservation Biology 8: 1078-1086.

Rodda, G.H. n.d. [no date]. How to keep snakes out of your house. Information page distributed by U.S. Department of Interior, Guam Division of Aquatic and Wildlife Resources, and Guam's Public Health Service, Mangilao, Guam.

Rodda, G.H. 1992. Foraging behaiour of the Brown Tree Snake, *Boiga irregularis*. Journal of Herpetology 2:110-114.

Rodda, G.H. 1993. Where's Waldo (and the snakes)? Herpetology Review 24:44-45.

Rodda, G.H. and T. H. Fritts. 1992a. Sampling techniques for an arboreal snake, *Boiga irregularis*. Micronesica 25:23-40.

Rodda, G.H. and T.H. Fritts. 1992b. The impact of the introduction of the Brown Tree Snake, *Boiga irregularis*, on Guam's lizards. Journal of Herpetology 26:166-174.

Rodda, G.H. and T.H. Fritts. 1997. Modeling of Brown Tree Snake size distributions highlights sampling problems and high adult mortality. Page 254 *in* American Society of Ichthyologists and Herpetologists, 77th Annual Meeting, University of Washington, Seattle, Washington.

Rodda, G.H., T.H. Fritts, and P.J. Conry. 1992a. Origin and population growth of the Brown Tree Snake, *Boiga irregularis*, on Guam. Pacific Science 46:46-57.

Rodda, G.H., R.J. Rondeau, T.H. Fritts, and O.E. Maughan. 1992b. Trapping the arboreal snake *Boiga irregularis*. Amphibia-Reptilia 13:47-56.

Rodda, G.H., E.W. Campbell, III, and S.R. Derrickson. 1998a. Avian conservation research needs in the Mariana Islands, western Pacific Ocean. Pages 367-381 *in* Avian conservation: research and management (J. M. Marzluff and R. Sallabanks, editors). Island Press, Washington, D.C.

Rodda, G.H., T.H. Fritts, G. Perry, and E.W. Campbell, III. 1998b. Managing island biotas: can indigenous species be protected from introduced predators such as the Brown Treesnake? Pages 95-108 *in* Transactions of the 63rd North American Wildlife and Natural Resources Conference (K.G. Wadsworth, editor). Wildlife Management Institute, Washington, D.C.

Rodda, G.H., T.H. Fritts, and E.W. Campbell, III. 1999a. The feasibility of controlling the Brown Treesnake in small plots. Pages 468-477 *in* Problem snake management: the habu and the brown treesnake (G. H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Rodda, G.H., T.H. Fritts, C.S. Clark, S.W. Gotte, and D. Chiszar. 1999b. A state-of-the-art trap for the Brown Treesnake. Pages 268-305 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Rodda, G.H., T.H. Fritts, M.J. McCoid, and E.W. Campbell, III. 1999c. An overview of the biology of the Brown Treesnake, *Boiga irregularis*, a costly introduced pest on Pacific Islands. Pages 44-80 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Rodda, G.H., M.J. McCoid, T.H. Fritts, and E.W. Campbell, III. 1999d. Population trends and limiting factors in *Boiga irregularis*. Pages 236-253 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Rodda, G.H., Qualls, C.P., Perry, G., Fritts, T.H., Qualls, F.J., and Dean-Bradley, K. 2000. Chain-link fence bulge barrier specifications. Report by U.S. Geological Survey, Midcontinent Ecological Science Center, Fort Collins, Colorado.

Saether, B.E. and O. Bakke. 2000. Avian life history variation and contribution of demographic traits to population growth rate. Ecology 81:642-653.

Sakai, H.F. and C.J. Ralph. 1980. Observations on the Hawaiian crow in South Kona, Hawaii. Elepaio 40:133-138.

Sakai, H.F., C.J. Ralph, and C.D. Jenkins. 1986. Foraging ecology of the Hawaiian crow, an endangered generalist. Condor 88:211-219.

Santana-Bendix, M.A., O.E. Maughan, V. Meretsky, and C.B. Schwalbe. 1994. Movement and activity patterns of *Boiga irregularis* (Colubridae), introduced predator on the island of Guam. Unpublished report on file with the Arizona Cooperative Fish and Wildlife Research Unit, University of Arizona, Tucson, Arizona.

Savage, H.M., C.J. Mitchell, M. Roppul, L.T. Castro, R.L. Kepple, and S.P. Flood. 1993. Mosquito faunal survey of Saipan, Mariana Islands (Diptera: Culicidae): taxonomy and larval ecology. Mosquito Systematics 25:17-25.

Savarie, P.J., and R.L. Bruggers. 1999. Candidate repellents, oral and dermal toxicants, and fumigants for Brown Treesnake control. Pages 417-422 *in* Problem snake management: the habu and the brown treesnake (G.H. Rodda, Y. Sawai, D. Chiszar, and H. Tanaka, editors). Cornell University Press, Ithaca, New York.

Savarie, P.J., R.L. Bruggers, and W.S. Wood. 1991. Methyl bromide fumigation of Brown Tree Snake on Guam. Unpublished report on file with the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Denver Wildlife Research Center, Denver, Colorado.

Savarie, P.J., J.E. Brooks, and W.S. Wood. 1995. Fumigation of brown tree snakes with methyl bromide, sulfuryl fluoride, and phosphine on Guam. Unpublished report on file with the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Denver Wildlife Research Center, Denver, Colorado.

Savarie, P.J., D.L. York, J.C. Hurley, S. Volz, and J.E. Brooks. 2000. Testing the dermal and oral toxicity of selected chemicals to Brown Treesnakes. Pages 139-145 *in* Volume 19, Proceedings of the 19th Vertebrate Pest Conference (T. P. Salmon and A. C. Crabb, editors). University of California, Davis; Davis, California.

Savarie, P.J., J.A. Shivik, G.C. White, J.C. Hurley, and L. Clark. 2001. Use of acetaminophen for large scale control of Brown Treesnakes. Journal of Wildlife Management 65:356-365.

Savarie, P.J., W.S. Wood, G.H. Rodda, R.L. Bruggers, and R.M. Engeman. in press. Effectiveness of methyl bromide as a cargo fumigant for the Brown Tree Snake (*Boiga irregularis*). The Snake.

Savidge, J.A. 1986. The role of disease and predation in the decline of Guam's avifauna. Ph.D. dissertation. University of Illinois, Champaign, Illinois.

Savidge, J.A. 1987. Extinction of an island avifauna by an introduced snake. Ecology 68:660-668.

Savidge, J.A. 1988. Food habits of *Boiga irregularis*, an introduced predator on Guam. Journal of Herpetology 22:275-82.

Savidge, J.A., L. Sileo, and L. M. Siegfried. 1992. Was disease involved in the decimation of Guam's avifauna? Journal of Wildlife Diseases 28:206-214.

Scott, J.M., S. Mountainspring, F.L. Ramsey, and C.B. Kepler. 1986. Forest bird communities of the Hawaiian Islands: Their dynamics, ecology, and conservation. Studies in Avian Biology 9.

Seale, A. 1901. Report of a mission to Guam. Honolulu: Occasional papers of the Bernice P. Bishop Museum 1:17-128.

Shivik, J.A. and L. Clark. 1997. Carrion-seeking in brown tree snakes: importance of olfactory and visual cues. Journal of Experimental Zoology 270:549-553.

Shivik, J.A., W.G. Wright, and L. Clark. 2000. Seasonal variability in Brown Tree Snake (*Boiga irregularis*) response to lures. Canadian Journal of Zoology 78:1-6.

Silva-Krott, I., M.K. Brock, and R.E. Junge. 1998. Determination of the presence of *Mycobacterium avium* on Guam as a precursor to reintroduction of indigenous bird species. Pacific Conservation Biology 4:227-231.

Sinclair, A.R.E., R.P. Pech, C.R. Dickman, D. Hik, P. Mahon, and A.E. Newsome. 1998. Predicting effects of predation on conservation of endangered prey. Conservation Biology 12:564-575.

Snyder, N.F.R., S.R. Derrickson, S.R. Beissinger, J.W. Wiley, T.B. Smith, W. D. Toones, and B. Miller. 1996. Limitations of captive breeding in endangered species recovery. Conservation Biology 10:338-348.

Stattersfield, A.J. and D.R. Capper. 2000. Threatened birds of the world. Birdlife International. Lynx Edicions, Barcelona, Spain.

Steadman, D.W. 1992. Extinct and extirpated birds from Rota, Mariana Islands. Micronesica 25:71-84.

Steadman, D.W. 1995. Determining the natural distribution of resident birds in the Mariana Islands, phase I. Preliminary report (22 April 1995) on the results of field work conducted during June-July 1994. Unpublished report on file with the U.S. Fish and Wildlife Service, Honolulu, Hawai`i.

Steadman, D.W. 1998. Determining the natural distribution of resident birds in the Mariana Islands. Final report (24 February 1998) on the results of field work conducted during June-July 1994. Unpublished report on file with the U.S. Fish and Wildlife Service, Honolulu, Hawai`i.

Steadman, D.W. 1999. The prehistory of vertebrates, especially birds, on Tinian, Aguiguan, and Rota, Northern Mariana Islands. Micronesica 31:319-345.

Stone, B.C. 1970. The flora of Guam. Micronesica 6:1-659.

Strong, A.E., T. J. Goreau and R. L. Hayes. 1998. Ocean hot spots and coral reef bleaching: January-July 1998. Reef Encounter 24:20-22.

Stophlet, J.J. 1946. Birds of Guam. Auk 63:539-40.

Swezey, O.H. 1942. Insects of Guam – 1. Culicidae of Guam. Bernice P. Bishop Museum Bulletin 172:199-200.

Tarr, C.L. and R.C. Fleischer. 1999. Population boundaries and genetic diversity in the endangered Mariana crow (*Corvus kubaryi*). Molecular Ecology 8:941-949.

Taylor, R.H., and B.W. Thomas. 1993. Rats eradicated from rugged Breaksea Island (170 hectares), Fiordland, New Zealand. Biological Conservation 65:191-198.

Thomas, L., J.L. Laake, S. Strindberg, F. Marques, D.L. Borchers, S.T. Buckland, D.R. Anderson, K.P. Burnham, S.L. Hedley, and J.H. Pollard. 2001. Distance 4.0. Beta 2. Research Unit for Wildlife Population Assessment, University of St. Andrews, United Kingdom.

Tobin, M.E., R.T. Sugihara, P.A. Pochop, and M.A. Linnell. 1999. Nightly and seasonal movements of *Boiga irregularis* on Guam. Journal of Herpetology 33:281-291.

Tomback, D.F. 1986. Observations on the behavior and ecology of the Mariana crow. Condor 88:398-401.

U.S. Census Bureau. 2001a. Census bureau releases census 2000 population counts for Guam. News Release from the U. S. Census Bureau, Public Information Office, Department of Commerce (www.census.gov).

U.S. Census Bureau. 2001b. Census bureau releases census 2000 population counts for the Commonwealth of the Northern Mariana Islands. News Release from the U. S. Census Bureau, Public Information Office, Department of Commerce (www.census.gov).

U.S. Department of the Interior, Office of Insular Affairs. 1997. Fact sheets, United States insular areas. U.S. Department of the Interior, Office of Insular Affairs, Washington, D.C.

U.S. Department of State. 1999. Coral bleaching, coral mortality, and global climate change. Report to the U.S. Coral Reef Action Force. Bureau of Oceans and International Environmental and Scientific Affairs, 5 March 1999. Available at <http://www.state.gov/www/global/global_issues/coral_reefs/990305_coralreef_rpt.html>.

[USFWS] U.S. Fish and Wildlife Service. 1981. Endangered and threatened wildlife and plants; petition acceptance and status review. Federal Register 46:26464-26469.

[USFWS] U. S. Fish and Wildlife Service. 1984. Endangered and threatened wildlife and plants; Determination of endangered species status for seven birds and two bats of Guam and the Northern Mariana Islands. Federal Register 49:33881-33885.

[USFWS] U. S. Fish and Wildlife Service. 1987. Endangered and threatened wildlife and plants; Determination of endangered species status for *Serianthes nelsonii* Merr. (Hayun Lagu or Tronkon Guafi). Federal Register 52:4907-4910.

[USFWS] U. S. Fish and Wildlife Service. 1990. Native forest birds of Guam and Rota of the Commonwealth of the Northern Mariana Islands Recovery Plan. U.S. Fish and Wildlife Service, Portland, Oregon.

[USFWS] U. S. Fish and Wildlife Service. 2004a. Endangered and threatened wildlife and plants; designation of critical habitat for the Mariana Fruit Bat and Guam Micronesian Kingfisher on Guam and the Mariana Crow on Guam and in the Commonwealth of the Northern Mariana Islands. Federal Register 69:62944-62990.

