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Research Article

Typhoon Mawar Enables an Assessment of *Cycas micronesica* Conservation Plans

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ABSTRACT

Typhoon Mawar damaged Guam's northern forests on 24 May 2023. This disturbance was the first major typhoon to test the island's *Cycas micronesica* population resilience since the cycad-specific armored scale *Aulacaspis yasumatsui* pest invaded the island in 2003. This tropical cyclone has enabled an assessment of conservation actions initially designed to mitigate biotic damage to the host cycad population by chronic insect infestations as well as population-level responses to the typhoon. The incidence of windsnap and defoliation during Typhoon Mawar were increased when compared to historical typhoons, but the incidence of windthrow was decreased. The damage aligned with our previously published predictions based on scale-induced changes in stem and leaf traits, illuminating the importance of scientific evidence to steer conservation decisions. The assessment of post-typhoon damage shows that current conservation interventions are not effectively reducing the extinction risk for *C. micronesica*. The lessons learned from Typhoon Mawar point to the need to more effectively address the non-native insect infestations as the primary driver of population decline, and may aid conservationists to better prepare for recurring cyclones and develop more tailored conservation approaches to mitigate major threats to species persistence.

Keywords: *Aulacaspis yasumatsui*; Conservation ethics; Cycad conservation; Tropical cyclones

INTRODUCTION

Large scale natural disturbances are unavoidable. Most native plants from geographic regions that are prone to certain forms of natural disturbances have evolved traits that resist damage, respond favorably to the damage, and increase resilience following these events. For example, triggering of seed bank germination following fire disturbances is of benefit to many native plant species [1-3]. Similarly, defoliation by tropical cyclones may benefit a native plant population by synchronizing flower initiation which fosters mast seed production [4]. The island of Guam is located within the most active tropical cyclone region globally [5]. Typhoon Mawar skirted northern Guam on 24 May 2023 as the latest tropical cyclone to impact the island, leaving behind widespread damage to the island's forest resources.

Cycas micronesica K.D. Hill is the island's only native gymnosperm, and the interplay between tropical cyclones and this arborescent cycad has been the subject of several publications [6-9]. *Cycas micronesica* experienced dramatic population declines following invasion by *Aulacaspis yasumatsui* scale insects in 2003 and was uplisted from Least Concern to Endangered on the IUCN Red List of threatened species [10]. It was subsequently listed under the United States Endangered Species Act (ESA) in 2015 [11], and the listing generated a sudden increase in federal spending on species conservation efforts. The federal agencies involved in permitting and funding conservation programs for Guam's terrestrial resources need to factor in the recurrence of

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tropical cyclones in their conservation planning. Conservation practitioners who accept federal funding for mitigating threats to this species are required to consider the best available science while defining protocols to enable species persistence and recovery. Yet to date there has been no independent evaluation of how effective the conservation actions have been in general, specifically with regard to mitigating tropical cyclone damage to *C. micronesica*.

Each of us are members of the Cycad Specialist Group of the International Union for Conservation of Nature's Species Survival Commission (IUCN SSC). Each of us have authored peer-reviewed journal articles that inform *C. micronesica* ecology, horticulture, and conservation. We are individually and collectively among the stakeholders who have invested into the efforts to see this unique tree persist into the future. Herein we use the passage of this tropical cyclone to discuss the nexus among funded conservation actions, management decisions by conservationists, recurrent tropical cyclones, and survival of the island's only native gymnosperm species to improve the outcomes of conservation trajectories.

MATERIALS AND METHODS

The plant

Forest inventory analyses indicated *C. micronesica* was the most abundant tree on Guam in 2002 [12]. Plant mortality following the 2003 invasion of *Aulacaspis yasumatsui* Takagi was immediate [13], and *C. micronesica* was no longer among the 20 most abundant tree species by 2013 [14]. The 2015 ESA listing was a direct result of the threats caused by this and other subsequent non-native specialist insect invasions [15]. Decadal changes to *C. micronesica* survival and health have been documented and reported [16-18]. The overall appearance of a thriving, healthy *C. micronesica* tree prior to the 2003 invasion contrasts sharply with that of the persistent unhealthy trees of 2023 as shown in Figure 1.

