Guam's *Cycas micronesica* Populations Ravaged by Supertyphoon Paka

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THE PLANT

Cycas micronesica K.D. Hill is Guam's only native gymnosperm. It is an arborescent cycad in the *C. rumphii* species complex (Hill, 1994), which grows to 8 m or more in height. The stems of this and other arborescent *Cycas* species are comprised of a large parenchymatous pith and cortex and secondary vascular tissue (Stevenson, 1990). The pinnately compound leaves are up to 1.8 m long (Hill, 1994) and highly sclerophyllous. Leaf production is synchronous, where one leaf cohort is added to previously retained cohorts. Plants are dioecious, with pale orange/brown male cones borne terminally. The male cones remain upright and grow to 0.5 m in length. This determinate growth habit is overcome by formation of adventitious buds at the base of the cone. Branching of male plants commonly occurs following formation of a cone, with more than one adventitious bud beginning growth simultaneously. Megasporophylls form a crown of leaf-like structures up to 0.3 m in length. Megasporophylls are not terminal, although they appear so, and a subsequent cohort of leaves emerges from the center of the crown. Some female plants produce megasporophylls and true leaves during the same flushing event.

Rarely is anything written about Guam's flora without mention of the horticultural value of this species. It is not currently considered endangered, but is legally protected, along with all other cycads, by the Convention on International Trade of Endangered Species (Charles Hubbuck, personal communication). The species is also of importance culturally and historically, since *C. micronesica* seeds have long been a source of flour for consumption on Guam (Safford, 1905). Leaching during flour preparation, a process used by other indigenous peoples to prepare cycads for consumption (Whiting, 1963), removes water-soluble toxins. However, traces of the toxins may be retained in the flour following traditional preparation (Kisby et al., 1992), and its consumption has been proposed as an etiological factor in the high incidence of amyotrophic lateral sclerosis (ALS) and parkinsonism-dementia on Guam (Whiting, 1963). Kurland and Mulder (1954) reported that the incidence of ALS on Guam was 50 to 100 times that in the continental United States during the early 1950s.

The largest population of *C. micronesica* is located on the northern tip of the island, primarily within U.S. Dept. of Defense lands. The canopy cover of the limestone forests in which this population exists rarely exceeds 12 m in height and is perpetually shaped and reshaped by typhoons. Cycad populations also occur in central and southern Guam, but population densities are lower than in the north. Damage to these central and southern populations by Supertyphoon Paka was minimal and erratic. However, the northern populations of *C. micronesica* sustained considerable damage during Supertyphoon Paka. This report documents the initial types and extent of damage to *C. micronesica* caused by high winds and rainfall.

THE TYPHOON

As the 1997–98 El Niño season unfolded, forecasters predicted that typhoons affecting the Western Pacific region would develop later in the season than normal. Supertyphoon Paka proved the prediction correct when it passed by the northern tip of Guam on 16 Dec. 1997. Preliminary reports indicated that Guam experienced peak winds exceeding the international wind speed record of 372 km·h⁻¹. However, final analysis of the information

indicated that sustained winds were ≈230 km·h⁻¹, with gusts to 298 km·h⁻¹. Sustained winds >96 km·h⁻¹ impacted the island for 16 to 20 h.

As the typhoon approached Guam, a double eye wall emerged. The outer eye wall passed over the central part of the island, with the inner eye wall remaining off the northern tip of the island. The outer eye wall collapsed over Guam, and the typhoon subsequently re-intensified as it gradually moved away from the island. The major damage to vegetation and structures on Guam occurred early in the second half of the storm, shortly after the closest point of approach of the inner eye.

The southern half of the storm, which passed over Guam, carried the greatest amount of rainfall. The eye was moving at ≈13 km·h⁻¹ as it passed, with a rainfall intensity of 10 to 20 cm·h⁻¹. The northern and central portions of the island received ≈50 cm of typhoon-related rain. Estimates suggest that Guam, with an area of 550 km², received nearly 4 billion L of water during the storm (National Weather Service, unpublished data).

THE DAMAGE

Damage to individual *C. micronesica* plants varied considerably, from complete physical destruction due to falling debris to little or no

Fig. 1. *Cycas micronesica* specimens that were unharmed by the violent winds of Supertyphoon Paka. (A, left) 3-m male plant protected by terrain and wind direction. The developing cone was probably present prior to the typhoon. The photograph was taken in Jan. 1998, 1 month after the typhoon. (B, right) The leaves of this 2.5-m female plant were unharmed, but the *Cocos nucifera* L. canopy cover in this micro-site was virtually destroyed. The cycad shade leaves probably experienced extensive photoinhibition during the sunny days following the typhoon.

Received for publication 1 July 1998. Accepted for publication 24 Aug. 1998. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

Fig. 2. Large canopy gap created during the typhoon. Aggressive vine species such as *Mikania scandens* rapidly have exploited the gap, covering many understory plants such as *Cycas micronesica*.

visible damage. The following categories were used to assess the extent of damage to the northern populations as a whole, and the order reflects our opinion of the ease of recovery from typhoon damage.

No apparent damage

Despite the velocities and prolonged duration of cyclone force winds, micro-site variation enabled $\approx 10\%$ of the northern cycad population to withstand the typhoon with no apparent physical trauma (Fig. 1A). Wind direction shifted from the northwest during the typhoon's approach to the south as the storm moved away from the island. The combination of terrain and wind direction apparently created protected micro-sites where no cyclone force winds occurred.

Loss of canopy cover

Complete loss of the forest overstory occurred in a few sites with little or no apparent damage to understory cycad plants (Fig. 1B). High pressure predominated immediately following the typhoon and a pattern of mostly sunny days ensued. Sunny conditions and abrupt loss of protective cover probably resulted in photoinhibition of photosynthesis in intact leaves that had developed in shade. We did not quantify photo-damage, but estimated that $<2\%$ of the northern cycad population was in this category.

