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Gary J. Wiles
Washington Department of Fish & Wildlife

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THE STATUS, BIOLOGY, AND CONSERVATION OF *Serianthes nelsonii* (FABACEAE), AN ENDANGERED MICRONESIAN TREE

Gary J. Wiles

College of Agriculture and Life Sciences, University of Guam, Mangilao, Guam 96923, USA

Ilse H. Schreiner, Donald Nafus

College of Agriculture and Life Sciences, University of Guam, Mangilao, Guam 96923, USA

Laura K. Jurgensen

Pacific Southwest Research Station, US Forest Service, 2400 Washington Avenue, Redding, CA 96001, USA

&

James C. Manglona

Department of Natural Resources, Rota, Commonwealth of the Northern Mariana Islands 96952, USA

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Abstract

Serianthes nelsonii *Merr. is a rare leguminous tree endemic to Rota and Guam in the Mariana Islands of Micronesia. Current population estimates are 121 adult trees on Rota and one adult tree on Guam. Surviving trees occur exclusively on limestone substrates, although the species formerly inhabited volcanic soils in southern Guam. Populations on both islands are senescent, with little or no regeneration occurring. More than 84% of the trees have trunk sizes >40 cm diameter at breast height. The species is threatened primarily by browsing from introduced deer and pigs and infestations of herbivorous insects, especially undetermined seed predators, four species of mealybugs, and a butterfly. Recovery goals call for the reestablishment of at least two large subpopulations on each island. Prevention of ungulate browsing through fencing and control of insect damage are essential for recovery of the species. Copyright © Elsevier Science Limited.*

Keywords: *Serianthes nelsonii*, Rota, Guam, Mariana Islands, endangered plant conservation.

Correspondence to: Gary J. Wiles, PO Box 24471, GMF, Guam 96921, USA, Tel.: 671-735-3957; Fax: 671-734-6570.

INTRODUCTION

Oceanic islands are vulnerable to a variety of human-related ecological perturbations because of their long isolation from some of the selective forces that have influenced the evolution of continental organisms (Vitousek, 1988). Through habitat alteration, the introduction of exotic species, and direct exploitation, native ecosystems on many tropical Pacific islands have experienced considerable disruption and degradation since the arrival of the first humans, leading to considerable loss of natural diversity (Stone & Scott, 1985; Loope *et al.*, 1988; Ash, 1992; Fosberg, 1992; Thaman, 1992; Steadman, 1995). Indeed, Oceania is believed to support more endangered taxa per unit of land area than anywhere else in the world (Dahl, 1984). Species declines are best documented among native faunas (Scott *et al.*, 1986; Savidge, 1987; Steadman, 1995), and indigenous plants have experienced similar decreases.

In the Mariana Islands of Micronesia, changes in native plant communities continue to occur. These are attributable to many causes, including forest losses due to agricultural and wartime activities (Baker, 1946; Bowers, 1950; Fosberg, 1960*a*); rapid modern development; the introduction of alien animals (Walter & Robins, 1974; Conry, 1988; Wiles *et al.*, 1990), plants, and plant pathogens; the annual burning of grasslands (Fosberg, 1960*a*; Stone, 1970); and declines in populations or extirpations of some pollinators and seed dispersers, such as fruit bats, insects and, on Guam, nearly all of the indigenous forest birds (Savidge, 1987; Wiles *et al.*, 1989; Cox *et al.*, 1991). Changes have been most severe on the five southernmost islands of Guam, Rota, Aguijan, Tinian, and Saipan.

Little study has been devoted to declining populations of native plant species in the Marianas and the rest of Micronesia. Although a number of species probably deserve protection, only one plant, *Serianthes nelsonii* (Mimosoideae, Fabaceae), is currently designated as endangered in the Marianas by the US Fish & Wildlife Service. *S. nelsonii* is endemic to the islands of Rota and Guam. Because of its rarity, basic information on its biology and apparent factors causing its decline were previously unavailable. This report summarizes these topics and the current status of *S. nelsonii* based on recent field observations. This information will aid in the formulation of management and conservation strategies for this species.

S. nelsonii is one of the largest native trees in the archipelago. Trees on Rota reach heights of up to 36 m and have trunk diameters of up to 183 cm. Merrill (1919) reported trunks of nearly 2 m on Guam. Trees have cylindrical boles in all but the largest specimens, which develop deep folds in the trunk, and often have one or more large roots exposed on the surface of the ground. Mature individuals frequently have large spreading crowns, with several of the largest trees on Rota having crown diameters of 21–23 m. Inflorescences are about 3 cm long, with long protruding pinkish filaments. Fruit pods are 2–12 cm long, 1.5–2.5 cm wide, and contain one to seven seeds. Further descriptions of the species appear in Kanehira (1933), Stone (1970), and Raulerson and Rinehart (1991).

S. nelsonii is one of 15 species in the genus *Serianthes* Benth., whose members are distributed from the Malay Peninsula eastward to Micronesia and French Polynesia (Fosberg, 1960*b*; Kanis, 1979). Little published information is available on the current status of most other *Serianthes*. In several species, abundance varies from rare to common among populations (Kanis, 1979). For example, *S. melanesica* Fosb. is common in parts of Vanuatu and Fiji (Chew, 1975; Alston, 1982), but is considered endangered in Tonga (Whistler, 1989). *S. robinsonii* Fosb. is known from just a few collections on two Indonesian islands (Kanis, 1979) and may also be threatened. The only other species of *Serianthes* native to Micronesia, *S. kanehirae* Fosb., is widespread and locally common in Palau and Yap (Cole *et al.*, 1987; M. V. C. Falanruw, pers. comm.).