The tropical cyclone

The southern eyewall of Typhoon Mawar damaged the terrestrial biodiversity of the limestone plateau that comprises the northern half of the island. Although direct landfall did not occur, initial assessments indicated sustained winds of 225 kph and gusts to 249 kph impacted the northern forests. More than 60 cm of rain was deposited on northern Guam during the hours of the storm. The calcareous substrate is of Pliocene derivation [19] and has historically supported a high density *Cycas micronesica* population [12,16]. Two recent tropical cyclones followed the same path as Typhoon Mawar, with the southern cyclonic eyewall battering the island's northern half. These were Typhoon Paka in 1997 [7] and Typhoon Dolphin in 2015 [9]. Typhoon Dolphin carried minimal winds compared to the other two tropical cyclones, but Typhoon Paka and Typhoon Mawar exhibited similar windspeeds and rainfall as shown in Table 1. A formal assessment of the damage to the cycad population during Typhoon Paka [6] occurred when the healthy cycad population did not experience any severe biotic threats. We look to Typhoon Paka to serve as a historical benchmark for comparing the damage during Typhoon Mawar, which occurred two decades after the *A. yasumatsui* invasion and at a time that only 4% of the pre-invasion population survived the consequences of the non-native insect herbivory [16].

Figure 1: Guam's *Cycas micronesica* tree.

Note: (A) Healthy trees supported numerous large, dark green compound leaves prior to the 2003 invasion of the armored scale *Aulacaspis yasumatsui*; (B) 2023 trees exhibit fewer and smaller unhealthy leaves.

Table 1: The characteristics of tropical cyclones, plant traits, and population damage during 1997 Typhoon Paka and 2023 Typhoon Mawar on the northern Guam *Cycas micronesica* population.

Characteristic	Typhoon Paka	Typhoon Mawar
Sustained wind (km/hr)	230	225
Peak gusts (km/hr)	298	249
Rainfall	50 cm	61 cm
Rachis length (cm) [z]	112 ± 1	72 ± 1
Leaf number per tree [z]	63 ± 2	17 ± 1
No observed damage [y]	12%	0%
Partial defoliation [y]	65%	20%
Complete defoliation [y]	10%	52%
Windsnap elevated [y]	10%	19%
Windsnap at ground [y]	1%	8%
Windthrow [y]	2%	1%

Note: [z] n=400, [y] Based on 1000 assessed trees

The population damage

Cycas micronesica habitats were observed during the three weeks after Typhoon Mawar to assess the extent of damage. Latitude and topography defined the extent of damage, which was greatest on the northwest coast and across the northern plateau, a pattern that mirrored the damage during Typhoon Paka. The topography partially protected the forests along the northeast coast, and the winds were less intense in southern Guam due to distance from the eye of the storm during the closest point of approach.

We focused on the northern half of the island for a formal assessment of the damage. The latitudinal limits of the survey were the same as in Typhoon Paka and were N13°27' to N13°38'. To ensure the assessment was unbiased, linear transects 10 m × 100 m were positioned in various habitats and every tree within each transect was assigned one form of damage in conformity with the damage assessment protocols following Typhoon Paka [6]. The damage was similar throughout the northwest coast and on top of the plateau, and we accumulated data until we reached 1000 assessed trees in this terrain. The damage was less severe along the northeast coast, and we accumulated data in these habitats until we reached 1000 trees. Some of the areas of occupancy still supported 150-200 trees per hectare, so reaching this number of trees was not difficult.

In the northeast coast habitats protected by topography, the damage during Typhoon Mawar was much less severe than in the other northern habitats. Partial defoliation occurred among 57% of the trees, complete defoliation occurred among 36% of the trees, and 7% of the trees were subjected to windsnap, the process where stems rupture under the force of the wind and the entire canopy above the rupture falls.

In the habitats with greatest level of tree damage, 72% of the *C. micronesica* trees were defoliated by Typhoon Mawar, with a majority of these exhibiting 100% defoliation as shown in Table 1. Additionally, 27% of the trees were damaged by windsnap. Most of these trees exhibited windsnap at elevated strata rather than the stratum near the ground. Finally, 1% of the trees were toppled by uprooting, a process known as windthrow [20].