[USFWS] U. S. Fish and Wildlife Service. 2004b. Endangered and threatened wildlife and plants; determination of endangered status and prudency determination for designation of critical habitat for two plant species from the Commonwealth of the Northern Mariana Islands. Federal Register 69:18499-18507.

[USGS] U.S. Geological Survey. 2000. National Wildlife Health Center, Wildlife Health Alert #00-002B. Available at <http://www.nwhc.usgs.gov/whats_new/wha/wha0002b.html>.

[USGS] U.S. Geological Survey. 2003. Patuxent Wildlife Research Center, bird longevity records. Available at <http://www.pwrc.usgs.gov/bbl/homepage/long3930.htm>.

[USGS] U.S. Geological Survey. 2004. National Wildlife Health Center, web site for the West Nile Virus Project. Available at http://www.nwhc.usgs.gov/research/west_nile/west_nile.html.

U. S. Navy. 2001. COMNAVMARIANAS final integrated natural resources management plan for Navy lands, Guam. U. S. Department of the Navy, Pacific Division, Naval Facilities Engineering Command, Pearl Harbor, Hawai'i.

VanderWerf, E.A, and D.G. Smith. 2002. Effects of alien rodent control on demography of the Oahu Elepaio, an endangered Hawaiian forest bird. Pacific Conservation Biology 8:73-81.

Veitch, C.R. 1985. Methods of eradicating feral cats from offshore islands in New Zealand. Pages 125-141 *in* Conservation of island birds (P.J. Moors, editor). Technical Publication No. 3. International Council for Bird Preservation, Cambridge, England.

Wiles, G. J. 1985. Preliminary results of a radio-tracking study of brown tree snakes on Guam. Pages 127-135 *in* Annual report, Fiscal year 1985 (R.D. Anderson, P.J. Conry, and M.E. Molina, editors). Guam Aquatic and Wildlife Resources Division. Guam Department of Agriculture, Mangilao, Guam.

Wiles, G.J. 1986. Movements, home range and activity patterns of brown tree snakes. Pages 138-140 *in* Annual report, Fiscal year 1986 (R.D. Anderson and P.J. Conry, editors). Guam Aquatic and Wildlife Resources Division. Guam Department of Agriculture, Mangilao, Guam.

Wiles, G.J. 1987. Movements, home range and activity patterns of the Brown Tree Snake. Pages 139-142 *in* Annual report. Fiscal year 1987 (G. R. Grimm and L.L. Mariano, editors). Guam Aquatic and Wildlife Resources Division. Guam Department of Agriculture., Mangilao, Guam.

Wiles, G.J. 1998. Records of communal roosting in Mariana crows. Wilson Bulletin 110:126-128.

Wiles, G.J. and C.F. Aguon. 1995. Survey and inventory of non-game birds. Pages 80-90 *in* Annual Report, Fiscal Year 1995 (R.D. Anderson, G.W. Davis, T.J. Pitlik, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Wiles, G.J. and C.F. Aguon. 1996. Survey and inventory of non-game birds. Pages 79-88 and 97-106 *in* Annual Report, Fiscal Year 1996 (R.D. Anderson, G.W. Davis, T.J. Pitlik, and G.J. Wiles, editors). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Wiles, G.J., C.F. Aguon, and M.W. Ritter. 1993. Survey and inventory of non-game birds. Pages 89-99 *in* Annual Report Fiscal Year 1993 (R.D. Andersen, G.W. Davis, L.L. Mariano, T.J. Pitlik, and G.J. Wiles, eds.). Guam Division of Aquatic and Wildlife Resources. Guam Department of Agriculture, Mangilao, Guam.

Wiles, G.J., C.F. Aguon, G.W. Davis, and D.J. Grout. 1995. The status and distribution of endangered animals and plants in northern Guam. Micronesica 28:31-49.

Wiles, G.J., J. Bart, R.E. Beck, Jr., and C.F. Aguon. 2003. Impacts of the brown tree snake: patterns of decline and species persistence in Guam's avifauna. Conservation Biology 17:1350-1360.

Wodzicki, K. 1978. A review of existing control methods. Pages 195-205 *in* The ecology and control of rodents in New Zealand nature reserves (P. R. Dingwall, I. A. E. Atkinson, and C. Hay, editors). New Zealand Department of Lands and Survey (Information Series 4), Wellington, New Zealand.

Work, T. M., J.G. Massey, B.A. Rideout, C.H. Gardiner, D.B. Ledig, O.C.H. Kwok, and J.P. Dubey. 2000. Fatal taxoplasmosis in free-ranging endangered 'Alala from Hawaii. Journal of Wildlife Diseases 36:205-212.

APPENDIX 1

Endangered and Threatened Species Recovery Priority Number Guidelines*

Degree of Threat	Recovery Potential	Taxonomy	Priority
High	High	Monotypic genus	1
	High	Species	2
	High	Subspecies	3
	Low	Monotypic genus	4
	Low	Species	5
	Low	Subspecies	6
Moderate	High	Monotypic genus	7
	High	Species	8
	High	Subspecies	9
	Low	Monotypic genus	10
	Low	Species	11
	Low	Subspecies	12
Low	High	Monotypic genus	13
	High	Species	14
	High	Subspecies	15
	Low	Monotypic genus	16
	Low	Species	17
	Low	Subspecies	18

Criteria for determination of recovery potential

	High recovery potential	Low recovery potential
Biological and ecological limiting factors	Well understood	Poorly understood
Threats to species' existence	Well understood, easily alleviated	Poorly understood or pervasive and difficult to alleviate
Management needed	Intensive management not needed, or techniques well documented with high probability of success	Intensive management with uncertain probability of success, or techniques unknown or still experimental

* adapted from Listing and Recovery Priority Guidelines (1983), Federal Register 48:43098-43105

APPENDIX 2

Summary Information for Aga Released on Guam as of January 2004

Name	Sex	Origin	Release Date	Status
Joga	Male	Guam	January 1997	Died August 1997
Nunu	Female	Guam	February 1997	Died sometime in 1999?
Fadang	Female	Rota	March 1997	Status unknown as of September 2003
Kafu	Male	Rota	April 1997	Died May 1997
Pengua	Female	Rota	April 1997	Died in 2000?
Umumu	Female	Rota	April 1997	Died April 1997
Faia	Female	Rota	June 1997	Died in 1999?
Ahgao	Male	Rota	June 1997	Died in 1999?
Una	Unknown	Rota	September 1999	Died September 1999
Segundo	Unknown	Rota	September 1999	Died September 1999
Okgok	Female	Rota	September 2000	Died in 2002?
Pago	Male	Rota	September 2000	Died in 2003
Umumu	Female	Rota	September 2000	Alive as of January 2004
Frank	Male	Rota	September 2000	Alive as of January 2004
Camacho	Male	Rota	September 2000	Alive as of January 2004
Unknown	Unknown	Rota	September 2000	Died in 2000?
Unknown	Unknown	Rota	September 2000	Died in 2000?
Magas	Female	Rota	May 2001	Died June 2001
Gampapa	Male	Rota	May 2001	Died in 2003
Ifit	Female	Rota	May 2001	Alive as of January 2004
Duge	Male	Rota	May 2001	Alive as of January 2004
Taksunok	Male	Rota	May 2001	Alive as of January 2004
Agaga	Unknown	Rota	September 2003	Alive as of January 2004
Amarizu	Unknown	Rota	September 2003	Alive as of January 2004
Kahit	Unknown	Rota	September 2003	Alive as of January 2004
Kezau	Unknown	Rota	September 2003	Alive as of January 2004

References: Aguon 1997; Aguon and Henderson 1998; Aguon 1999b; Aguon *in litt*. 2000, 2002, 2003, 2004; DAWR 2002, 2003, 2004 (see Section IV for all references cited)

APPENDIX 3

Population Trend of Aga on Rota

An analysis by Fancy *et al.* (1999) indicated that aga on Rota have declined substantially during the past 20 years. Subsequently, however, it was suggested that much of the observed decline may have been due to changes in how many young and incubating birds were present, rather than to a change in the number of breeding-age adults present. This prompted the Mariana Crow Recovery Team to undertake a new analysis of the population data including a series of roadside point counts not used in the initial analysis.

Methods

Two data sets were available for study: a series of point counts surveyed away from roads (offroad surveys) and a series of point counts along roads (onroad surveys). In the onroad surveys, observers recorded all aga detected at 50 points distributed fairly evenly along the road network on Rota. Many, but not all, of these points were surveyed quarterly during 1991 to 1993 and 2000 to 2001 (Table 1). During 1991 to 1993, surveyors recorded for 5 minutes at each station. During 2000 to 2001, surveyors recorded for 3 minutes at each station (in April 2001, surveyors also played an aga recording after the initial 3 minutes but we used only records obtained during the first 3 minutes). Since the later surveys were only 60 percent the length of the earlier ones, we multiplied the earlier results by 0.60. This adjustment probably underestimates the number of crows recorded during the first 3 minutes of the surveys during 1991 to 1993, thus making decreases harder to detect. But in a study of Puerto Rican birds, where the numbers seen after 3 minutes and 5 minutes were recorded, the adjustment factor was 0.69 (J. Bart, U.S. Geological Survey, unpubl. data) which suggests that the error in using 0.60 was probably small.

Table 1. Timing of roadside surveys on the island of Rota.

Year	January	April	June/July	October
1991				X
1992	X	X	X	X
1993	X	X	X	
2000	X	X	X	X
2001	X	X		

In the offroad surveys, trained observers conducted 8-minute variable circular plot (VCP) counts at stations located approximately every 150 meters (492 feet) on 13 transects in 1982 (211 stations), and 17 transects in 1995 and 1998 (311 and 314 stations respectively). The transects were widely dispersed across Rota. Distance to each aga detected, either audibly or visually, was recorded during a 4-hour period following sunrise on days when weather conditions did not interfere with detecting birds (see Scott *et al.* 1986).

Change in population size was estimated by comparing the mean number of aga recorded per station (both surveys) and by using distance methods (offroad surveys only). Means per station were calculated using only stations surveyed during every survey and acknowledging the two-stage sampling design. For the offroad surveys, the mean for a given year (1982, 1995 or 1998) was

$$\frac{1}{\boldsymbol{n}}\sum_{i}^{n}\left(\sum_{j}^{m_i}\boldsymbol{x}_{ij} / \boldsymbol{m}_i\right)$$

where x_{ij} = the number of aga recorded at station j on transect i, m_i was the number of stations on transect i that were surveyed in each year, and n was the number of transects surveyed during each year (11). For the onroad surveys, the mean per station for a given period (1991 to 1993 or 2000 to 2001) was

$$\frac{1}{\boldsymbol{n}}\sum_{i}^{n}\left(\sum_{j}^{m_i}\overline{\boldsymbol{x}}_{ij} / \boldsymbol{m}_i\right)$$

where $\overline{\boldsymbol{x}}_{ij}$ = the mean number of aga recorded during month j at station i (*e.g.*, the mean of the numbers recorded in October 1991 and October 1992) and n was the number of stations surveyed on every occasion (46).

Change was defined as the ratio, $\overline{\boldsymbol{x}}_2 / \overline{\boldsymbol{x}}_1$, where $\overline{\boldsymbol{x}}_1$ and $\overline{\boldsymbol{x}}_2$ are the means from 2 years (offroad surveys) or periods (onroad surveys). The standard error of $\overline{\boldsymbol{x}}_2 / \overline{\boldsymbol{x}}_1$ was estimated using

$$\boldsymbol{se}(\overline{\boldsymbol{x}}_2 / \overline{\boldsymbol{x}}_1) = (\overline{\boldsymbol{x}}_2 / \overline{\boldsymbol{x}}_1)\left(\boldsymbol{cv}(\overline{\boldsymbol{x}}_2)^2 + \boldsymbol{cv}(\overline{\boldsymbol{x}}_1)^2\right)^{0.5}$$

which is a standard formula for the ratio of independent random variables (“ratio of means” approach). This approach assumes that transects for the offroad surveys and stations for the onroad surveys can legitimately be viewed as simple random samples from Rota or from aga habitat on Rota.

The variable circular plot data was analyzed using program DISTANCE and VCPDATA (Scott *et al.* 1986; Fancy 1997; Thomas *et al.* 2001). No difference was found between reference conditions and actual conditions. Model selection was *a priori* restricted to half-normal with a hermite polynomial adjustor, hazard-rate with a simple polynomial adjustor, and uniform with cosine adjustor. Effective detection radius (EDR) and percent coefficient of variation (%CV) values for the 1982 survey followed Fancy *et* *al.* (1999) (EDR = 128.880m, %CV = 7.81). EDR and %CV values were calculated for pooled 1995 and 1998 surveys. Population estimates were calculated by multiplying density by survey area (the two areas estimated were "Breeding and Foraging Habitats" [6,056.8 hectares {14,967 acres}] and "All Habitats" [8,525.9 hectares {21,068 acres}]).