STUDY AREA

Rota (14°9'N, 145°13'E) and Guam (13°27'N, 144°47'E) are the southernmost islands in the Marianas. Rota has a land area of 85 km^2 and consists of a series of uplifted limestone terraces and plateaus, with a maximum elevation of 496 m. Guam is 540 km^2 in size. The northern half of the island features a large limestone plateau, while southern Guam is largely dominated by volcanic substrates and rolling hills. Maximum elevation is 406 m. The islands comprise two political entities: Rota is part of the US Commonwealth of the Northern Mariana Islands and Guam is a US Territory.

The climate of both islands is warm and relatively constant during the year, with daily temperatures ranging from 22 to 33°C. Average annual rainfall at low elevations is estimated to range from 2000 to 3000 mm, most of which falls from July to November. Higher elevations on Rota, which are often shrouded in heavy clouds and mist in the rainy season, receive considerably more rainfall than the rest of the island, but the amount is unmeasured. A dry season occurs between January and May, when rain diminishes to 0–150 mm per month.

Typhoons are common in the Mariana Islands and are a key factor in determining the structure of plant communities (Stone, 1970). Most storms inflict only limited damage. However, severe typhoons tend to strike each of the islands in the archipelago on an average of about once every 10–20 years, causing extensive damage to forests.

Descriptions of vegetation types on Rota and Guam appear in Fosberg (1960*a*). Both islands feature substantial areas of primary and secondary forest on limestone substrates. Ravine forests on volcanic soils also occur in southern Guam.

METHODS

Two week-long censuses of *S. nelsonii* were made on Rota in April and May 1992. All previously known groups of trees were visited, and searches for new trees were made by scanning a number of hillsides with binoculars. The diameter at breast height (DBH) of most trees was measured and all trees were mapped. Incidental observations were also collected on tree heights, the general condition of trees, the presence of seedlings, flowers, and seed pods, and potential threats. Surveys of arthropods on eight or nine trees on Rota were conducted in October 1990 and May 1991.

General observations of *S. nelsonii* on Guam were made from 1983 to 1993. These included irregular visits to living trees and searches for new trees. The phenology of leafing, flowering, fruiting, bud death, and arthropod communities were monitored on two wild trees, one at Ritidian Point from October 1990 to May 1992, and one at Northwest Field from December 1991 to May 1992, and on one cultivated tree in Yona from September 1990 until its death in December 1990. Trees were climbed with aluminum ladders. On each tree, 20 accessible stem tips were randomly selected and tagged. All leaves on the tips were sampled for insects and other arthropods at 2- or 3-week intervals. If a tip died during the course of the study, a new tip was tagged to replace it. These data were supplemented with incidental information from Merrill (1919), Robinson (1984), D. Herbst (pers. comm.), and specimens from the University of Guam Herbarium (GUAM). Foliage on additional branches was also searched for insects. Records of insect damage were also kept on about 20 potted seedlings on the campus of the University of Guam.

RESULTS AND DISCUSSION

Historic range and population status

The earliest known collection of *S. nelsonii* was made on Guam by A. A. Marche in the late 1800s, but this material remained unstudied until after World War II (Fosberg & Sachet, 1957). Specimens of *S. nelsonii* were also collected in 1916 and 1918 by P. Nelson and were used by E. D. Merrill to describe the species (Merrill, 1919; D. Herbst, pers. comm.). The species was first reported on Rota by Kanehira (1933).

There are no historic accounts of the status and distribution of *S. nelsonii* on Rota, and the locations where Kanehira collected his specimens are unknown. A brief initial inventory of the tree on Rota was completed by Robinson (1984), who reported 64 trees in eight subpopulations (Table 1, Fig. 1). He was unable to ground check the number of trees in each group; thus additional individuals may have been present. None of the trees examined had estimated trunk diameters of < 40 cm. Despite an abundance of seed pods in the crowns of some trees, Robinson (1984) found evidence of regeneration only in Subpopulation 7. It had 40–50 small seedlings that were 10–30 cm tall and two older seedlings, one of which was 60 cm tall, that were probably from a previous cohort.

The original distribution of *S. nelsonii* on Guam is poorly known, but most reported trees are from locations in the northernmost portion of the island (Fosberg, 1960*b*; D. Herbst, pers. comm.; herbarium specimens (GUAM)). The type locality designated from Nelson's specimens was 'Upe District and hills back of Abu' (Merrill, 1919). Upe is the general area now occupied by the main airfield and housing complex on Andersen Air Force Base (Fig. 2). Abu is located next to the embayment now known as Abo Cove in inner Apra Harbor in the west-central part of the island. The hills behind this site undoubtedly refer to Mt Tenjo and Mt Alutom, the slopes of which are now largely covered in grassland savanna, groves of the small introduced tree *Leucaena leucocephala* (Lam.) de Wit, and pockets of degraded ravine forest.

S. nelsonii was rare on Guam at the time of its discovery. Nelson reported that it was 'very scarce' and that few residents were familiar with the tree (Merrill, 1919). Stone (1970) also considered the species to be rare. Only six mature trees have been recorded in the wild since the early 1970s (Fig. 2). Two were located at Ritidian Point, one each at Northwest Field and Pati Point, and two in a ravine along the Tarzan River in south-central Guam. The presence of the southern trees suggests that the species was once widespread on the island. As on Rota, no successful regeneration was seen during the 1970s and 1980s. Small seedlings <30 cm tall were observed periodically under several trees, but none survived to a larger size. Single small cultivated trees planted as seedlings in the late 1970s survived at the University of Guam campus until 1989 and at a private home in Yona village until 1990.

Current range and population status

Increased vegetational survey work on Rota and Guam

Table 1. Population estimates of mature *Serianthes nelsonii* on Rota in 1984 and 1992
Locations of subpopulations are shown in Fig. 1.