Our assessment of damage from Typhoon Mawar on the northwest coast enables a direct comparison to the damage during Typhoon Paka from the same habitats. In both typhoons, some of the windsnap was exclusively caused by wind force and some was caused by a combination of wind force and the impact of falling debris from canopy trees. Numerous changes in the manner that the *C. micronesica* trees responded to tropical cyclone winds occurred from 1997 to 2023, changes that we attribute primarily to the 2003 *A. yasumatsui* invasion. First, about 12% of the northwest population endured no visible forms of direct damage during Typhoon Paka. In contrast, we found no *C. micronesica* trees from our transects in northern Guam that escaped observable damage during Typhoon Mawar. Second, 2% of the 1997 population was damaged by windthrow, but only 1% of the trees exhibited windthrow during Typhoon Mawar. Third, 11% of the stems exhibited windsnap in 1997, but 27% of the stems exhibited windsnap during Typhoon Mawar. Fourth, the catastrophic damage categories of windthrow and windsnap combined to account for 13% of the population damage in 1997, but accounted for 28% of the damage in 2023. Fifth, only 10% of the trees in 1997 experienced complete defoliation, but 52% of the trees in 2023 experienced complete loss of leaflets or entire leaves.

These data indicated the 1997 tropical cyclone that carried greater wind speeds caused less catastrophic damage to the pre-invasion *C. micronesica* trees in northern Guam, while the 2023 tropical cyclone with less wind speed damaged more of these post-invasion trees. Moreover, the forms of 1997 damage to individual trees were less detrimental to plant recovery than the forms of 2023 damage. These before-invasion and after-invasion tropical cyclones offer a glimpse into many issues related to the consequential *A. yasumatsui* invasion of 2003, issues we discuss below.

RESULTS AND DISCUSSIONS

Our past predictions and recommendations

Typhoon Mawar brings to light some of our published predictions about the threats to and conservation of *C. micronesica* that have resulted from the *A. yasumatsui* invasion. We enumerate several of these.

An increase in the incidence of *C. micronesica* windsnap during tropical cyclones was predicted due to the observable decline in plant health following several years of chronic *A. yasumatsui* herbivory. Force-displacement data were generated on *C. micronesica* stems to reveal a decrease in stem strength following chronic *A. yasumatsui* herbivory [21]. Moreover, an increase in *C. micronesica* stem failure became noticeable during the passage of several less intense typhoons subsequent to Typhoon Paka, and was attributed to the nascent increases in the extent of insect herbivory [8]. Four lines of evidence from Typhoon Mawar align with our published predictions of increased windsnap. First, despite lesser windspeeds during Typhoon Mawar, the percent of trees experiencing windsnap was more than double that of Typhoon Paka. Second, the stratum of windsnap in Typhoon Mawar was greater than we observed during Typhoon Paka or any other tropical cyclone in the past 25 years as shown in Figure 2. One unusual development among the *C. micronesica* population has been a decline in apical stem diameter following the *A. yasumatsui* invasion [18]. For many of the 2023 trees exhibiting windsnap at an elevated stratum, the mechanical failure occurred within this apical stratum where stem diameter had declined following the chronic *A. yasumatsui* herbivory. These narrow stem strata were not present during the 1997 typhoon. Third, many of the stems that were ruptured by Typhoon Mawar exhibited contiguous cortex with no signs of necrosis or insect damage as shown in Figure 3. In Typhoon Paka and other tropical cyclones, the stratum of stem rupture during windsnap was associated with antecedent events which caused localized necrotic cortex tissue [8]. This outcome aligns with the assertion that the increase in incidence of windsnap resulted from decreased general stem strength, not from increased incidence of localized stem tissue necrosis. Fourth, in Typhoon Paka the trees that experienced stem or root failure were typically supporting native epiphytes which added canopy weight and increased wind drag [6]. In Typhoon Mawar there was no evidence of greater epiphyte load for the trees that exhibited windsnap, further indicating the increase in incidence of windsnap was a direct result of a decline in stem strength and not due to an increase in canopy drag coefficients. This tropical cyclone serves as an example of how published recommendations and predictions from the peer-reviewed literature may accurately inform forecasting of endangered plant population responses to chronic abiotic disturbances. Moreover, Guam will receive a direct hit from a strong tropical cyclone in the future, and the damage during that direct hit will likely exceed the damage from Typhoon Mawar which did not make landfall.