Invasive vine growth

The loss of overstory canopy led to altered interactions of coexisting species in some sites, including epidemic vine growth within weeks (Fig. 2). The most abundant of these species was *Mikania scandens* (L.) Willd., but *Momordica charantia* L. and *Passiflora suberosa* L. were also commonplace. Rarely were any species other than these three introduced species part of the competitive vine communities. Less than 2% of the northern population of cycads were in micro-sites overcome by vine cover.

Partial defoliation

The majority of the cycad population was left with a portion of the canopy intact, and varied percentages of leaves removed or severely damaged by the winds (Fig. 3). We estimated that $\approx 65\%$ of the northern population of cycads sustained leaf damage but retained some intact and functional leaves or leaflets.

Complete defoliation

Plants that suffered complete defoliation without apparent stem trauma were also common following the typhoon. Loss of whole leaves was common, including petiole and rachis (Fig. 4A). However, in some cases petioles and portions of the rachis remained on the stem, while the entire set of leaflets was stripped. We estimated that $\approx 10\%$ of the northern population of cycads sustained no stem damage but were completely defoliated.

Decapitation

Some plants lost the growing point of the stem along with the entire leaf canopy, but most of the stem remained upright and intact (Fig. 4B). The stem tips of many cycads on Guam possess large masses of the epiphytic fern *Polypodium punctatum* (L.) Swartz. The presence of fern masses apparently increased susceptibility to decapitation, although many plants without ferns also suffered broken stems. Cycad stems do not possess true lateral buds; thus, recovery from loss of the stem apex is dependent on adventitious bud formation. Some decapitated specimens were devoid of any apparent adventitious lateral stems, others possessed one or more lateral stems that were available to re-foliate the canopy immediately. We estimated that $\approx 10\%$ of the northern population of cycads were decapitated with a majority of the stem still intact.

Stem broken at or near soil

Damage to cycad plants in this category was similar to those we designated as decapitated, except that the intact portion of the stem

Fig. 3. A 2-m female *Cycas micronesica*, loaded with seeds, that suffered major damage to its leaves during the typhoon.

was limited (Fig. 4C). Although these plants were not uprooted, we speculated that the possibility of rebuilding the canopy was minimized by the small amount of stem tissue from which adventitious buds could develop. A larger percentage of these plants supported massive *P. punctatum* plants than did decapitated plants at the time of the typhoon. We estimated that $<2\%$ of the northern population of cycad plants were broken off near the soil.

Uprooting and toppling

In addition to *P. punctatum*, a common epiphyte in these forests is *Ficus tinctoria* var. *neo-ebudarium* (Summerh.) Fosb. This fig starts as an epiphyte, then becomes a terrestrial tree. These two epiphytes were responsible for virtually all of the toppled cycads (Fig. 5). In the case of *P. punctatum*, weight was probably the major factor; because of the heavy rainfall that accompanied the typhoon, their large aerial root masses undoubtedly became saturated and very heavy. In the case of *Ficus tinctoria*, wind resistance was probably the major factor. Of the toppled cycads with this epiphyte, the combined canopy height that the cycad roots were supporting was two to three times that of the cycad plant itself. We estimated that $<2\%$ of the northern population of cycad plants were toppled, with varying percentages of roots still intact on the leeward side.

Impaction by falling trees

In several sites extensive toppling of large forest trees occurred, and cycad plants were among the understory plants damaged by their fall. Less than 2% of the northern population of cycads suffered physical damage from falling trees. The major reason for this extremely low percentage is the monotonous regularity of typhoons that repeatedly "prune" the trees

Fig. 4. Many of Guam's *Cycas micronesica* plants suffered complete defoliation and/or stem breakage during the typhoon. (A, left) Stem completely defoliated. (B, right) Stem broken; adventitious buds will form to rebuild the canopy, due to the absence of lateral buds on cycad stems. (C, bottom) Stem broken near base. The root mass visible on the fallen stem is comprised of *Polypodium punctatum* plants. The presence of this epiphyte increased the likelihood of decapitation or stem breakage near the soil.

Fig. 5. This 3.5-m male *Cycas micronesica* was uprooted by the typhoon. All of the uprooted cycads were burdened with epiphytes, which added weight and wind resistance.

on Guam. Stone (1971) suggested that Guam's forests be called "typhoon forests" because of this regularity. A second reason is the relatively low emergent canopy height of these forests.

CONCLUSIONS

Cycas micronesica foliage is metabolically costly to produce because of the sturdy construction of the long-lived leaves. Greater initial costs require a longer time before a leaf pays back its costs. Moreover, sturdy leaf construction may lead to the dilution of photosynthetic tissue by supportive tissue (Chabot and Hicks, 1982). Therefore, we believe that any loss of foliage due to a stochastic event, such as a typhoon or acute herbivory, may be more detrimental to the growth and productivity of *C. micronesica* than of other species with less costly foliage. Cycad plants that lose part or all of their fully constructed leaves during the typhoon will require considerable time before the photosynthetic output matches the cost required to rebuild the foliage during recovery. The payback time should be proportional to the percentage of leaves destroyed. Moreover, recovery of plants losing their growing points may be further delayed by the absence of lateral buds on the stems of these and other cycads. The possibility of adventitious bud formation, and therefore the extent and speed of recovery, may decline with the amount of stem tissue remaining after stem breakage. Topped plants will require support from the remaining intact portion of the root system, or will require adventitious root formation along the stem section in contact with the soil. Finally, the incidence and extent of herbivory may increase for plants damaged by the typhoon. We are monitoring recovery of plants in each of these categories, in an effort to improve conservation efforts of this valuable horticultural resource.

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