Model selection for both 1995 and 1998 data, pooled, was achieved with a truncation of 158.0 meters (521 feet) and 157 observations. The best-fit model was a uniform function with cosine series expansion of order one. No evidence to reject the model was found with Chi-square goodness-of-fit analysis ($\chi^2 = 26.0372$, df = 16, $P = 0.05351$). Annual density estimates were calculated using the pooled EDR and %CV values and data pertaining from independent census efforts only (1998 and 1995 data not pooled).

Results

The numbers of aga recorded per station declined substantially in both surveys (Table 2). In the onroad survey, the mean declined 50 percent between the time periods 1991 to 1993 and 2000 to 2001. The decline was highly significant ($P < 0.001$).

In the offroad survey, the mean number of aga detected per station declined by 54 percent between 1982 and 1995, and by 83 percent between 1982 and 1998. Both changes were highly significant ($P < 0.001$). The variable circular plot density estimate declined by 38 percent between 1982 and 1995, and by 67 percent between 1982 and 1998 (Table 2). Both of these changes were also highly significant. We repeated the mean per station analysis of the offroad data using all stations surveyed in each year and results were very similar. The decrease between 1982 and 1995 was 51 percent, and the decrease between 1982 and 1998 was 76 percent. The proportion of stations with at least one aga detected (using all stations surveyed in each year) was 52 percent in 1982, 28 percent in 1995 and 18 percent in 1998. Decreases were widespread across Rota but showed no strong spatial pattern (Figure 1).

Note: all references are provided in Section IV.

Table 2. Mean number of aga per station in onroad (A) and offroad (B) surveys.

A. Onroad surveys	**Means/station**		**Decline**
Variable	**1991-1993**	**2000-2001**	
Aga/station	0.22	0.11	50%***
Standard error	*0.03*	*0.03*	*15%*

*** $P < 0.001$

B. Offroad surveys	**Means/station**			**Declines**	
Variable	**1982**	**1995**	**1998**	**1982 to 1995**	**1982 to 1998**
Aga/station	1.12	0.52	0.19	54%***	83%***
Standard error	*0.16*	*0.13*	*0.07*	*13%*	*7%*
Population estimate[1]	1098	680	356	38%***	67%***
Standard error	*114*	*92*	*61*	*6%*	*6%*

*** $P < 0.001$

[1] For all habitats. Density estimates for breeding and foraging habitats (and SEs) during 1982, 1995, and 1998 were 780 (81), 483 (65) and 253 (43) birds respectively. The declines and their SEs, calculated from these estimates, were identical to the declines calculated from the All Habitats analysis.

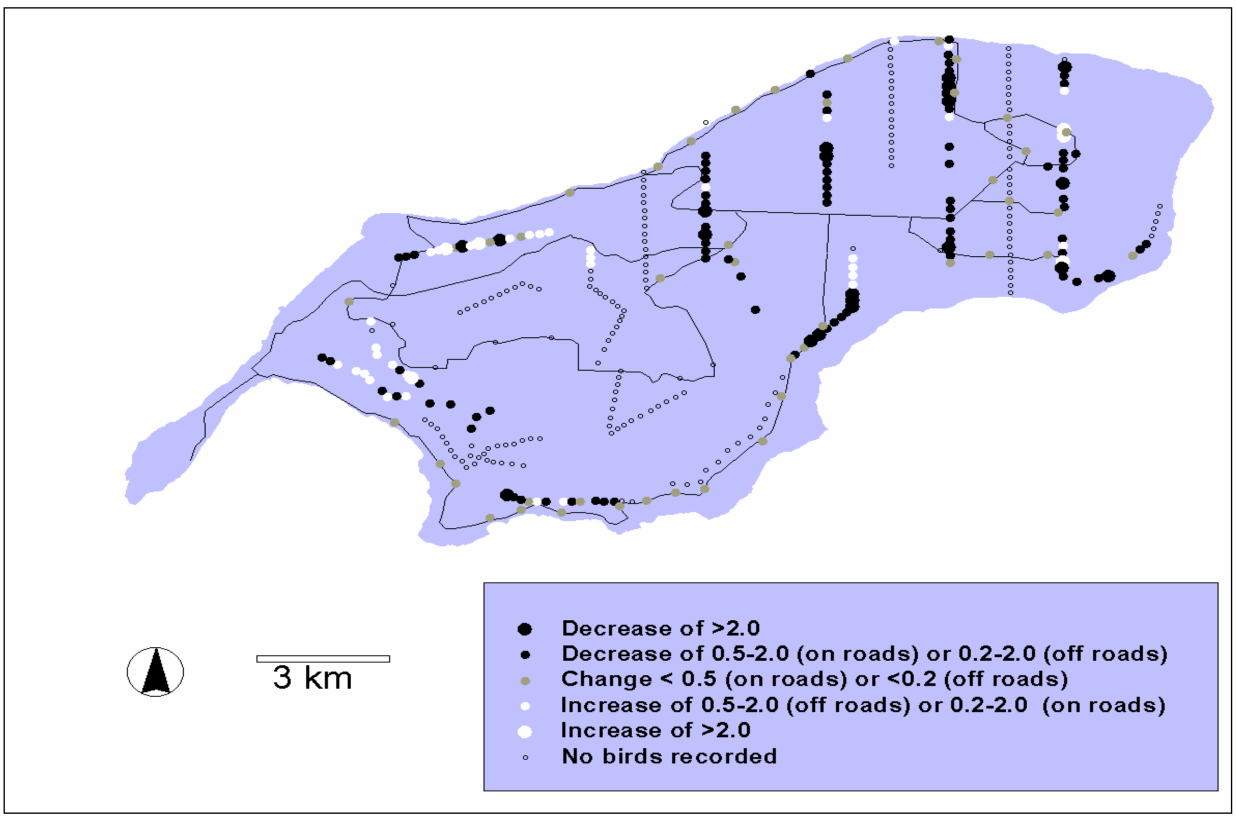

Figure 1. Change in number of aga detected per station in offroad surveys on Rota, 1982 to 1995.

APPENDIX 4

Population Viability Analysis for Aga on Rota

Introduction

The Mariana Crow Recovery Team used the software RAMAS GIS (Akcakaya 1999) to model deterministic growth for the aga population on Rota. Using a pre-breeding model transition matrix, we estimated fecundity and survivorship parameters to calculate lambda (λ, the geometric rate of population change). In this appendix we explain calculations leading to our parameter estimates, explore the sensitivity of demographic parameters as a way to determine which of those parameters are most important to population change, and outline some implications for aga recovery.

It is important to keep in mind that the parameter estimates we used came from Morton and coworkers' (1999) study of aga in six relatively undisturbed native forest areas on Rota. This is unlikely to affect our insights into the sensitivity of various demographic parameters, but our results concerning population viability are not applicable to the aga population on the entire island of Rota. This is likely to explain why population surveys conducted over the last two decades suggest that an island-wide lambda is less than 1, but our estimates suggest a lambda of approximately 1.0 is reasonable within Morton and coworkers' study plots. We suspect that populations are declining island-wide due to human persecution and habitat loss in the broad sense (including effects of introduced predators). Our model of population viability, therefore, is best viewed as a representation of the potential of the Rota population when habitat loss and persecution of adults have little effect on the population.

Particulars of Our Analyses with RAMAS GIS

We conducted a single species analysis and did not include explicit genetic effects or effects of competition, predation, mutualism, or other interspecific interactions. It is possible to observe these effects, but only as constant, stationary, or deterministically varying impressions on demographic parameters. All breeders were derived directly from the pre-breeding stage. Implicit in any matrix calculation is that vital rates are not density dependent and that the environment is constant. We assumed the Rota population to be a continuous, panmictic (matings are random) population.

For our basic model, we divided the aga population into three stage classes (fledgling, pre-breeding, and breeding [= "adult"]) and assumed stage-specific fecundity and survival rates did not vary within classes. We used a 3 $\times$ 3-transition matrix (Table 1) for analyses of the three stage classes. The top row of the matrix represents stage-specific fecundity. The second and third rows represent survival for the corresponding stage-specific column. For example, aga adult fecundity is 0.33 female fledglings per female per year, but because aga do not breed before the adult stage, pre-breeding and fledgling fecundity is zero (Table 1). The time step of our model is 1.0 year. Survivorship is only crudely known for aga, but possible values for the fledgling and adult stages are 76 percent and 90 percent, respectively. Because aga do not breed, on average, until they are 3.5 years of age (age measured from date of fledging rather than date of hatching), pre-breeding individuals can either survive to remain in the pre-breeding stage or survive into the adult stage. This is shown in the pre-breeding column as 59.2 percent and 19.1 percent transition probabilities, respectively (Table 1).

Table 1. Sample transition matrix displaying the stage classes for aga. All cells represent transition probabilities per year. The top row represents fecundity for all stages. The bottom two rows represent survivorship for the corresponding columns. For example, fledgling survivorship is 0.76, pre-breeding survivorship is 0.592 and 0.191, and adult survivorship is 0.90. The pre-breeding stage column has two survivorship values because pre-breeding individuals can either survive to remain in the pre-breeding stage (0.592) or can survive into the adult stage (0.191).

	Fledgling	Pre-breeding	Breeding	
Fledgling	0.000	0.000	0.333	*Fecundity*
Pre-breeding	0.760	0.592	0.000	*Survivorship*
Breeding	0.000	0.191	0.900	*Survivorship*

To investigate the possible effects of breeding senescence on population viability, we added a "post-breeding" stage to the transition matrix. We modeled senescence after 10, 15, and 17 years of breeding. To determine how much of an effect senescence could have on a growing population of aga, we only investigated its effects when breeder survival was greater than or equal to 90 percent (see below). We assumed that all females beyond 10, 15, or 17 years of breeding (actual age of approximately 13, 18, and 20 years) did not breed. This is an assumption (Gustafson and Part 1990) that allowed us to see various possible effects of reproductive senescence. We allowed senescent females to survive at a constant rate of 90 percent per year, although the rate is irrelevant for the outcome of the model. We did not model actuarial senescence (reduction in adult survival with increasing age) because it happens very slowly in birds and may have little effect on lambda, especially if those that survive have increased reproductive output as found in Florida scrub-jays (McDonald *et al.* 1996). This type of senescence should be modeled when long-term survival and reproductive data become available for aga.

Demographic Parameters

To fill in the transition matrix, we used survival and fecundity estimates from the final report by Morton and coworkers (1999) of a 3-year demographic study of aga on Rota. Following fledging, juveniles remain with family groups for roughly their first year (n = 15, mean = 241 days, median = 197 days, range = 99 to 537 days). After dispersal from the family groups, pre-breeding crows forage on their own for a time before pairing and establishing a territory. In all three cases where known-aged birds entered the breeding cohort, they did so at 3.5 years post-fledging. Thus, we divided the matrix into three life stages, fledgling, pre-breeding, and breeding or "adult." As discussed above, we added a post-breeding stage to model viability if breeders senesce.

Fecundity Estimates

Fecundity was defined as the number of female offspring produced annually per monitored adult female. Over the 3 years of study, 48 young were fledged by 86 monitored pair-years. Of the juveniles that were sexed, 59.6 percent were females. Therefore, the mean annual fecundity estimate was 0.333 female offspring per female per year.

Survival Estimates

Survival estimates varied widely depending on assumptions made about birds of unknown fate (individuals that are not confirmed to have died, but are not detected alive in the stage of interest). Still it was possible to define a range of possible values based on whether birds of unknown fate were dead or alive.

Fledgling Survival — This estimate was the most accurate because Morton and coworkers (1999) specifically examined reproduction and fledgling survival. We considered fledglings to have survived to the pre-breeding class if they survived to 1 year (365 days). Morton and coworkers monitored survival and dispersal for a total of 61 fledglings from 1990 to 1999. Of the 61 monitored, we discarded 24 because they were followed too late in the study to be followed for more than 365 days (and therefore make it to the pre-breeding stage before the study ended). This left 37 fledglings for use in our analysis. Twenty of the 37 fledglings were of unknown status at the completion of the study, leaving 17 fledglings of known status. Of the 17 fledglings of known status, 13 survived to the pre-breeding stage (13/17 = 0.764 fledgling survivorship). If we count the 20 fledglings of unknown status as alive, then 33 survived to the pre-breeding stage (33/37 = 0.891 fledgling survivorship). If we count the 20 fledglings as dead then survivorship decreases dramatically (13/37 = 0.351 fledgling survivorship). This gives us a range for fledgling survivorship of 35 percent if all unknown status birds were dead, 76 percent for only known status birds, and 89 percent if all unknown birds were counted as alive.