Figure 2: When *Cycas micronesica* tree stems exhibited windsnap in Typhoon Mawar, the rupture occurred at higher strata. Yellow arrow points to decapitated stem section.

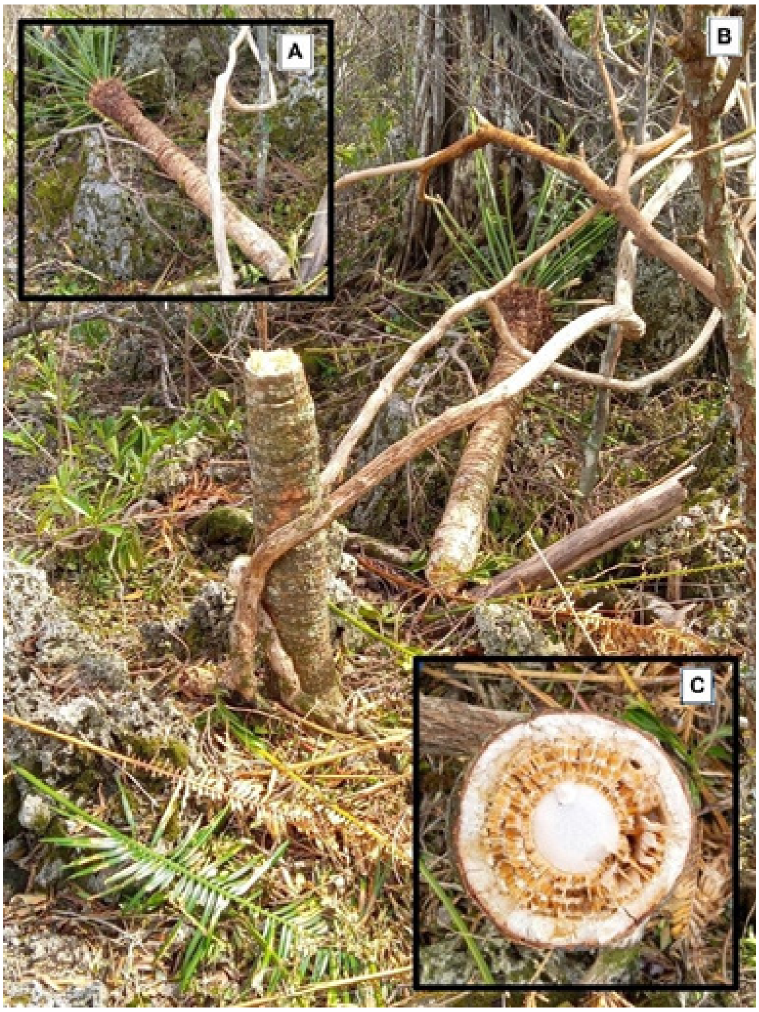

Figure 3: (A) Upper tree trunk: Broken stems may be exploited for asexual propagation; (B) A windsnapped *Cycas micronesica* stem in Typhoon Mawar; (C) Lower tree trunk: Radial view of the failed stem stratum showing intact pith, vascular, and cortex tissue.

Cycas micronesica leaves have become smaller and fewer in number in recent years due to the chronic *A. yasumatsui* herbivory. We counted leaf number and measured rachis length on a random set of 400 trees immediately following Typhoon Paka and Typhoon Mawar. The large petiole base of a *C. micronesica* leaf enabled this procedure, which summed undamaged leaves, leaves with partial removal of leaflet and rachis sections, and fresh leaf scars from abscised petiole bases. The number of leaves per tree declined 73% and the mean rachis length declined 36% as the trees responded to the chronic *A. yasumatsui* damage as shown in Table 1. This combination of fewer leaves with shorter mean rachis confirmed our prediction that a reduction in the wind drag of the trees during future tropical cyclones would result [18]. In conformity with this prediction, these relatively weak leaves were more affected by Typhoon Mawar with 52% of the tree population exhibiting 100% defoliation as shown in Figure 4a. This form of damage in the 2023 tropical cyclone was more than 5-fold greater than this form of damage in the 1997 tropical cyclone. Our predictions concerning the recent changes in leaf morphology and allometry were consistent with the results of Typhoon Mawar wind damage, and the reduced drag that resulted from the changes in leaf form undoubtedly reduced the population-level stem damage by abscission of the leaf tissues early in the typhoon's winds.