Subpopulation no.	Site name	Estimated number of trees: Robinson (1984)[a]	Estimated number of trees: 1992	Ownership
1	Aplalago	—	15	Private
2	Gayaugan	2	2	CNMI[b]
3	Gayaugan	2	4	CNMI
4	Gayaugan	—	1	CNMI
5	Gayaugan	12	14	CNMI
6	Isang	7	4	CNMI
7	Gayaugan	39	36	CNMI
8	Gayaugan	—	3	CNMI
9	Gayaugan	—	1	CNMI
10	Linansa	—	2	Private?
11	Uyulan Hulo	—	11	CNMI
12	Hocog farm, Isang	—	14	Private
13	Hocog farm, Isang	2	3	Private
14	Lupok	—	8	CNMI
15	Palii	—	1	CNMI
16	Palii	—	2	CNMI
Total		64	121	

[a]Some of Robinson's (1984) subpopulations were combined to correspond with those found in 1992.
[b]Commonwealth of the Northern Mariana Islands.

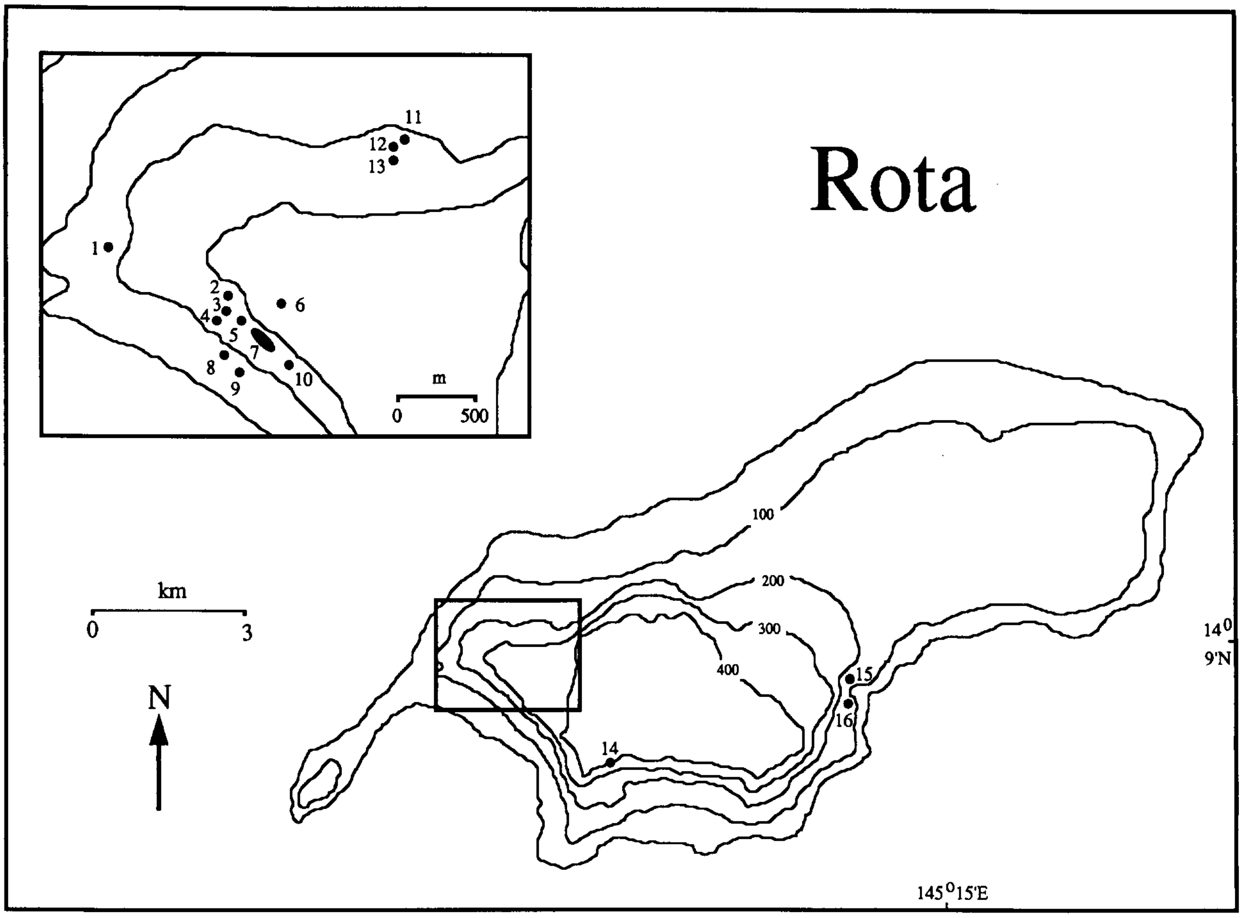

Fig. 1. Map of 16 known subpopulations of *Serianthes nelsonii* on Rota. Inset shows locations of Subpopulations 1–13. Contour lines represent 100-m intervals.

during the 1980s and early 1990s by government and university researchers located some additional *S. nelsonii.* The current total population estimate for both islands is 122 trees. Populations remain senescent, comprising almost entirely adult trees with small to moderate numbers of young seedlings (mostly < 40 cm tall) growing beneath some of them. Two saplings exist on Rota, but none are known to occur on Guam.

Since 1984, 57 additional trees have been discovered on Rota, bringing the total population estimate for the island to 121 trees (Table 1). Many of the new trees were found during the censuses in 1992. A total of 16 subpopulations are now known, the largest of which contains 36 trees (Table 1). Most of the population is located on the western side of the island (Fig. 1). Some mortality has occurred since 1984. Of the seven trees in Subpopulation 6, only four now survive and three of 39 individuals have likely died in Subpopulation 7.

On Guam, only one adult tree located near Ritidian Point is known to survive in the wild (Fig. 2). A second tree discovered in Northwest Field in July 1991 was killed during Typhoon Omar in August 1992. Its finding gives hope that a few more individuals may occur in the same general area. As of July 1993, five seedlings < 50 cm tall remained on the site of the storm-killed tree, while one seedling of 1.2 m was beneath the surviving tree. A survey of the Abu site in the Mt Tenjo and Mt Alutom region failed to find any trees in 1992.