Pre-breeding Survival — Morton and coworkers (1999) provided few data to estimate pre-breeding survival. There was no confirmed mortality of pre-breeding individuals. Four birds banded as juveniles were known to survive to adulthood, and three others were known to have reached the pre-breeding stage but of these three, none were resighted as adults. It is likely that overall pre-breeding survivorship falls somewhere between the rates seen in adult and fledgling classes. For our best estimate, then, we simply took the average (0.783) of the range of annual adult survival (0.803) and known bird fledgling survival (0.764) rates. Because aga remain in this stage for roughly 2.5 years, the survival rate of 0.783 is divided into 0.592 (annual proportion remaining as pre-breeders) and 0.191 (annual proportion moving from the pre-breeder stage to the breeder stage). This apportionment led to a residence in the pre-breeder stage of 2.45 years.

Adult Survival — Adult survival was based on a very small sample of marked birds. Morton and coworkers (1999) stated that the data are inadequate to make an estimate of adult survivorship due to the fact that most of the monitored pairs were unmarked. For known fate birds (n = 7, in this case those that were likely alive at the end of the study), annual survivorship cannot be estimated without making an assumption about the fate of unseen birds. Two other adults were banded in the early 1990's and never seen again. The range of adult survivorship we modeled was 70 to 90 percent.

Results

We modeled deterministic growth to calculate lambda. Lambda (finite rate of growth) is the ratio of the population size during the next time period to the population size for the current time period. Based upon a range of transition matrix values and the resulting lambda values we evaluated the sensitivity of the model parameters and explored various management scenarios.

Range of Transition Matrix Estimates – Data from Morton and coworkers allowed us to estimate a reasonable transition matrix for aga on Rota (Table 2) with 0.33 females per female per year for fecundity, 35 to 89 percent fledgling survivorship, 76 percent pre-breeding survivorship, and 70.5 to 90 percent adult survivorship. The transition matrices produced a range of lambda values from 0.8220 to 1.0261 (Table 3). These estimates suggest that the aga population on Rota is stable only if adult survivorship is at least 90 percent (Table 3) and fledgling survivorship is at least 60 percent (Table 3). *Note: for assistance in reading Table 3, refer back to description of transcription matrix for Table 1.*

Table 2. Our best estimates for the range of transition matrix values.

	Fledgling	Pre-breeding	Adult	
Fledgling	0	0	0.333	*Fecundity*
Pre-breeding	0.351 - 0.765 - 0.891	0.592	0	*Survivorship*
Adult	0	0.1	0.70 – 0.90	*Survivorship*

Sensitivity of Lambda – Lambda was most sensitive to changes in adult survivorship (Table 3; elasticity values). When adult survivorship was 90 percent, populations were stable even if fledgling survivorship was as low as 60 percent. However, when adult survivorship was at our minimum estimate of 70.5 percent, fledgling survivorship could be as high as 95 percent and still not allow for positive growth (Table 3). Given the uncertainty of our data in estimating adult survivorship and the overriding importance of adult survivorship in affecting the population growth rate, we suggest acquiring better estimates of this parameter.

To further illustrate the influence of adult survivorship on lambda, we have provided a surface graph (Figure 1) of lambda in terms of fledgling survivorship versus adult survivorship. For this graph, as with our other calculations, we kept pre-breeding survivorship constant at 78 percent. The steep slope for adult survivorship (Adult l_x) compared to the relatively flat slope for fledgling survivorship (Fledgling l_x) suggests that lambda decreases precipitously when adult survivorship drops below 0.90.

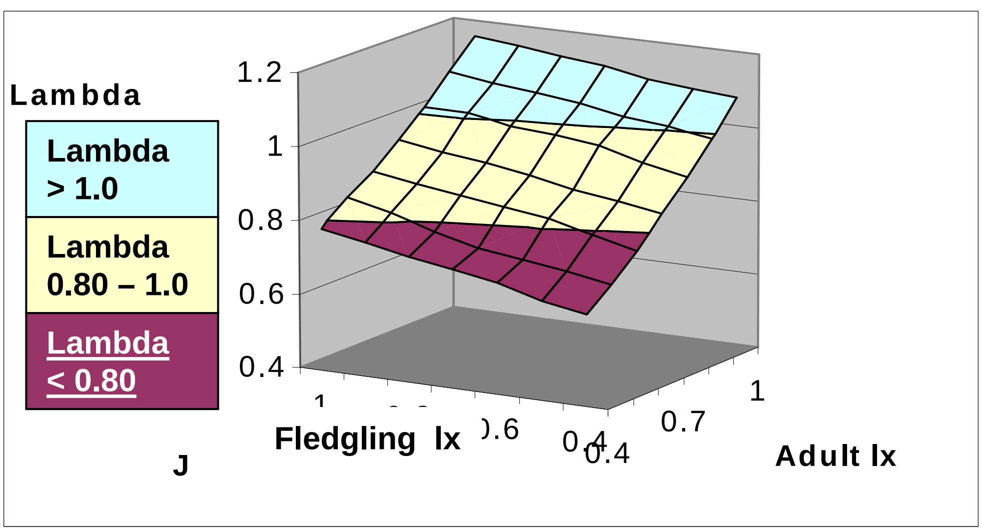

Figure 1. Adult survivorship (Adult l_x) plotted against fledgling survivorship (Fledgling l_x) to produce a surface graph of lambda. We held pre-breeding annual survivorship constant at 78%. The graph illustrates the importance of adult survivorship in excess of 90% to population viability.

Table 3. This table illustrates the importance of adult survivorship to lambda (population growth rate; lambda ≥1.0 indicates a stable or growing population). When adult survivorship is 0.90, the population is stable if fledgling survivorship is 0.60. However, if adult survivorship is <0.90, the population never reaches positive growth even when fledgling survivorship is at the unrealistic level of 0.95. Elasticity indicates the relative influence of each parameter in the transition matrix on lambda. Higher elasticity (1 is the maximum) indicates that a change in that variable will have a greater impact on lambda. In all modeled cases, elasticity indicated that adult survivorship was the most influential parameter on population viability.

	Low Adult Survivorship							
		Transition Matrix			**Elasticity**			
Lambda		Fledgling	Pre-breeding	Breeding	Fledgling	Pre-breeding	Breeding	
0.8220	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.0862	*Fecundity*
	Pre-breeding	0.3510	0.5920	0.0000	0.0862	0.2219	0.0000	*Survivorship*
	Breeding	0.0000	0.210	0.7050	0.0000	0.0862	**0.5194**	*Survivorship*
0.8882	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.1130	*Fecundity*
	Pre-breeding	0.7650	0.5920	0.0000	0.1131	0.2259	0.0000	*Survivorship*
	Breeding	0.0000	0.21910	0.7050	0.0000	0.1131	**0.4349**	*Survivorship*
0.9041	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.1185	*Fecundity*
	Pre-breeding	0.8910	0.5920	0.0000	0.1185	0.2248	0.0000	*Survivorship*
	Breeding	0.0000	0.1910	0.7050	0.0000	0.1185	**0.4197**	*Survivorship*
0.9110	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.1208	*Fecundity*
	Pre-breeding	0.9500	0.5920	0.0000	0.1208	0.2242	0.0000	*Survivorship*
	Breeding	0.0000	0.1910	0.7050	0.0000	0.1208	**0.4134**	*Survivorship*

Table 3 (continued). This table illustrates the importance of adult survivorship to lambda (population growth rate; lambda ≥1.0 indicates a stable or growing population). When adult survivorship is 0.90, the population is stable if fledgling survivorship is 0.60. However, if adult survivorship is <0.90, the population never reaches positive growth even when fledgling survivorship is at the unrealistic level of 0.95. Elasticity indicates the relative influence of each parameter in the transition matrix on lambda. Higher elasticity (1 is the maximum) indicates that a change in that variable will have a greater impact on lambda. In all modeled cases, elasticity indicated that adult survivorship was the most influential parameter on population viability.

	High Adult Survivorship							
		Transition Matrix			**Elasticity**			
Lambda		Fledgling	Pre-breeding	Breeding	Fledgling	Pre-breeding	Breeding	
0.9621	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.0524	*Fecundity*
	Pre-breeding	0.3510	0.5920	0.0000	0.0524	0.0838	0.0000	*Survivorship*
	Breeding	0.0000	0.1910	0.9000	0.0000	0.0524	**0.7590**	*Survivorship*
0.9945	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.0714	*Fecundity*
	Pre-breeding	0.6000	0.5920	0.0000	0.0715	0.1051	0.0000	*Survivorship*
	Breeding	0.0000	0.1910	0.9000	0.0000	0.0714	**0.6806**	*Survivorship*
1.0130	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.1185	*Fecundity*
	Pre-breeding	0.7650	0.5920	0.0000	0.0809	0.1137	0.0000	*Survivorship*
	Breeding	0.0000	0.1910	0.9000	0.0000	0.0808	**0.6438**	*Survivorship*
1.0261	Fledgling	0.0000	0.0000	0.3330	0.0000	0.0000	0.0869	*Fecundity*
	Pre-breeding	0.8910	0.5920	0.0000	0.0870	0.1186	0.0000	*Survivorship*
	Breeding	0.0000	0.1910	0.9000	0.0000	0.0869	**0.6206**	*Survivorship*

Senescence – The effect of early and complete reproductive senescence (after 10 years of breeding) was substantial. The model suggests that lambda will be reduced by 3 to 5 percent if females leave the breeding cohort after 10 years (Table 4). However, the effect of later senescence (17 years) on lambda is less severe (1 to 2 percent). Fledgling survival rates affected lambda very little (low elasticities) compared to changes in the age of senescence. This suggests that we need to accurately characterize the reproductive lifespan of wild aga. All indications suggest that aga need to live long reproductive lives if the population is to remain viable while producing 0.33 female offspring per female per year.

Table 4. The effect of modeling complete reproductive senescence after 10, 15, and 17 years of breeding for the aga population. Lambda for each transition matrix is provided and compared to lambda without senescence by reporting the percentage decrease relative to lambda values presented. Adult survivorship was kept at 90% and pre-breeder transition probabilities of 59.2% (remain a pre-breeder) and 19.1% (become a breeder) were used in all models.

Lambda (λ)	% decrease in value of λ relative to λ with no senescence	Years of Breeding	Fledgling Survival
0.9431	5.2	10	0.60
0.9700	4.2	10	0.765
0.9879	3.7	10	0.891
0.9588	3.6	15	0.60
0.9825	3.0	15	0.765
0.9984	2.7	15	0.891
0.9763	1.9	17	0.60
0.9995	1.4	17	0.765
1.0150	1.1	17	0.891

Discussion

Even for species with many years of reliable data, there is a high level of uncertainty associated with projecting deterministic growth rates. For the factors we can measure well, we can rarely afford to measure them for long enough to detect the real range of variation in parameters. Regardless of the data accuracy, we are always projecting into an uncertain future, which is risky. For example, consider the introduction of the brown treesnake to Guam. A population model constructed with flawless data prior to this event would have failed to accurately predict the fate of the aga on that island. Thus, when species, such as aga, have only moderate amounts of stage-specific data available, much care must be taken in interpreting results. Moreover, the "population viability" we have modeled is only relevant if our assumptions about lack of habitat loss and human persecution remain in effect (our demographic figures were from six populations where habitat was mostly suitable, availability did not change, and human persecution was not known to occur). The island carrying capacity could change and reduce the population (as it likely has over the last two decades), even if reproduction in relatively undisturbed habitats is sufficient to balance mortality.

Despite these caveats, this modeling exercise has identified three points of interest for future research and management:

1. The clearest result is the importance of adult survival for population growth (Table 3). Given the parameter estimates, only when adult survivorship is at or above 90 percent is a positive population growth rate achieved (Figure 1). These results reveal the need to better understand adult survivorship for setting future monitoring and recovery goals. The simplicity of the model and few data for the pre-breeding stage could lead to underestimating the importance of the other stages (*i.e.*, pre-breeding survivorship). However, similar conclusions are found in nearly all long-lived birds (Saether and Bakke 2000).
2. In addition to adult survivorship greater than or equal to 90 percent, fledgling survivorship also needs to be relatively high (more than 60 percent) to maintain a positive population growth rate. Thus, to maintain a viable population of aga on Rota, adult survivorship cannot be compromised <u>and</u> the population must be managed to increase fledgling survival. Despite the fact that adult survivorship has high elasticity, managers may be able to do little to increase it above 90 percent. Therefore, as long as adult survivorship can be maintained at about 90 percent, managers may make their biggest contribution to recovery of aga by reducing threats to juvenile survivorship.
3. Perhaps the most important conclusion to be drawn from our modeling effort is that further research is needed to refine our estimates of adult breeding lifespan (age of first reproduction, annual survivorship, actuarial senescence, and age of senescence). These parameters are important determinants of demographic viability and need to be precisely understood and carefully compared among the variety of settings on Rota. Our results suggest that if adult survivorship is at least 90 percent and senescence of breeders is not extreme, then aga breeders should replace themselves and the population would be able to remain stable as long as the island carrying capacity does not decline due to habitat loss.