Several of us developed the official 2013 management plan for *in situ* conservation of *C. micronesica* in northern Guam [22]. This plan included the installation of guy wires to ensure every tree within the conscribed and funded protected areas would remain standing during tropical cyclones. The efficacy of this guy wire protection was confirmed during Typhoon Dolphin in 2015 when windsnap outside of the protected areas greatly exceeded that inside the protected areas [9]. Subsequent to Typhoon Dolphin, a decision was made to uninstall the guy wire protection. This decision led to toppling of protected area trees during the minimal winds of Typhoon Wutip on 24 February 2019 and more toppling of trees within the protected areas during Typhoon Mawar. This avoidable damage was not a result of the typhoons, it was a result of the decisions by conservationists to remove the protective guy wires. Typhoon Mawar inflicted similar avoidable wind damage to Guam's single mature *Serianthes nelsonii* Merr. tree. The urgent need to install cabling and guy wire anchoring to keep this critically endangered Guam tree from suffering windsnap or windthrow in future tropical cyclones was a prominent recommendation in 2014 [23] and was repeated as an emergency priority in 2015 [24]. This recommendation was disregarded by the conservation decision-makers and the tree suffered catastrophic windsnap damage during Typhoon Mawar as a result. The U.S. Sikes Act requires the use of sustainable approaches for protecting and enhancing wildlife on these federal lands, and conforming to the best available science communicated by published species experts is required in order to adhere to this law. The material costs for constructing guy wire anchoring are nominal, and efficacy is ensured if the anchoring is installed appropriately. This case study provides an example where the conservationists disregarded the best available science, and *S. nelsonii* and *C. micronesica* ESA-listed trees suffered catastrophic damage during Typhoon Mawar as a direct result of the lack of guy wire anchoring.

Predictions and recommendations regarding population recovery

Typhoon Mawar has provided an opportunity to enumerate and study newly developing conservation needs of this gymnosperm tree. We now discuss several predictions based on knowledge of these plants and recommend ongoing monitoring of the population to confirm the accuracy of these predictions and to adapt management responses accordingly. We anticipate the following responses following Typhoon Mawar.

- An increase in plant mortality of the standing stems during the upcoming 12-24 month recovery period. After the 1997 Typhoon Paka, about one-fifth of trees in the most affected habitats exhibited standing stems with no leaves, but about three-fourths of the 2023 Typhoon Mawar trees in the most affected habitats were in the categories of complete defoliation and windsnap. These trees lost 100% of their leaves while retaining all or some of the standing stems that may enable recovery. Complete defoliation is not fatal to a healthy cycad plant because of the typically copious nonstructural resources within stems and roots that support regrowth (hereinafter referred to as energy reserves). However, Guam's 2023 *C. micronesica* trees will be forced to grow new leaves using energy reserves that have been severely depleted by almost two decades of *A. yasumatsui* infestations. None of the Typhoon Paka trees were killed by complete defoliation because the trees were healthy at the time of the tropical cyclone. The initial refoliation event following Typhoon Mawar will be rapid, and we predict that deployment of limited energy reserves for this refoliation may be lethal for some of the defoliated trees. Some *C. micronesica* trees also initiated reproductive organs (microstrobili as shown in Figure 4b or megastrobili as shown in Figure 4c, hereafter referred to as strobili) immediately after tropical cyclone defoliation. We expect these trees that initiate strobili will experience greater mortality than trees that initiate leaves as the first growth event after Typhoon Mawar because production of strobili will use up existing energy reserves before the plant can produce new leaves and begin restoring energy reserves.