It is unlikely that significant numbers of additional trees remain to be discovered on either island. However, continued surveys on Rota and Guam may find a few more solitary trees or small subpopulations.

Life history

The life history and demographic characteristics of *S. nelsonii* are poorly known. Other members of the genus *Serianthes* occur mainly on islands and inhabit a variety of soil types (Fosberg, 1960*b*; Kanis, 1979). Most *S. nelsonii* recorded on Rota and in northern Guam since the 1970s have grown in primary limestone forest, with a few individuals also present in secondary forest. These trees, plus those from Merrill's (1919) Upe locality, occur on thin limestone-derived soils. Most of the trees on Rota are located on or near steep hillsides (Fig. 1).

A few *S. nelsonii* grew on volcanic clay soils in southern Guam. The two trees in the Tarzan River valley occurred in a small sloping patch of ravine forest surrounded by grassland dominated by *Miscanthus floridulus* (Labill.) Warb. ex K. Schum & Laut. The trees near Abu may have grown on the steep hillsides that dominate this area, but little else can be inferred about their habitat because of the degraded conditions now present.

In 1992, the population of *S. nelsonii* on Rota had a mean DBH of 70.1 cm (SD = 32.3, n = 90), with most

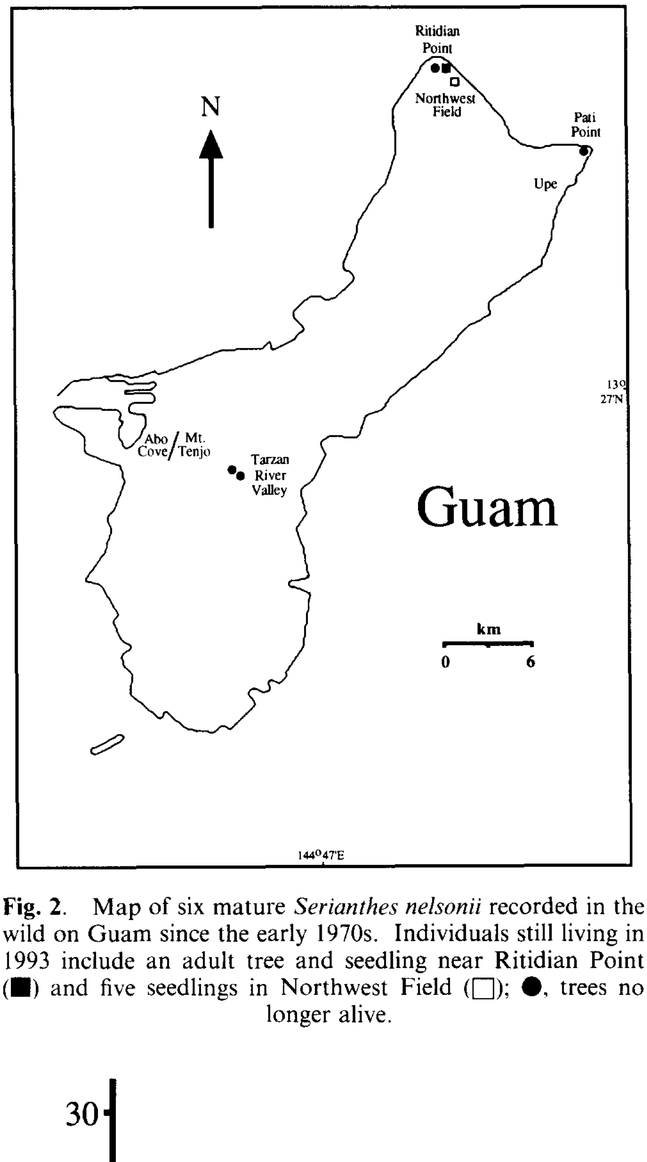

Fig. 2. Map of six mature *Serianthes nelsonii* recorded in the wild on Guam since the early 1970s. Individuals still living in 1993 include an adult tree and seedling near Ritidian Point (■) and five seedlings in Northwest Field (□); ●, trees no longer alive.

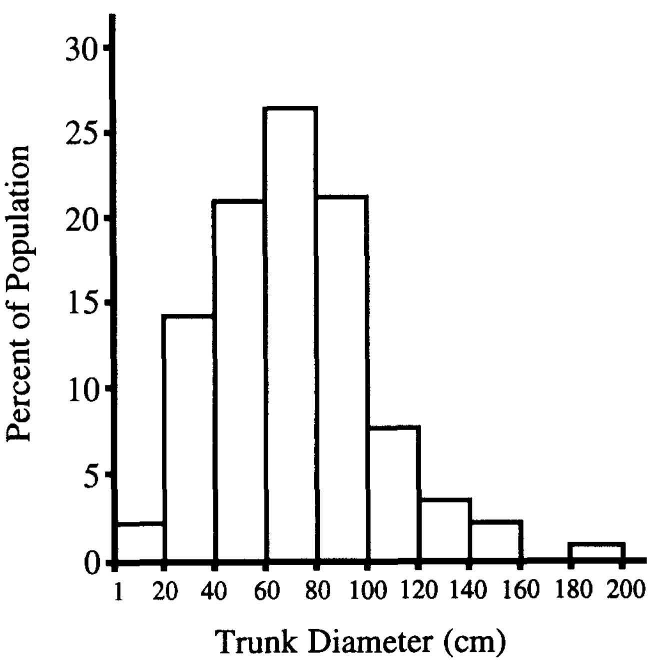

Fig. 3. Distribution of trunk diameters (DBHs) of *Serianthes nelsonii* (n = 90) on Rota in 1992.

(68.9%) individuals having diameters ranging from 40 to 100 cm (Fig. 3). About 3% of the population had DBHs >140 cm, while the two smallest trees had diameters of 13 and 17 cm. Heights averaged 18.0 m (SD = 8.3, n = 32) and ranged from 6 to 36 m. Trees at Ritidian Point and Northwest Field, Guam, had DBHs of 50 cm and 64 cm, respectively, in 1992.