Note: all references are provided in Section IV.

APPENDIX 5

Review of Brown Treesnake Control Techniques

by Gordon Rodda

1. Visual Searches

Visual searches for brown treesnakes in native forest have a low yield (average yield for Wildlife Services [U.S. Department of Agriculture Animal and Plant Health Inspection Service] and U.S. Geological Survey researchers working in natural vegetation in recent years was 0.66 snakes detected per hour of search effort [n = 5,085 hours; 1995 to 1999]). In addition, the yield is strongly dependent on the searchers' skill and motivation level (Rodda 1993); for example, considering only searchers with more than 20 documented search hours, the yield from the best searcher (0.97 snakes per hour) was about 24 times that of the worst (0.04 snakes per hour) in the 1995 through 1999 database. Therefore, visual searches are not a very reliable tool for conservation work in natural areas. However, visual searches are widely used to control brown treesnakes in transportation because most transportation facilities on Guam are surrounded by chain-link fences, on which brown treesnakes are readily spotted and captured. Furthermore, vehicles can be driven alongside most chain-link fences, facilitating rapid searches. From 1993 to 1998, Wildlife Services removed 2,051 snakes from chain-link fences surrounding the civilian airport on Guam (Fritts 2000); several thousand more were removed from the area by the Government of Guam Department of Agriculture (M. Kuhlmann, Guam Department of Agriculture, pers. comm. 1998).

Visual searches of fence lines appear to be among the most justifiable tools for reducing snake densities in the vicinity of transportation facilities, as they are inexpensive, capture all snakes present on the fence, and can be conducted opportunistically by crews that would otherwise experience greater job monotony during nighttime shifts of limited activity. There is limited scope for expanding this activity, however. Visual searches could be expanded to natural (*i.e.*, non-fence) surfaces, though the yield in most cases on Guam would be less than that obtained for the same number of hours of trapping effort (Rodda and Fritts 1992a), and the work is less appealing to many people. If a technique for readily detecting snakes in natural habitat were developed (dog-aided or machine-aided), expansion of visual searches to natural habitat would become more attractive for conservation work. In environments with high prey densities, such as Rota, trap capture is relatively ineffective (Rodda *et al*., pers. comm. 2001), tipping the balance towards greater relative effectiveness of visual searching.

2. Snake Trapping

Snakes traps are the most commonly utilized brown treesnake control measure. The exact structure of snake traps has evolved over time, but all models consist of a cylindrical wire mesh body capped on the ends by inward-pointing funnels. At the apex of each funnel is a one-way flap that permits a snake to enter but not leave. The exact configuration of the flap is crucial to success of the snake trap and has undergone repeated testing and improvement (Rodda *et al.* 1992b, 1999b; Linnell *et al.* 1998). Minor features such as the angle of the flap door, the material, the color, air flow and other features have a strong effect on the capture success of particular flap variants. In addition to testing entrances with and without flaps, and flaps made of clear plastic (numerous variants), plastic mesh, and metal (stainless, aluminum, and galvanized steel have been tested with drilled holes or woven mesh), researchers have experimented with sprung trap doors, labyrinthine entrances, and slither-through entrances made of limp nylon stockings. Although a rigid metal mesh entrance flap of galvanized steel has been in regular operational use since 1993, direct (*i.e.*, video tape; L. Clark *et al.*, National Wildlife Research Center, pers. comm. 2001) and indirect (flap trap entrance rates compared to flapless traps; Rodda *et al.* 1999b) evidence indicate that about half of the snakes that approach such a trap are deterred by the entrance flap.

A live rodent inside the trap motivates the snakes to enter (Rodda *et al.* 1992b). The rodent is provided with snake-proof living quarters, so the mice cannot be considered a “bait.” In such a trap mice are merely an attractant. New food and water are provided to the mice weekly (or more often as needed), allowing the mice to serve as an attractant continuously.

Snake traps have been steadily improved in terms of durability and ease of use. The two primary innovations have been a more durable flap hinge design and a heavier gauge mouse chamber that is accessible from the outside of the snake trap, thereby minimizing the hassles and time spent in cage cleaning. The effective flap uses a hinge that is fixed to the flap and precisely machined so that the flap will not bind against its housing when the flap is accidentally rotated away from the ideal level orientation. Traps that do not need to be set level can be set in a wider variety of convenient locations, with less loss of functionality if they are set at a tilt.

Snake trapping has produced the largest total yield of any snake control activity and is used extensively in control of brown treesnakes in transportation and for aga conservation efforts on Guam. However, it has several limitations, as described below, and there has been some controversy over its application in conservation efforts.

a) Mouse care. Caring for the mice used in the traps is tedious and all parties would like to see it replaced with another attractant. A variety of alternate prey types (chicken litter, quail, geckos, skinks) have been tested and found to be less effective than live mice as brown treesnake attractants (Rodda *et al.* 1992b; Perry *et al.*, USGS/Ohio

State University, pers. comm. 1998). An effective inanimate attractant has been the ultimate objective of trap research for many years, and some progress has been made, though most field tests with non-decaying materials have yielded capture rates only a tiny fraction of those obtained with live mice. Dead mice have sometimes produced captures on par with live mice traps (Shivik and Clark 1997), though the dead mice must be replaced every third day as they decay. Under some circumstances, the capture rate associated with dead mice is substantially less than that with a live mouse attractant (Shivik *et al.* 2000). The initial assessment was that the variability in capture success associated with dead mice was seasonal, but too few years were sampled to confirm this hypothesis. In any event, the need to replenish dead mice at 3-day intervals increases the frequency of trap maintenance and increases the number of mice used. Tofu blocks impregnated with the odors of decaying mice have been shown to be about 50 percent as effective as whole rodent attractants (L. Clark, pers. comm. 2001), potentially providing an attractant that is reasonably effective and does not require mice.

b) Difficulty capturing small snakes. Snakes traps do not appear to be effective at capturing small snakes. One reason for this may be related to several features of trap design. The flap is relatively heavier to small snakes and therefore might be a greater impediment to entry. We know from various experiments that details of flap design can have a major effect on entry rates. One such detail could be flap weight. Current flaps weigh 1 to 2 grams (0.03 to 0.07 ounces). A brown treesnake weighs 5 to 9 grams (0.2 to 0.3 ounces) at hatching (275 to 350 millimeters [11 to 14 inches] snout-vent length). It may be appreciably more difficult for a 5 gram (0.2 ounce) snake to push away a 2 gram (0.07 ounce) flap than it is for an adult snake (60+ grams [2.1 ounces]) to do so. Consistent with this expectation is the result that smaller snakes are proportionately more common in captures from flapless traps than from the flap design currently favored.

Another reason why snake traps are not effective at capturing small snakes is that the rodent attractant used may be both a non-attractant and a repellent for small snakes. Professional herpetoculturists never feed live rodents to their snakes, as live mice attack and sometimes kill snakes, especially small snakes. A mouse can weigh up to about 30 grams (1 ounce), and therefore can be a formidable predator to a snake weighing less. If a brown treesnake can eat up to 70 percent of its mass at a time (this has been observed several times in wild brown treesnakes), a brown treesnake must weigh about 43 grams (1.5 ounces) to consider eating a 30 gram (1 ounce) mouse. The average brown treesnake weighing 43 grams (1.5 ounces) has a snout-vent length of 744 millimeters (29 inches), which is about the size at which brown treesnakes begin appearing in conventional snake traps. Of a U.S. Geological Survey sample of 942 individual brown treesnakes caught in conventional snake traps, only 17 (less than 2 percent) were smaller than 700 millimeters (27.5 inches) snout-vent length. In contrast, 713 (31 percent) of 2,314 brown treesnakes caught were of this small size class when snakes were hand-caught instead of trapped.

Not all mice are as large as 30 grams (1 ounce), of course, and snakes smaller than 700 millimeters (27.5 inches) snout-vent length may choose to consume small or neonatal mice. Captive feeding trials (F. Qualls, USGS/ Colorado State University, unpubl. data) involving offering pinkies (hairless baby mice) to brown treesnakes indicate that snakes less than 500 millimeters (20 inches) snout-vent length will rarely eat pinkies, whereas brown treesnakes larger than 700 millimeters (27.5 inches) snout-vent length virtually always will. Thus snakes in the 500 to 700 millimeter (20 to 27.5 inch) snout-vent length size range are making the transition towards developing a taste for mice. It is not surprising that snakes under this size are not readily trapped in conventional traps.

An attempt was made to model the size distributions of brown treesnakes on Guam, as a means of estimating basic life history parameters (growth, survivorship, detectability) (Rodda and Fritts 1997). The major conclusion of this mathematical model was that no plausible combination of growth and survivorship could produce the observed brown treesnake size distributions without gross undersampling of juvenile brown treesnakes. Quantification of this phenomenon is hamstrung by the absence of data on the true size distribution. An alternate approach to this problem is to quantify the size selectivity of snake traps. This is possible using a mark-recapture procedure if you can assume either that the probability of recapturing a snake is similar to the probability of capturing the snake the first time (*i.e.*, assume no trap shyness or trap happiness), or if you assume that brown treesnakes are not leaving, entering, dying, or being born in a snake trapping grid while the trapping is going on (*i.e.*, assuming a closed population). The birth and death assumption is plausible for a short-term study, but all lines of evidence indicate significant population turnover through movement on and off the plots during a 20 to 40 day trapping period (see movement notes below).

Using an open population analysis (a model that accommodates immigration and emigration), Rodda and Dean-Bradley (U.S. Geological Survey, unpubl. data 2001) found that capture probability in a sample of 942 individuals sampled repeatedly during 1991 to 2000 in diverse areas of Guam climbed from near zero at snake sizes of 700 millimeters (27.5 inches) snout-vent length to a peak of about 14 percent per night for snakes in the 900 to 1,000 millimeter (35 to 39 inch) snout-vent length size class. Relative to the peak value, capture probability was around 10 percent in the 600 to 700 millimeter (24 to 27.5 inch) snout-vent length size class, 53 percent in the 700 to 800 millimeter (27.5 to 31.5 inch) snout-vent length size class, 81 percent in the next higher size class, 100 percent in the peak class, and 91 percent among snakes larger than 1,000 millimeters (39 inches) snout-vent length. Captures for snakes smaller than 600 millimeters (24 inches) snout-vent length were simply too few to estimate a capture probability. This study went beyond the mathematical modeling done by Rodda and Fritts (1997), in providing a quantitative basis for inferring the extent to which traps undercapture small snakes.

This general result, that large snakes are easier to capture than small snakes, has been questioned by Richard Engeman (National Wildlife Research Center, pers. comm. 2000) on several grounds. One is that Rodda *et al*. (1999a) reported a preliminary example in which capture probability of small snakes was greater than that for larger snakes. Such a result could occur, but the cited article does not indicate that small snakes are normally easier to capture; instead that result was used to frame an analysis *if the values obtained in Orote 1991 turned out to be generally valid* (emphasis added; "Orote 1991" refers to the year and location of the study, which was conducted on the Orote peninsula of Guam). Subsequent analysis of a much larger data set from Orote (more extensive in sample size, time duration, and geographic locality) has revealed that it was not a general result. In addition, improvements in analytical software made available subsequent to the completion of that paper have allowed larger capture history matrices to be evaluated; upon reevaluation, the preliminary result did not hold up for the entire Orote peninsula trapping experiment originally sampled (1991). The general result (hereafter referred to as the "Orote result") is that small snakes are rarely trapped.

Average conditions may mask site to site or year to year variability, however. U.S. Geological Survey analysis of 30 trap experiments on Guam (1990 to 2000) found 16 in which the trend was lower capture probability of small snakes, 4 in which the opposite trend was evident, and 10 in which no unequivocal size-based trend was discernible (Rodda and Dean-Bradley, U.S. Geological Survey, unpubl. data 2001). Two interpretations of this tabulation are possible. One is that most individual trap experiments had sample sizes insufficient for the capture rate in individual size classes to be estimated. Support for that viewpoint comes from only 2 of the 30 analyses having a preferred model using this size group effect. The other possibility is that relative capture success varies from time to time, perhaps in response to relative prey density for the different size classes. More data on prey density conducted concurrently at each specific site are needed to evaluate that possibility.