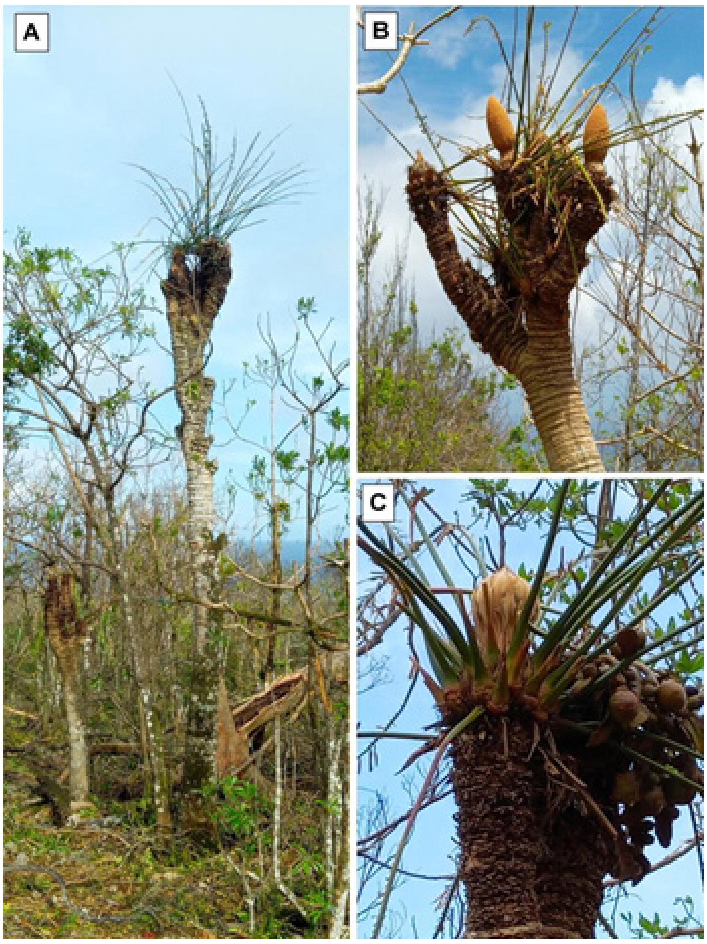

Figure 4: (A) Complete defoliation of *Cycas micronesica* trees was the most prevalent damage category in Typhoon Mawar; (B) Some male trees constructed strobili despite 100% defoliation; (C) Some female trees constructed strobili despite 100% defoliation.

- A delay in refoliation will not occur for the first flush of new leaves because complete defoliation typically triggers immediate regrowth in most cycad species. However, longer than usual delays in the emergence of the second flush of new leaves will occur for the defoliated *C. micronesica* trees. Cycas stem carbohydrates have declined in response to chronic *A. yasumatsui* herbivory [25,26]. The growth of *C. micronesica* leaves comprises an expensive resource sink that partially relies on energy reserves [27], hence the expected delay. We also anticipate that leaf size during the first refoliation events will be less than leaf size immediately prior to Typhoon Mawar, as a reduction in leaf size was documented following Typhoon Paka [7].

- A strong likelihood of a transient irruption of the native *Acalolepta marianarum* Aurivillius stem borer population will occur within 12 months due to the abrupt declines in post-typhoon health status of the cycad population. This increase in stem borer damage will cause a consequential increase in windsnap of the surviving cycad trees during subsequent tropical cyclones, reaffirming the need to install or reinstall guy wire protection to support the trees within the funded protected areas.

- An increase in invasive plant density is likely, notably for *Carica papaya L.*, *Leucaena leucocephala* (Lam.) de Wit, and *Passiflora suberosa L.*, which occur within Guam's *C. micronesica* habitats. These invasive plant species rapidly occupy northern Guam canopy gaps following Guam's tropical cyclones. The original *in situ* conservation management plan [22] included the monthly removal of all non-native plants from within the designated protected areas because the direct influence of non-native plant competitors on *C. micronesica* tree health has not been determined to date. This critical component of the management plan has not been implemented since 2015, and the plots have become heavily invaded with non-native plants as shown in Figure 5. Non-native plants can alter Mariana Island ecosystem properties [9,28], and until these ecosystem changes are shown not to have negative impacts on *C. micronesica* health, the precautionary principle should be applied and non-native plants should be removed within publicly funded conservation protected areas. Failures to follow this aspect of the management plan goes against the best available scientific advice and further risks the survival of *C. micronesica* within Guam's publicly funded conservation projects.