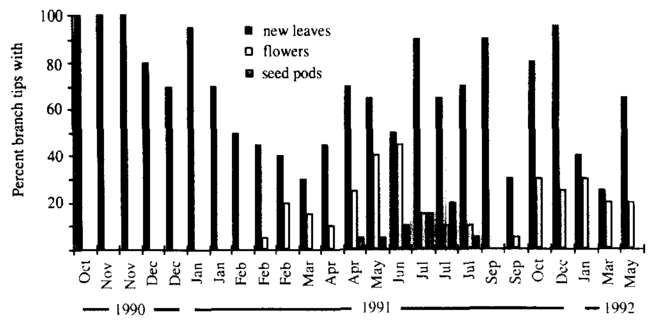

Fig. 4. Leaf, flower, and fruit production by one *Serianthes nelsonii* at Ritidian Point, Guam, from 1990 to 1992.

New leaves are produced continuously throughout the year, but fewer are produced during the dry season from January to June. Flowers and flower buds are present in all months. In the Ritidian tree, flowering was greatest in the dry season (Fig. 4). Mature seed pods have been found in all months, and on the Ritidian tree were most abundant at the beginning of the wet season in June and July. Seed crops can be large, with 500–1000 pods seen in the crown of one large tree on Rota. Pods on the Ritidian tree averaged 4.7 seed compartments (SD = 1.1, range = 2–7, n = 35), with a mean of 1.8 viable seeds per pod (SD = 0.9, range = 1–4, n = 35). The age and size at which reproduction begins in the wild are unknown, but flowers and pods were produced by an approximately 10-year-old cultivated tree with a DBH of 19 cm.

Methods of pollination and seed dispersal are unreported for *S. nelsonii.* On Rota, Marianas fruit bats *Pteropus mariannus* Desmarest occasionally feed at the flowers of *S. nelsonii* (E. M. Taisacan, pers. comm.) and may assist in pollination. Seedlings found on Rota and Guam in recent years have all been located under the crowns of parent trees. This suggests that seed dispersal is poor under natural conditions or has been greatly reduced for undetermined reasons. The current distribution of *S. nelsonii* on Rota, where trees are frequently found in groups or pairs, further indicates that vagility is poor and that most regeneration takes place near existing trees.

On both islands, *S. nelsonii* supports a diverse community of arthropods, including a number of predators such as spiders, preying mantids, ants, beetles, and mites. Arthropod predators are abundant for much of the year and help control outbreaks of other insects. Maintenance of predator populations is probably critical to the health of the trees.

Numerous epiphytic ferns (*Asplenium laserpitifolium* Lam., *A. nidus* L., *A. pellucidum* Lam., *Davallia solida* (Forst. f.) Sw., *Nephrolepis acutifolia* (Desv.) Christ, *Polypodium punctatum* (L.) Sw., *P. scolopendria* Burm. f., *Pyrrosia lanceolata* (L.) Farw., *Vittaria incurvata*

Cav.), orchids (*Bulbophyllum* Thou. sp., *Dendrobium guamense* Ames, and *Taeniophyllum mariannense* Schltr.), and other plants (*Dischidia puberula* Decne., *Ficus* L. sp., *Freycinetia reineckei* Warb., and *Peperomia mariannensis* C. DC.) grow in the crowns of *S. nelsonii.*

Threats to population

Herbivory by introduced ungulates

The native flora of the Mariana Islands evolved in an environment free of ungulates, which makes many species susceptible to heavy browsing. Forests on Guam, Rota, and other islands exhibit distinctive signs of overbrowsing, and regeneration of many plant species appears to be greatly reduced or eliminated in some areas. Three species of ungulates, Philippine sambar deer *Cervus mariannus* Desmarest, feral pigs *Sus scrofa* L., and domestic cattle *Bos taurus* L., are probably involved in the destruction of young *S. nelsonii.*

Deer were introduced to Guam by the Spanish in the 1770s (Safford, 1905) and were established on Rota by at least the 1880s (Marche, 1889). Currently, they are common in all areas with *S. nelsonii* on both islands, as evidenced by browsing sign, the presence of pellet groups and game trails, and sightings of animals. Feral pigs on Guam, which are most likely descendants from domestic stock brought to the island in the 1600s (Intoh, 1986), are abundant in the limestone forests of northern Guam. Pigs and pig signs (i.e. rooting and rubbing on trees) were observed close to both remaining trees in 1991. The historic occurrence of feral pigs on Rota is poorly known, but they apparently were present in the 1880s (Marche, 1889) and then died out. A small population became reestablished along the northern coast from Sakaya to Tatgua in the 1980s (C. G. Rice, pers. comm.), and occurs within 1 km of the nearest known *S. nelsonii.* Small numbers of cattle are sometimes allowed to graze in forests near farms on Rota. In 1992, a few cattle droppings were observed in Subpopulation 1.

Deer consume the seedlings of *S. nelsonii* (Lucas & Synge, 1978). It is likely that feral pigs and domestic cattle also feed on the young shoots of the species or may destroy them through rooting or trampling. Deer are probably the major cause of seedling mortality on Rota because of their much greater numbers, but on Guam seedling losses may be equally attributable to feral pigs. The only data on this problem exist for Guam, where seedlings were removed by animals under both of the trees remaining in 1991. At the tree in Northwest Field, five of 37 seedlings had their stems nipped off at ground level during a 5-week period before protective screening was installed.

Insect infestations

A variety of insects, many of which are introductions with broad host species ranges, feed on wild and captive *S. nelsonii* (Table 2). The diversity of insect herbivores and seed predators appears to be greater on Rota than Guam, but this is probably because of the larger number of trees examined on Rota. Large variations in the composition of insect communities were noted among individual trees, with some species such as weevils Curculionidae common on some trees and absent from others. Introduced species comprise a larger percentage of the insect fauna on *S. nelsonii* on Guam than Rota. It is possible that some native species of insects that once fed on *S. nelsonii* on Guam were lost because of the small number of surviving trees.