An argument that has frequently been raised in association with the apparent undersampling of traps refers to the discrepancy between the small snake fraction from hand and trap samples. As noted above, about 31 percent of hand-capture samples are snakes under 700 millimeters (27.5 inches) snout-vent length, whereas less than 2 percent of snakes are this small in trap samples. The stated viewpoint is that this discrepancy could arise not because traps undersample small snakes, but because hand-capture oversamples small snakes. To a large degree this is a semantic controversy. Hand-captured snakes range in size down to 300 millimeters (12 inches) snout-vent length, the size at which brown treesnakes hatch. Trap samples never detect these newly hatched individuals. In some large trap series from operational trapping (*e.g.*, the 477 individuals reported in Savarie *et al.* 2001), zero snakes smaller than 700 millimeters (27.5 inches) snout-vent length were obtained. Whatever their true relative abundance, snakes in the

300 to 700 millimeter (12 to 27.5 inch) snout-vent length size class must be undersampled by traps.

Engeman (National Wildlife Research Center, *in litt.* 2000) raised the possibility that snakes 300 to 700 millimeters (12 to 27.5 inches) snout-vent length may not have existed at the time when the 30 U.S. Geological Survey trap experiments were conducted (1990 to 2000). This notion is inconsistent with the demonstrable lack of seasonality in brown treesnake reproduction. Furthermore, the mark-recapture data were collected from all parts of Guam, during all seasons, and in almost all years. For example, data adequate to compare the mean sizes of hand and trap-caught snakes are available for the years 1985, 1988, and 1990 through 2000; in all cases the trap-caught snakes are larger and the smallest individuals were caught only by hand.

A more serious objection is that the size selectivity estimated by Rodda and Dean-Bradley (unpubl. data 2001) is based on an open model and is therefore measuring recapture probability, not first capture probability. If small snakes become "trap happy" as a result of their captivity and large snakes do not, it would be possible for first capture probability to be unbiased in relation to snake size, whereas recapture probability would show the size-biased pattern reported. Unfortunately, there appears to be no rigorous way to test this possibility, given that an appreciable number of brown treesnakes wander out of a plot during a trapping experiment and the influence of trap happiness or shyness and immigration/emigration are statistically inseparable in mark-recapture analyses. Evidence for trap response (happiness or shyness) has not been revealed to any brown treesnake researchers using the relative frequency of recaptures (recaptures ought to be statistically less frequent if animals are becoming trap shy, and vice versa; contrary data are shown in Savarie *et al*. 2001, Fig. 3, and comparable USGS data, unpubl.; G. Rodda, pers. obs. 2001).

c) Prey Abundance. The effectiveness of snake traps seems to be much lower in areas with high natural prey density (G. Rodda, pers. obs. 2001). The interaction between natural prey availability and snake control based on prey attractants (toxicants and snake trapping) is of great potential significance for the control of snakes in incipient populations (*e.g.,* Rota, Saipan, etc.) and in snake exclusion zones (where prey densities may climb in the absence of snakes).

A complication of brown treesnake control in long-term wildlife restoration areas is that the effectiveness of trapping or toxicants may decline appreciably under the circumstance of high prey density. Why would a snake go into a trap if the space outside of the trap were replete with the same kind of food? No hard data are available to judge the magnitude of that effect, but a recent series of U.S. Geological Survey snake trapping experiments on Guam may cast some light on the issue. In the fall of 2000, a trapping experiment using marked snakes on Guam's Northwest Field area produced an average capture success of 28 percent per night (based on snakes greater than 800 millimeters [31.5 inches] snout-vent length). In other words, the array of traps caught 28 percent of the snakes known to be in the area each night. Rodent density was relatively low at that site at that time. A few months later the same snake traps were used at War in the Pacific National Park on Guam, but in an area of high rodent density. In that case the average capture success was 3 percent of the population per night. The two values cannot be contrasted directly, as habitat differences may be responsible for some of the difference, but it seems likely that prey density played a significant role. The difficulty of trapping brown treesnakes in an area of high prey density may also help explain the poor trap capture success experienced when using gecko or skink attractants to capture small snakes, as geckos and skinks are generally superabundant in Guam forests.

One would expect that partial snake control would lead to elevated prey densities, which would in turn lead to reduced snake control capture success. Thus partial success at snake population reduction would be associated with an initial exponential decay (caused by a combination of reduced snake numbers and reduced catchability of the remaining individuals) in capture success, which would reach an equilibrium at some lower but non-zero level. Unfortunately, the existence of an exponential decay to some lower level does not cast any light on whether the achieved snake density is only slightly lower than an uncontrolled density, near the desired threshold level, or below the desired threshold. The existence of an equilibrium demonstrates that removal is likely to be exactly offset by immigration and internal recruitment (snakes reaching a trappable size), though no obvious means exist to separate those two phenomena.

d) Untrappable snakes. Any lethal control technique, such as trapping, results in selection for individuals that are immune to that technique. For example, suppose that some snakes bear a mutation that reduces their appetite for rodent prey. Because all ordinary snakes are killed and removed from the population, resistant snakes will soon come to dominate the areas subject to regular snake trapping, even though they may experience some reduction in foraging success. A similar outcome might arise via aversive conditioning to toxic baits.

An attempt to judge a behavioral trap response can be made by using a closed population model and estimating first capture probability separately from the recapture probability. Shivik *et al.* (National Wildlife Research Center and Colorado State University, pers. comm. 2000) have conducted such an analysis based on the Savarie *et al.* 2001 data set. Rodda and Dean-Bradley (unpubl. data 2001) have done the same with the data set that produced the size selectivity values given above. Divergent results were obtained. The Shivik analysis showed that first capture probability was maximal at 800 millimeters (31.5 inches) snout-vent length (due to small sample size, neither capture probability [first capture or recapture] could be estimated below 800 millimeters [3.15 inches] snout-vent length) and declined monotonically at increasingly larger sizes. Rodda and Dean-Bradley (unpubl. data. 2001) found a bell-shaped first capture probability curve, with probabilities rising from about 2 percent for snakes 600 to 700 millimeters (23.5 to 27.5 inches) snout-vent length to about 9 percent near the 1,000 millimeter (39 inch) snout-vent length maximum and declining to about 6 percent at 1,200 millimeters (47 inches) snout-vent length, with no statistical difference between first capture and subsequent capture probabilities. The obvious interpretation of that result is that trap happiness or trap shyness did not occur, but unfortunately such an interpretation requires the assumption of population closure (no immigration/emigration), which is known to be false in this case. Thus, the unmet or unknown assumptions for mark-recapture models preclude obtaining a definitive answer so far. It is troubling that the Shivik *et al.* estimate of first capture probability peaks at 800 millimeters (31.5 inches) snout-vent length, a size at which there were negligible captures. The abundance of small snakes in hand-capture samples and their absence from concurrent trap-capture samples provides direct evidence for the failure of traps to capture small snakes, though estimation of the exact amount of bias at the present time would appear to require untestable model assumptions.

Evidence that some fraction of the snake population on Guam is untrappable was obtained by a toxicant trial conducted in 2001 on the Munitions Storage Area (E. Campbell, National Wildlife Research Center, pers. comm. 2002). In areas of the Munitions Storage Area that had not been subjected to snake control, the initial rate of poison bait take was 85 percent. In the area that had already been subjected to 14 months of trapping, the poison bait take was initially 55 percent, but this value dropped asymptotically to 5 percent after 4 weeks of poisoning. The high initial level of bait-take, despite the preceding long-term trapping, implies that a large number of trap-resistant snakes were residing in the area.

Trap-resistance might arise for several reasons. For example, a snake might not be interested in the type of attractant present in the trap. We know of several reasons why a snake might temporarily cease to be motivated by food. Herpetoculturists report, for example, that captive snakes of both sexes may cease eating for weeks or months when they are pursuing mating opportunities (N. Ford, University of Texas-Tyler, pers. comm. 2000). This may seem like a very long time to go without eating, but it is well within the comfortable fasting period for most snakes (snakes are notorious for tolerating fasts that last years; Nakamoto *et al.* 1981). Snakes that have just eaten a very large meal may be temporarily uninterested in eating. Given the high gut passage rate for brown treesnakes, this probably lasts only a matter of days (Perry 1999; Jackson and Perry 2000). Snakes that are shedding appear to go through a 5 to 15-day long period of voluntary fasting. None of these phenomena (reproduction, post-prandial inanition [abstinence from food for some time following a meal], and shedding) would appear to block eradication of brown treesnakes through trapping, though it might be necessary to trap an area several times in order to intercept snakes that were temporarily fasting during prior trapping occasions.

It is possible that individual brown treesnakes differ appreciably in their vulnerability to trap or toxicant capture. Although large brown treesnakes in captivity appear universally to seek mice as food, heavy continuous trapping in some areas of Guam or natural heterogeneity in dietary preferences may produce a coterie of snakes that are more or less permanently resistant to conventional traps and toxicant bait stations. Such resistant animals may give birth to both resistant and non-resistant young, and therefore may be in part responsible for the continued trap capture success at areas such as Guam's Won Pat Airport, where about 1,000 snakes are removed per year at equilibrium (Fritts 2000). Most likely many of these snakes are immigrants from surrounding areas, but much of the area surrounding the airport is urban in character and is not ideal snake habitat. In addition, some of the 1,000 snakes captured at the airport each year may be snakes that are just now reaching a size that is suitable for trapping. If this were the only source of new captures, one would have expected it to end after several years of trapping (no one knows how long it takes for a brown treesnake to grow to a trappable size, but in captivity they can reach such a size in just over 1 year). Nonetheless, there is no known means for distinguishing immigration from recruitment by resident snakes, so the means of ending the influx into the airport and similar protected sites is uncertain. Hard data on the avenue or arrival of snakes in the area would be most welcome, especially for developing control techniques for wildlife reserves.

One source of information on the relative contribution of immigration versus recruitment can be obtained from very short-term studies. Over a time scale of days the amount of reproductive recruitment is probably negligible, and therefore most of the snakes that enter in a matter of days can be assumed to be immigrants. An experiment along these lines is reported in Rodda *et al.* (1999a). In the Orote-1991 study, a mark-recapture snake trapping grid had demonstrated an average population density of about 37 to 44 snakes (greater than 700 millimeters [31.5 inches] snout-vent length) in a 1.5-hectare (4-acre) area (Campbell 1996 demonstrated that mark-recapture accurately estimates population size in this situation). Capture success was about 20 percent per night for snakes in the optimal size class (900 to 1,100 millimeters [35 to 43 inches] snout-vent length). At the conclusion of the mark-recapture trapping, removal trapping was initiated and continued for 15 days. Given the documented capture success rate, the population of medium-to-large snakes should have declined by about one-fifth per night if immigration was negligible. Furthermore, the total yield of snakes should have been similar to the estimated total population size. For example, if one-fifth (= 8) of the 40 snakes was removed the first night, there should have been only 32 snakes remaining in the area on the second night, 26 snakes on the third night, and so forth. By the end of 15 days the theoretical population would be about two snakes, and one would expect days to pass without either of these two being captured. As it happens, 155 snakes (instead of 38) were removed from the area in 15 days, and the number of captures on the last day

(8) was statistically indistinguishable from the 9 taken out of the area on the first removal day. Thus the population of snakes did not appear to be depleted by the removal of 155 individuals (from an area one-fifteenth the size of an aga territory). We cannot rigorously estimate the immigration rate from this example, but we can set a lower limit on the estimated rate of immigration by observing that at least 115 snakes (155 minus the 40 present when the trapping began) appeared to have immigrated into the 1.5-hectare (4-acre) area during the 15 days. One would like to have a standard way to express this rate. If one assumes that the immigration rate is a function of the boundary length of the 1.5-hectare (4-acre) square area, the 115 snakes leaked in over a total perimeter length of about 0.5 kilometers (0.3 miles). In that case the immigration rate was 115 snakes per 0.5 kilometers (0.3 miles) over 15 days, or about 15 snakes per kilometer per day (25 snakes per mile per day). Because the number of captures at the end of the 15-day period was indistinguishable from the capture rate at the beginning of the 15-day period, it could be argued that about 40 snakes remained present in the area at the conclusion of the study, which implies that about 155 snakes immigrated into the area during the 15 days (approximately 20 snakes per kilometer per day [34 snakes per mile per day]). Whatever the true value, these data indicate that appreciable snake population reduction would not be possible under these circumstances without restricting immigration in some way.

The same type of depletion analysis can be done for two other areas of continuous forest on Guam: Northwest Field -1992 and Ordnance Annex -1996. In the Northwest Field case the number of snakes removed (26) was fewer than the number believed resident (57), so the lower bound on the immigration rate estimated by depletion rate is zero. If removal did not deplete the population (the number removed declined overall, but the number captured on the last day, 2 snakes, was the same as that captured on the first day), the immigration rate was around 2.6 snakes a day for the 540-meter (0.3 mile) boundary, or about 4.8 snakes per kilometer per day (7.8 snakes per mile per day).

There is a more rigorous way to estimate immigration rate. The Orote-1991 mark-recapture data was analyzed with an open model that estimates average daily emigration. If one assumes that on average net emigration is offset by net immigration, one can estimate average net immigration. For Orote-1991, the estimate of daily emigration was 8.5 percent of the population, or about 3.4 snakes per day, or 6.8 snakes per kilometer per day (10.8 snakes per mile per day). That is lower than the range of values estimated from the number removed, but in the same ballpark. The immigration rate estimated for Northwest Field -1992 from the open mark-recapture model was 4.0 snakes per kilometer per day (6.4 snakes per mile per day), near the upper limit from the depletion estimate.

The Ordnance Annex-1996 grid was larger (nominal area 4 hectares [10 acres]) and had a lower density of snakes than the other areas studied, so one would expect both smaller absolute and relative numbers of immigrants. The range of values based on depletion was zero to 4.1 snakes per kilometer per day (zero to 6.6 snakes per mile per day). The immigration rate estimated from the mark-recapture analysis was 3.8 snakes per kilometer per day (6 snakes per mile per day), again near the upper limit.

These unpublished U.S. Geological Survey values for immigration rates in continuous forest cannot be compared with any literature values, as there are no published values for continuous forest. There are, however, recolonization rates for forest patches in urban and rural areas (Engeman *et al.* 1998a, 1998d, 2000). Unfortunately, these are not computed in the same way as the continuous forest values, and in any event they may not represent the circumstances applicable to aga recovery (which will be mostly in continuous forest). One study (Engeman *et al.* 2000) was conducted in scrubby ravine forest of southern Guam in 1997 (Ordnance Annex). Mowed grass, munitions bunkers, and an irregularly-used road 2.4 kilometers (3.8 miles) in length surrounded the area. In that study, a 17.8-hectare (44-acre) area was subjected to long-term removal trapping. After the initial depletion in the capture rate, a steady state condition was achieved for a 4-month period. This period is longer than the criterion of a "short-term" study; thus some depletion of the snake population in surrounding areas presumably occurred. Nonetheless, trap removal apparently offset immigration for that time period, during which an average of 0.7 snakes were removed per day. Thus the demonstrated immigration rate was about 0.29 snakes per kilometer per day (0.46 snakes per mile per day). This area appears to have relatively few snakes (estimated from depletion at about 5.6 per hectare [2.3 per acre]), about one-third that at the Ordnance Annex area studied by the U.S. Geological Survey in 1996.

Comparable analysis of the long-term removal project at the Munitions Storage Area in 2001 gives an immigration average of about 0.07 snakes per kilometer per day (1.12 snakes per mile per day), also in an area surrounded by mowed grass, munitions bunkers, and an irregularly-used road, although the density of snakes in the neighborhood of the Munitions Storage Area site was probably originally in the range of 10 to 12 snakes per hectare (4 to 5 snakes per acre), about double that of the Ordnance Annex site. This entire region was subjected to intense snake trapping for more than 1 year prior to this immigration assessment, so the surrounding density was probably very low by the time the study began. Even taking into account the differing snake densities at the various sites, it appears that forest fragmentation reduces immigration rate appreciably over that seen in continuous forest, but the residual rate of migration would nonetheless be sufficient to rapidly recolonize an unbounded aga preserve if control efforts were suspended. Evidence for this was provided by a study in the same Munitions Storage Area conducted 6 months after the virtual elimination of snakes by an intensive snake toxicant campaign. At the 6-month checkup, the snake population appeared to be no different in density from that sampled prior to poison baiting (R. Bruggers, National Wildlife Research Center, *in litt*. 2000). Thus even with a very low estimated immigration rate (0.07 snakes per kilometer per day [0.11 snakes per mile per day]) in a severely fragmented landscape, complete repopulation was relatively rapid.

One vital point to be taken from the very wide range in estimated immigration rates (from 0.07 to 20 snakes per kilometer per day [from 0.11 to 32 snakes per mile per day]) is that circumstances vary, particularly with regard to habitat connectivity and the variability of snake movements. Without a better understanding of the role of immigration, it will not be plausible to assume that any specific value applies. The amount of fragmentation of the forested habitat appears to be responsible for some of the variation in immigration rate, which makes it especially important not to extrapolate from highly fragmented urban areas to continuous forest (Engeman and Linnell 1998; Engeman *et al.* 1998a, 1998b, 1998d, 2000). One unsurprising factor that affects immigration rate is the size of the area; larger areas are relatively less influenced by immigration than are small areas (Rodda and Dean-Bradley, unpubl. data 2001). This generalization of the relative immigration rate does not contradict the reasonable assumption that the absolute immigration rate will increase as progressively larger areas are subjected to snake control.

e) Saturation versus perimeter trapping. The desirability of perimeter trapping versus saturation trapping for conservation efforts has generated some controversy. In saturation trapping an area is blanketed with snake traps. In perimeter trapping the traps are placed only around the outside. Saturation trapping requires the cutting of trails through an area to check snake traps, whereas placing traps only around the perimeter of a forest allows a trap checker to drive a vehicle between traps. The greatest benefit is that it spreads the traps apart, so that each trap gets a maximal number of captures. For this reason it maximizes yield per trap check. The disadvantage of maximally spreading out snake traps is that it simultaneously minimizes the number of trap captures per unit area. In other words, saturation trapping maximizes the number of snakes caught per unit area, but perimeter trapping maximizes the number caught per trap check. Therefore, the relative merits of saturation versus perimeter trapping depend on one's goal.

An additional consideration of perimeter trapping is that if the area is large enough one may be leaving snakes uncaptured within the untrapped core. Based on the studies to date (Engeman and Linnell 1998; Engeman *et al.* 1998a, 1998d, 2000), it appears that areas of more than a few hundred meters across have small numbers of snakes that fail to enter perimeter traps, but definitive data are lacking. Presumably larger areas have increasing numbers of snakes left untrapped in the core. There is also an interaction between the time span needed for effective snake control and reliance on perimeter trapping. Due to snake movement, the snakes in the interior of large areas will probably eventually travel to the perimeter of an area and be caught by a perimeter trap. However, if one is using an immigration barrier such that perpetual trapping is not needed, it may be more cost effective to trap the entire area at once and reduce the time needed before traps can be moved to another area.

3. Dog-aided Searches

Visual searches and snake traps reduce populations of brown treesnakes near cargo, but the ideal is to have a method for extracting or exterminating all snakes from the cargo itself. Visual searches of cargo have proven impractical (most shippers will not allow their carefully-prepared packets to be disassembled), but dog-aided searches make possible the detection of many snakes by odor alone (Imamura 1993, 1999; Engeman *et al.* 1998c, 1998e, 2002). Wildlife Services makes extensive use of dog-aided searches, with the goal of screening all cargo destined for high-risk destinations such as Rota. In the period 1994 through 1999, dog-aided searchers working at the civilian airport on Guam found 15 snakes. Although this total is far lower than that for trap or hand captures, most of these 15 snakes were physically in cargo, thus they were the most important captures. Dog teams are also maintained by the Commonwealth of the Northern Mariana Islands and State of Hawai`i. Both programs screen incoming cargo selectively; neither has detected a snake to date (2001).

Dog-aided searches are limited by the skill and motivation of both the handler and the dog. About 62 percent of snakes intentionally planted in cargo for test purposes are detected by handlers (Engeman *et al.* 2002). It is not clear whether planted snakes are easier or harder to detect than naturally occurring stowaway snakes. The error rate of dog teams on Guam (they have not been tested elsewhere, but are likely to perform more poorly on islands where regular reinforcement with a variety of training snakes is not possible – see below) has led to the suggestion that additional brown treesnake interdiction measures should take place at destination ports. Although destination ports have their own set of unique challenges (*e.g.*, low capture success leading to boredom on the part of handlers, poor dog performance, etc.), an independent search team in a destination port will discover cargoes that were inadvertently (or even intentionally) passed around the Guam-based inspection teams. Shippers have various motivations for concealing shipment, and all inspections are voluntary, so there is no penalty for non-compliance. Naturally, there are no precise data on the level of non-compliance. Rota is undoubtedly the port having the lowest level of compliance, as it alone is readily accessible by Guam with small private boats.

Any dog-based program on an island other than Guam has a special problem with maintenance training of dogs. On Guam, sniffer dogs are maintained by exposing them to new brown treesnakes weekly. Presumably this refreshes their mental template as to what they are searching for. By changing the sample snake regularly, trainers ensure that the dogs are cueing on odors common to all members of the species. Repetitive use of the same snake may cause the dogs to target an individual odor that is not found in all brown treesnakes. However, it is not only impractical to ship a large number of brown treesnakes to snake-free islands, it is ecologically dangerous as well. Aside from using exceptional care (*e.g.*, cage locks) in the housing of the snakes, at least three safeguards have been used to insure that training snakes do not become colonizers. All snakes used for training sniffer dogs are: 1) males only, 2) sterilized, and 3) implanted with radio-transmitters. All three techniques have been known to fail, but in combination they probably present a fairly high level of assurance. In particular, a new technique for sterilization of males, bilateral hemipenectomy (Qualls and Qualls 2002), should eliminate sexing errors and provide a very high level of security in sterilization. The track record of reliability with radiotracking equipment is not particularly reassuring, particularly in the Marianas, but in combination with other tools it should help. To our knowledge, no formal reporting procedures are required to guard against escape of brown treesnakes used to train sniffer dogs outside of Guam. In the case of Rota, such precautionary safeguards may be needed for any training snakes brought to the island. In addition, it might be desirable to require peer-reviewed approval of a formal protocol for handling (*e.g.*, cage requirements, number of handlers, handling conditions), as well as a formal reporting system for documentation that the protocol is being followed. Informality is a hallmark of small island life; in many ways it is the most endearing aspect of small island life. Unfortunately, it is not a characteristic that lends itself well to the safe handling of hazardous biological materials. A potential problem with dog training aids that are handled under a rigorous biosecurity protocol is that sterilization and other procedures may alter the snake's natural odor. If the altered snakes smell different to a sniffer dog, the sniffer dog program may be invalidated. Given the low cost of airfares between Guam and the Commonwealth of the Northern Mariana Islands, consideration should be given to periodically flying sniffer dogs and their handlers to Guam for training, rather than flying snakes from Guam; presumably, the training could be coordinated with Wildlife Services' routine dog training.

4. Barriers

Snake barriers are temporary or permanent structures that restrict the movement of brown treesnakes. They vary widely in their design and cost depending on their use. They have been used in interdiction efforts on Guam and other islands to prevent the accidental introduction of brown treesnakes through cargo and in endangered species conservation efforts on Guam. For interdiction efforts, snake exclusion barriers are used primarily on Guam (to keep snakes out of cargo) and snake enclusion barriers (to keep snakes from leaving port areas) are used on snake-free islands. For conservation efforts, only snake exclusion barriers have been used.

A temporary enclusion barrier can be used to cover shipments involved in temporary shipping channels, typically a military exercise to a non-standard destination. For example, the Defense Department occasionally conducts exercises that simulate an invasion of the island of Tinian, and temporary barriers are used on both Tinian and Guam to guard against accidental movement of snakes in cargo during that exercise. The temporary barrier design currently in use by the U.S. Department of Defense consists of horticultural shade cloth supported by steel bars driven at an overhanging angle into the ground (Perry *et al.* 1997, 1998, 2001). The bottom of the overhanging cloth is anchored with sand or water-filled bags held in place by gravity (Perry *et al.* 2001). This structure is not durable against the long-term ravages of wind and rats, but suffices to reduce the probability of accidental snake transport during temporary exercises**.**

Permanent barriers overcome these limitations of temporary barriers, but permanent barriers cost more to construct. Three designs have proven valuable for permanent cargo facilities (aside from the creation of snake-proof buildings [Rodda, n.d.]): the bulge barrier, the vinyl barrier, and the masonry barrier (Perry *et al.* 1996, 1998, 2001). The bulge barrier (Rodda *et al.* 2000) can be retrofitted to a chain-link fence at low cost. It consists primarily of a 6.35 millimeter (0.25 inch) hardware cloth wall topped at the 1.15 meter (3.77 foot) level by a 15 centimeter (6 inch) overhanging bulge made of the same material. Bulge barriers for transportation protection are in use at the Rota port and Andersen Air Force Base's North Field. Relative to the other designs, the bulge barrier is less effective and the application of the hardware cloth to a chain-link fence lowers the probability that the fence will survive a typhoon. The vinyl barrier design relies on vertical slabs of a vinyl seawall material, held in place with a wood frame. The 1.15-meter (3.77 foot) tall vinyl slabs are light and easy to transport over rough terrain. No operational vinyl barriers have been built. The masonry barrier is also 1.15 meter (3.77 feet) tall, and is basically a smooth surface vertical wall topped by a horizontal overhang. The seaport on Tinian has a masonry barrier of this design. The masonry design has greater effectiveness than the other barrier types (the U.S. Geological Survey-preferred masonry design has proven to be 100 percent effective in tests to date), has the lowest long-term cost of the permanent barriers, and is nearly impervious to assaults by rodents and typhoons (though it may be damaged by falling trees, vandals, or errant vehicles). Implementation of the masonry barrier has been inhibited by high initial cost (see below), though recognition of the substantial, long-term cost savings associated with a durable, low-maintenance design is growing.