Initial observations suggest that insect predation on seeds is a significant factor reducing reproductive output in *S. nelsonii* on Rota, but not on Guam. Robinson (1984) found unidentified insect larvae in immature pods on a tree and reported that all of the mature pods had insect damage. Many infested pods were also observed in 1992. A weevil (possibly a species of Alleculidae) and moth larvae were found associated with damaged seeds in 1991.

Mealybugs and the butterfly *Eurema blanda* (Boisduval) appear to be the insects most damaging to *S. nelsonii* on Guam, but have not yet been found to be a problem on Rota. Three species of mealybugs, *Dysmicoccus neobrevipes* Beardsley, *D. brevipes* (Cockerell), and *Planococcus citri* (Risso), feed on the leaves, leaf buds, branch tips, and roots of trees and seedlings. These mealybugs live in close association with, or are tended by, a variety of ant species, which transport the mealybugs to new plants or new locations on the same plant, as well as protect them from parasitoids and predators.

In adult *S. nelsonii* on Guam, *D. neobrevipes* and *P. citri* form dense colonies on buds and newly emerging leaves. Early stages of infestation cause twisted, stunted branches and growing tips, and eventually branch tips can be killed. On the cultivated tree in Yona, up to 40% of the branch tips were killed every two weeks by a combination of *D. neobrevipes* and *P. citri.* Nearly all of the tree's branches had died by December 1990, when Typhoon Russ stripped the remainder of the tree and killed it. Mealybugs were also a problem on the two wild trees. A chronic infestation was present on the Ritidian tree, but only branches patrolled by the ant *Anoplolepis longipes* (Jerdon) were affected except for occasional outbreaks. Only a few twigs, all within the ant-patrolled area, died from mealybug damage. Most mealybug colonies outside this area were removed by predators, including the lady beetle *Nephus roepkei* (Fluiter) (Coccinellidae). The tree in Northwest Field suffered greater damage from mealybugs, with rates of infestation and twig death similar to the Yona tree. The entire tree was inhabited by the ant *Technomyrmex albipes* (Fr. Smith) living in epiphytes and cavities in dead limbs.

The ant *Pheidole megacephala* (F.) carried *D. brevipes* into 20 potted *S. nelsonii* seedlings kept on Guam in 1990 and 1991. The mealybugs occurred primarily below the soil line on the bases of stems, but also infested the leaves, causing distortion of the growing tips and leaves similar to that observed in wild trees.

Table 2. Arthropod fauna known or suspected to feed on *Serianthes nelsonii*
Identifications are pending for many of the species.

	Presence on mature trees		Presence on potted seedlings on Guam
	Rota	Guam	
Number of trees inspected	12	3	20
Acari			
Unidentified mite	x	x	
Hemiptera			
Aphis craccivora Koch			x
Lallemandana phalerata (Stål)	x		
Leptocentrus taurus (F.)	x		
Kallitaxila crini (Matsumura)[a]		x	
Steatococcus samaraius Morrison[a]	x	x	x
Ferrisia virgata (Cockerell)	x	x	
Planococcus citri (Risso)[a]		x	
Dysmicoccus neobrevipes Beardsley[a]		x	
Dysmicoccus brevipes (Cockerell)[a]			x
Homoptera			
Saissetia sp.			x
Coleoptera			
Myocallis guamensis (Zimmerman)	x		
Myocallis spinifer (Zimmerman)	x		
Curculionidae sp.	x		
Alleculidae sp. (?)	x		
Elateridae sp.	x		
Rhyparida sp.[a]		x[b]	x
Lepidoptera			
Eurema blanda (Boisduval)	x	x	
Geometridae sp. 1	x		x
Geometridae sp. 2	x		
Geometridae sp. 3			x
Geometridae sp. 4			x
Noctuidae sp.	x		
Micro-Lepidoptera sp.		x	
Isoptera			
Isoptera sp.		x[c]	

[a]Species known to be historic introductions to the Mariana Islands.
[b]Two beetles were found in a curled leaf, but were not observed feeding.
[c]Probably feeds only on dead wood.

The infestations killed 19 of the plants despite attempts to control them with insecticide drenches. Malathion effectively killed the mealybugs, but also may have damaged or killed some plants. As the seedlings grew older, the mealybugs moved beneath the larger lateral roots, making control more difficult. Seedlings >1 year old remained highly susceptible to mealybug infestations on the roots and were easily killed by them. It is unknown how large *S. nelsonii* must grow before it can withstand root damage caused by mealybugs. In the wild, seedlings under the heavy shade of the forest canopy appear to grow more slowly than cultivated individuals in full sunlight. Thus, wild seedlings may remain vulnerable to mealybugs for longer periods of time.

D. neobrevipes, *D. brevipes*, and *P. citri* are relatively recent introductions to the Marianas, and it is suspected that *S. nelsonii* has no genetic adaptations allowing it to tolerate even limited feeding by these insects. Another species of mealybug, *Ferrisia virgata* (Cockerell), also feeds on leaves and seed pods of *S. nelsonii*. Although it does not appear to damage leaves or twigs, it was observed to distort seed pods, and thus could affect seed production.

E. blanda lays large clusters of eggs on several host plants including *S. nelsonii*. The caterpillars feed gregariously and can remove large amounts of foliage. On one occasion during our survey, 25% of the leaves were removed from the Ritidian Point tree resulting in the death of 10% of its twigs. Smaller trees can be completely defoliated by the butterfly, with one of the cultivated trees on Guam dying after being stripped by *E. blanda*. Caterpillars of other Lepidoptera (Geometridae and Noctuidae) were abundant on *S. nelsonii* on Rota and may also be important herbivores. Adults of these species were not reared, so their identity is unknown.