Snake barriers are relatively costly (initial cost up to $350 per meter ($107 a foot) in 2001), unsightly in some contexts, an obstacle to security in some situations, and designs that are inexpensive to erect are vulnerable to storm damage or maintenance failures. They are also ineffective if they are not appropriately designed, maintained, or operated. For example, a snake enclosure is effective because snakes that have been trapped inside cargo or a vessel for some time are hungry and eager to escape under cover of darkness. To detect and capture such a snake, it is imperative that the cargo be held in the enclosure long enough for the snake to voluntarily leave the vessel or cargo (usually after nightfall), and it is necessary for snake food attractants to be present to lead the snake into a trap or other killing device. There are many ways in which a snake enclosure might not work. Among the ways that have been demonstrated by operation of the Rota port are: (1) snake traps not present; (2) snake traps not baited; (3) cargo not unloaded within enclosure; (4) vessel not docked within enclosure; (5) cargo moved out of enclosure before nightfall; (6) empty shipping containers stacked next to barrier, allowing snakes to exit; (7) plants growing on barrier, allowing snakes to exit; (8) vehicles ramming barrier, disabling it; (9) gate left open at night, disabling barrier; and (10) gate damaged by vehicles and left unrepaired, allowing snakes to exit.

5. Prey Reduction

In localized areas, such as ports, Wildlife Services practices rodent and commensal bird control to limit the attractiveness of such sites for brown treesnake entry. Pigeons and sparrows are the primary commensal birds at Guam transportation facilities. It is believed that snakes enter warehouses and the like in search of food. If such facilities are devoid of potential prey items such as geckos, rodents, and birds, it is less likely that brown treesnakes will enter or spend time there. The effectiveness of this approach has not been tested; it is not used in natural habitats, where costs of controlling all prey would be prohibitive for most situations.

6. Toxicants, Fumigants, and Biocontrol

A variety of compounds have been tested for their effectiveness at killing brown treesnakes by oral ingestion or dermal absorption (Savarie and Bruggers 1999; Savarie *et al.* 2000, 2001). In 2001, toxicant research focused on acetaminophen tablets (80 milligrams) inserted in dead neonatal mice housed in bait tubes. This formulation is being studied by the National Wildlife Research Center for eventual toxicant registration by the U.S. Environmental Protection Agency. The dosage appears too low to cause appreciable mortality in non-target species, most of which (especially crows and crabs) avoid eating the hard acetaminophen tablets (Savarie *et al.*, National Wildlife Research

Center, pers. comm. 2001). Snakes, which do not chew their food, have no way to avoid eating the tablets imbedded in a prey item. Potentially, acetaminophen stations may replace snake traps, as they may prove to be less expensive to maintain (L. Clark, pers. comm. 2001), though the bait lasts only about 3 days and full-fledged cost-benefit analyses have yet to be conducted. One potential advantage of a bait station compared to a trap is that the bait station would not need an entrance flap. Even the best entrance flaps repel some snakes (see Snake Traps, above).

Toxicants, like acetaminophen, appear to also have the same constraints as those encountered by snake trapping (*e.g.*, size selectivity, likelihood of reduced effectiveness in high prey environments, selection for resistance). Campbell (pers. comm. 2001) reported a study in which 129 snakes equipped with radios or electronic tags were offered dead pinkie mice tainted with acetaminophen tablets. The poison baits were offered in electronic sensor bait stations that registered the comings and goings of tagged snakes. Of the 99 snakes marked only with passive electronic tags, 74 were resident before the trial began and 30 were small snakes (snout-vent length less than 894 millimeters [35 inches]) introduced into the area to increase the small snake sample size. Twenty-five additional resident larger snakes were equipped with active radiotransmitters (small snakes are too small to carry a radio). Of the 25 with radios, 8 ate the toxicant and 7 of these were found dead and untouched. The remaining radioed snake was found dead and partially consumed by a monitor lizard (in other words, it may or may not have died from toxicant ingestion). Seventeen of the radioed snakes did not eat the toxicant, though some were not near the toxicant at times (on average 12 of the 17 were within the toxicant treated area at any one time). Of the 30 small snakes introduced into the area, 4 visited a poison bait station, but only the very largest one (snout-vent length = 894 millimeters [35 inches]) took the bait (and died). Of the 74 remaining snakes (those neither radioed nor small), 17 took the bait (their fate is unknown, but they probably died). Thus, of each of the 2 samples of large snakes (radioed and not), 23 to 32 percent (17 out of 74, and 7 or 8 out of 25) ate the poison bait. None of the 29 snakes smaller than 894 millimeters (35 inches) snout-vent length ate the poisonous pinkies. From this study it appears that the size selectivity of toxicants is roughly the same as for snake traps: snakes smaller than 700 to 850 millimeters (27.5 to 33.5 inches) snout-vent length are rarely attracted.

Savarie *et al.* (1991, 1995, 2001, in press) identified a number of fumigants that can be used to insure that any brown treesnake located in a shipping container does not survive. Methyl bromide is presently registered with the U.S. Environmental Protection Agency for this purpose, but no shipper has chosen to add this step to their procedures. Thermal “fumigation” (the heating of shipping containers to a mild temperature that is nonetheless lethal to brown treesnakes) is also available for immediate use (G. Perry and D. Vice, USGS/Ohio State University, Wildlife Services, pers. comm. 1999), but has not yet been employed, presumably because there is no incentive to do so.

A variety of frontier technologies have been suggested for brown treesnake control (BTSCC 1996; Campbell *et al.* 1999; Rodda *et al.* 1998b). The least costly is probably biocontrol. Several viruses have been suggested as candidates for long-term population suppression (Altizer and Dobson 200;, Nichols 2000), though the durability of disease control is questionable for vertebrate hosts (Holmes 1982; Nokes 1992). Undoubtedly, incremental improvements will be made to existing control technologies, yielding more cost-effective control over the long run. At present (2002), however, candidate control techniques for eradicating brown treesnakes from Guam are not known. Thus, brown treesnake control is likely to be a perpetual obligation.

Novel future technologies such as biocontrol are judged worthy of additional research effort (in part to assess their prospects), but none of the suggested approaches appears foolproof or guaranteed to succeed. For example, if for some reason a virus could be found that was lethal to a significant fraction of snakes on Guam (adult mortality is about 20 percent in the best strain identified so far; Nichols 2000) or – should it come to that – Rota, one would anticipate very rapid evolution of resistance to the virus and even more rapid evolution of lower virulence by the virus (Davis *et al.* 1976; Wodzicki 1978; Fenner 1983; Bykovskii and Kandybin 1988; Howarth 1999). Furthermore, if the virus should prove lethal to more than just the species *Boiga irregularis*, it would constitute a significant threat to the snake biodiversity of the rest of the world, either by aerial transport, or in association with brown treesnakes accidentally transported overseas. There are no viruses known to affect only brown treesnakes. The risk of accidental transport of snake viruses to other islands is presumed low, but the numerous records of brown treesnakes leaving Guam for places with native snakes (Australia, Asia, North America, and Europe; see Fritts *et al.* 1999) indicates that it occurs fairly regularly. Furthermore, there are regions of the world in which *Boiga irregularis* is a desirable component of natural biodiversity and accidental introduction of even a species specific fatal disease would not be universally appreciated. A non-specific snake disease could be catastrophic. Asian grain farmers in particular would appear vulnerable to crop failure associated with widespread loss of snakes as natural rodent predators.

7. Reproductive Inhibition

Currently, research is also underway to evaluate the effectiveness of brown treesnake immunocontraceptives. Immunological fertility control has been achieved in feral horses, white-tailed deer, and zoo ungulates through the induction of autoimmune responses. However, information on the typical breeding period of the brown treesnake indicates that reversible reproductive inhibition will not be practical for control efforts.

The brown treesnake, like humans, has a relatively slow reproductive rate. It probably lays a few eggs once or twice a year and not necessarily every year (Rodda *et al.* 1999c). Gravid females appear to reduce their activity prior to egg laying, and they probably lay eggs deep underground. As a consequence, few gravid female snakes have been found by researchers, a situation that has greatly retarded investigation of brown treesnake reproduction. Furthermore, the snakes often resorb their developing eggs (technically their follicles) if they are captured or disturbed, which stymies most captive breeding studies. In nature on Guam, the occurrence of gravid females during all times of year demonstrates that brown treesnakes do not breed synchronously (Rodda *et al.* 1999c; F. Qualls and C. Qualls, Colorado State University, pers. comm. 2001). That is, unlike aga, there is no time of year when all snakes will consistently be found to be breeding. Even male snakes fail to show reproductive readiness at a consistent time of year; some males will be sexually competent in each month, but there is no month during which all males will be ready to mate. Droughts, typhoons, and perhaps other major climatic events may stimulate a large fraction of the population to breed at certain times in certain years, but no consistent time of year has emerged as a predictable breeding period.

Note: all references are provided in Section IV.

APPENDIX 6

Glossary

arboreal	Living in trees; adapted for life in trees.
biocontrol	*also* biological control. The control of a pest by the introduction, preservation or facilitation of natural predators, parasites, or other enemies, by sterilization techniques, by the use of inhibitory hormones, or by other biological means.
carabao	A water buffalo or swamp buffalo of the Philippines.
commensal	As used in this plan, an organism that prefers to live in association with humans. Examples include Norway rats, house mice, pigeons, house sparrows, and European starlings.
corvid	A bird in the family Corvidae, which includes, for example, crows, ravens, jays, and magpies.
copra	Dried coconut meat, used for producing coconut oil.
diurnal	Active during daylight hours.
emergent	*in re* trees: a tree which reaches above the level of the surrounding canopy.
fecund(ity)	Producing offspring; potential reproductive capacity of an organism.
gravid	Carrying fertilized eggs or young.
habitat conservation plan	A plan that outlines ways of maintaining, enhancing, and protecting a given habitat type needed to protect listed species; usually includes measures to minimize impacts, and may include provisions for permanently protecting land, restoring habitat, and relocating plants or animals to another area. Habitat conservation plans are designed to allow development to proceed while simultaneously promoting the conservation of listed species, and are required before a permit may be issued to authorize the incidental take of a listed species as the result of a non-Federal activity. *Also see* "section 10 permit." Further details are available at http://endangered.fws.gov/landowner/index.html.

passerine	Birds in the order Passeriformes, the "perching birds." The largest order of birds.
safe harbor agreement	A voluntary agreement signed by the U.S. Fish and Wildlife Service (or NOAA Fisheries) and a property owner and any other cooperator that benefits listed species while providing the landowner with assurances from additional restrictions. Issued in association with "enhancement of survival" permits (*also see* "Section 10 permit"). Further details are provided at http://endangered.fws.gov/landowner.html.
section 10 permit	Section 10 of the Endangered Species Act lays out the guidelines under which a permit may be issued to authorize prohibited activities, such as take of endangered or threatened species. Section 10(a)(1)(A) allows for permits for the taking of threatened or endangered species for scientific purposes or for purposes of enhancement or survival ("enhancement of survival permit"). Section 10(a)(1)(B) allows for permits for incidental taking of threatened or endangered species ("incidental take permit").
seral stage	Refers to the developmental stages of ecological succession, not including the climax community.
snout-vent length (SVL)	A standard measurement of body length for reptiles. The measurement is from the tip of the nose (snout) to the anus (vent), and excludes the tail.
supertyphoon	A term utilized by the U.S. Joint Typhoon Warning Center for typhoons that reach maximum sustained 1-minute surface winds of at least 240 kilometers (149 miles) an hour.
take	As defined under the Endangered Species Act, to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct; may include significant habitat modification or degradation if it kills or injures wildlife by significantly impairing essential behavioral patterns including breeding, feeding, or sheltering.
typhoon	A tropical cyclone of the Northwest Pacific ocean with sustained wind speeds of 119 kilometers (74 miles) an hour.

Region 1
U.S. Fish and Wildlife Service
Ecological Services
911 NE. 11th Avenue
Portland, Oregon 97232-4181

May 2005