S. nelsonii is vulnerable to other insects as well. Several seedlings at the Waimea Arboretum and Botanical Garden in Oahu, Hawaii, were killed by black twig borers *Xylosandrus compactus* (Eichhoff) (Scolytidae; Coleoptera) (K. R. Woolliams, pers. comm.). This species is not known to be present in the Marianas. Unidentified termites have invaded at least three living trees on Guam in recent years, and may have contributed to several deaths. Termite damage can weaken tree trunks and major limbs, making them more susceptible to breakage during typhoons.

Typhoon damage
Severe typhoons represent little threat to plant and animal species that are common and well-distributed on an island. However, the loss of a few individuals to storms can be a serious problem to endangered populations.

Some *S. nelsonii* have been killed or had major limbs broken during typhoons. Insect damage may have contributed to the susceptibility of these trees. Losses have included a tree in Subpopulation 6 on Rota killed by Typhoon Roy in 1988 and the tree in Northwest Field, Guam, killed by Typhoon Omar in 1992. The trunk of the latter tree was snapped about 3 m off the ground where a termite colony had hollowed out the interior. In 1990, one of the small cultivated trees on Guam died soon after being defoliated by Typhoon Russ. Mealybugs had already killed about 90% of the branches on this tree, and the remaining ones were also heavily infested and badly distorted.

Several large trees on Rota exhibit major broken limbs or have been completely toppled, presumably by typhoons, but continue to survive. The tree on Pati Point, Guam, lost half its crown when a main branch broke off in Typhoon Pamela in 1976. This tree was invaded by termites, apparently through the wound of the lost limb, and eventually died about 1985. Many larger trees on Rota exhibit narrow cracks or fissures in the bark of their lower trunks. Healed scars are also common. These may be stress fractures caused by strong winds.

Habitat loss
Destruction of native forest probably played a role in the historic decline of *S. nelsonii*, although this is largely speculative. Fairly large areas of both islands still retain primary forest, yet have no *S. nelsonii*. On Rota, some trees may have been cut during the Japanese occupation in the 1930s, when up to 75% of the island was used for sugar cane production, phosphate mining, and other activities (Bowers, 1950). Currently, several trees growing next to small roads could be destroyed if the roads are ever expanded.

On Guam, the construction of Andersen Air Force Base during and immediately after World War II almost certainly destroyed some trees (perhaps including Merrill's Upe subpopulation) when significant areas of limestone forest were cleared to make room for runways and support facilities. The site of the former tree in Northwest Field appears to have been bulldozed many years ago, probably when the adjoining airfield was under construction. The only known recent incident of tree loss occurred in the early 1970s, when the Air Force inadvertently bulldozed a mature tree growing next to a small road on Ritidian Point. A Navy proposal to build a radar system in 1988 might have resulted in the destruction of the Northwest Field tree had the project not been canceled.

Inbreeding
Depauperate populations on both islands and the isolation of some trees, particularly on Guam, suggest that both populations are at risk of losing genetic diversity because of restricted opportunities for outbreeding and random genetic drift (Barrett & Kohn, 1991). Lowered levels of cross-pollination and increased self-fertilization can reduce reproductive output through lessened seed production, embryo viability, and seedling vigor (Ledig, 1986). Also, low genetic variation can decrease the ability of plant populations to adapt to changing environmental conditions and may increase their susceptibility to herbivory, infestations by insects, and disease (Huenneke, 1991).

Wildland fires
Large areas of grassland burn annually in southern Guam. Wildfires often burn into the edges of neighboring ravine forests, killing a few trees in the process. A fire of this type killed one of the *S. nelsonii* in the Tarzan River valley in the late 1970s and severely injured the second tree, which died in about 1982 (C. L. T. Noquez, pers. comm.).

Problems with other animals and plants
Robinson (1984) observed large numbers of broken branch tips with seed pods and new growth on the ground below a group of *S. nelsonii* on Rota. He speculated that the damage was caused by wind or black drongos *Dicrurus macrocercus* (Vieillot), an introduced bird that has been reported to strip the branches from other tree species. Similar damage was observed under a tree on Rota in 1991, when fruit bats had possibly clipped the twigs (I. M. Calvo, pers. comm.). Only a few broken twig tips of this type were noted during the population census in 1992. This problem has not been recorded on Guam.

A few of the *S. nelsonii* on Rota and three of the last four surviving individuals in northern Guam had small strangling figs *Ficus prolixa* Forst. f. or *F. saffordii* Merr. growing on them. None of the trees was severely damaged by the figs, but death may have eventually resulted had the figs not been removed.

Conservation measures
S. nelsonii was listed as endangered in March 1987 by the US Fish & Wildlife Service (1987). It has been given the same status on the Red Data List for Plants (Lucas & Synge, 1978) and on the Commonwealth of the Northern Mariana Islands and Guam Endangered Species Lists.

Recommendations for managing *S. nelsonii* have been recently set forth (US Fish & Wildlife Service, 1994) and are summarized here. Recovery efforts should focus on preventing or reducing browsing by ungulates and severe insect damage, with the ultimate goal of reestablishing viable populations on Rota and Guam. A minimum of two large subpopulations should be established on each island to lessen the threat of having a large percentage of an island's trees killed by a severe typhoon. The subpopulations should have age structures comprised of a large proportion of adult trees and a healthy number of seedlings and immature trees. Determination of minimum viable populations on both islands needs to be established through population viability analyses based on environmental conditions and plant traits (Menges, 1991).

Reestablishment of large subpopulations on each island will undoubtedly require the propagation of trees in captivity and the wild. Selection of parental stock for these programs should strive to preserve maximum genetic diversity in the species (Hamrick *et al.*, 1991; Huenneke, 1991). Research into the breeding system of *S. nelsonii* is recommended to help with assessments of genetic variety.

Prevention of predation of seedlings by ungulates is of primary importance. Probably the best method of protection is to fence off subpopulations or solitary trees to prohibit access of animals to seedlings. Individual cages are effective for seedlings, but require greater upkeep and frequent searches for newly sprouted individuals. Cages have already been placed around all existing seedlings on Guam.

Additional study is needed to examine the extent of seed predation on Rota and the species of insects involved. Control plans can be considered once this basic information is obtained. A solution is also needed for controlling mealybug herbivory on Guam. Possible control techniques include the introduction of parasitoids for biocontrol, the use of pesticides and toxic baits to control mealybugs and the ants attending them, and the pruning of dead limbs and removal of epiphytes to reduce nesting habitat for ants. These methods should be developed and tested, and implemented if successful.

Both sites with *S. nelsonii* on Guam remain safe from clearing or cutting because of their occurrence on Andersen Air Force Base, which is owned by the US government. On Rota, 12 subpopulations are located on land owned by the Commonwealth of the Northern Mariana Islands, with the remaining trees on private lands (Table 1). Commonwealth agencies need to be made aware of protecting trees on public lands. Measures should also be taken to prevent the accidental destruction of *S. nelsonii* on private property by establishing cooperative agreements or long-term leases with landowners, or by purchasing the land.

A variety of other management activities should also be considered (US Fish & Wildlife Service, 1994). These include the removal of strangler figs, cross-fertilization of flowers to enhance outbreeding, and supplemental fertilization to improve the vigor of trees. Systematic searches for new subpopulations should be continued, although significant numbers of unreported trees probably do not remain on either island.

Research into propagation techniques should be initiated and one or more nurseries should be started on Rota, Saipan, or Guam. Initial efforts to cultivate small numbers of *S. nelsonii* have had poor success, with most seedlings succumbing within a few months to 1 or 2 years. The primary cause of mortality was herbivory on roots by mealybugs on Guam (I. H. Schreiner and D. Nafus, personal observations; C. L. T. Noquez, pers. comm.) and black twig borers in Hawaii (K. R. Woolliams, pers. comm.).

The hard seed coats of *S. nelsonii* seeds result in reduced or slowed rates of germination. However, special treatment of seeds, such as boiling, wetting, and mechanical notching, can improve sprouting rates (R. L. Ando, pers. comm.). There is evidence that the seeds have a delayed germination mechanism that results in seed crops continuing to sprout over extended periods. Seeds left in pots at the University of Guam continued to germinate for up to a year after sowing.

A final action to guard *S. nelsonii* from extinction is to place it in *ex situ* collections (Eberhart *et al.*, 1991). Seeds should be gathered from as many trees as possible on both islands (Center for Plant Conservation, 1991) and placed in seed bank facilities for long-term storage. Efforts should be continued to establish the species in botanical gardens outside the Mariana Islands, such as in Hawaii, where several institutions have expressed interest in obtaining seed stock.

Aspects of rare plant conservation in Micronesia

Efforts to preserve rare plants are in the very early stages throughout Micronesia and most of Oceania. For the most part, few plant species have yet been identified as being potentially endangered, with baseline inventories lacking for large areas of many island groups. Extinctions are also generally poorly documented. In Micronesia, only a handful of additional plants have thus far been recognized as deserving of endangered status. These include the trees *Osmoxylon mariannense* (Kaneh.) Fosb. & Sachet (ined.), *Tabernaemontana rotensis* (Kaneh.) Fosb. ex Stone, *Heritiera longipetiolata* Kaneh., and nearly a dozen orchids, herbs, and ferns in the Mariana Islands (L. Raulerson, pers. comm.; L. A. Mehrhoff, pers. comm.); the palm *Gulubia palauensis* (Becc.) Moore & Fosb. in Palau; and the tree *Semecarpus kraemeri* Laut. ex Kaneh. in Chuuk. In contrast, considerable knowledge has already been gathered on rare plant populations and extinctions in Hawaii. The native flora of the Hawaiian archipelago contains nearly 1300 plant taxa, with 200 taxa already listed as endangered or threatened under the US Endangered Species Act, another 150 taxa recommended for listing, and about 100 taxa extinct (L. A. Mehrhoff, pers. comm.). Limited recovery actions are now underway for some Hawaiian plants.

The recovery measures for *S. nelsonii* described in US Fish & Wildlife Service (1994) represent the first attempt to recover an endangered plant in Micronesia. It is hoped that these efforts will focus attention on the conservation needs of other native plants and floral communities in the region. On Guam, *S. nelsonii* is only one of at least a dozen tree species experiencing poor regeneration (I. H. Schreiner and G. J. Wiles, personal observations). All of the species feature populations comprising almost entirely mature individuals and depressed recruitment rates. Many are plagued with poor seedling survival, probably because of herbivory by ungulates or insects. However, germination problems appear to affect at least one tree, *Elaeocarpus joga* Merr., which may have seeds that need to pass through the gut of a bird. The extirpation of native fruit-eating birds from the island because of predation by introduced brown tree snakes *Boiga irregularis* (Merrem) (Savidge, 1987) may be responsible. Another tree, *Pisonia grandis* R. Br., is rarely seen with fruit, and is perhaps illustrative that losses of native pollinators (i.e. birds, fruit bats, and possibly insects) may result in low seed set among some of the island's plants.

On Micronesian islands outside the Marianas, plants species are probably most threatened by the conversion of native forest to agroforest, disturbed secondary vegetation, and grasslands (MacLean *et al.*, 1986; Cole *et al.*, 1987; Falanruw *et al.*, 1987). Habitat alteration has been most severe in Chuuk, where remnant patches of native forest survive only on island summits (Falanruw *et al.*, 1987). With the exception of Pohnpei, none of the Caroline Islands is currently known to support significant wild populations of ungulates. Comprehensive inventories of rare plants are needed for all island groups.

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