- Increased herbivory of windsnap stems by feral pigs will commence. The existence of feral pigs in Micronesia may have originated with the oceanic voyages of the Neolithic Lapita culture, ancestors of the Polynesians [29]. In Guam, feral pigs are ecosystem engineers, exerting numerous negative effects including uprooting of soil, wallowing, and seedling herbivory [30]. We predict that all *C. micronesica* stem sections that were deposited onto the forest floor by windsnap will be consumed by these feral pigs, disallowing the natural adventitious root formation that would enable recovery of the dislodged stem section. This form of stem herbivory has been occurring for more than 20 years and will continue in the future. These issues illuminate the need for more fenced protected areas to exclude all non-native ungulates.

Figure 5: The presence of old *Carica papaya L.* plants within a northern Guam *in situ* conservation plot indicate these invasive plants have been growing for years. The formal management plan required the monthly removal of these invasive plants.

- Changing dynamics in interactions among the coalition of *C. micronesica* insect herbivores and how they interact with the host tree will occur. The *A. yasumatsui* population has not been acting in isolation during the past 20 years, but has been interacting with other invasive insect herbivores [15,31]. The aftermath of a consequential natural disturbance changes the dynamics of many biodiversity relationships [32]. The scale predator *Rhyzobius lophanthae* Blaisdell was purposefully released on Guam in 2005, and the fortuitous establishment of the parasitoid *Arrhenophagus chionaspidis* Aurivillius was noticed in 2013 [15]. These confirmed biological control agents have not stopped the ongoing plant mortality. Uncertainty defines whether the *A. yasumatsui* infestation will temporarily increase following Typhoon Mawar due to disruption of these established biological control agents, or whether the scale insect population will decrease due to direct disruption of regeneration and recruitment. The answer to these and other questions cannot be accurately predicted at this time because the *C. micronesica* population has never experienced tropical cyclone damage of this intensity since the 2003 invasion initiated the chronic biotic damage. Conservation managers would generate important information to guide conservation decisions for *C. micronesica* and other cycads in the region by ensuring that evolving changes to the herbivore relationships are studied during the next 12-24 months, and ensuring these findings are published.

- The strata where *C. micronesica* stem diameter has decreased from chronic *A. yasumatsui* herbivory will likely result in permanent points of weakness in the stems of the affected trees. The narrow stem sections are 30-50 cm in length as of 2023. If effective biological control is ultimately established and the surviving trees begin to recover in health, we predict that stem growth above the narrowed stem stratum will increase in diameter to match the pre-2003 stem diameter, but the narrowed stem stratum will persist. This narrowed stratum will represent the weakest section of affected stems, and will be the area most likely to suffer from windsnap damage during tropical cyclones of the next several centuries.

Recommendations and a call for a change in direction

Typhoon Mawar has revealed examples of how scientific evidence can inform better conservation planning and decision-making for ESA-listed plant species, but also how these plans are only effective if implementation adheres to evidence-based advice and is informed by ongoing monitoring. We use this consequential event to revisit several general recommendations for improving future *C. micronesica* species recovery efforts.

A core maxim in conservation is that direct threats must be identified and mitigated to reduce extinction risks [33]. In the case of *C. micronesica*, the overwhelming evidence is that the invasion by the *A. yasumatsui* scale insect is the primary cause of extinction risk. The scientific community noted in 2005 that "Rapid establishment of a complex of effective biological control agents is currently the only feasible long-term strategy for protecting these plants" [34]. This advice has been repeated numerous times throughout the years [15,16,18,35-41]. To our knowledge, none of the heavily funded mitigation efforts for Guam's federal lands have been invested into biological control efforts to date. Additionally, a plan to identify the causes of the fortuitous decreases in *A. yasumatsui* incidence in recent years has not been funded. During the first five years that *C. micronesica* was protected by an ESA-listing, 36% of the trees died among Guam's habitats [16], which represents thousands of trees dying throughout federal lands on Guam each of those years. The funding focus on plant salvage from construction sites has caused a distraction from the need for species experts to provide a roadmap for adaptive management during evolving conservation challenges.

The implementation of a dedicated multi-step procedure for establishing classical biological control, as recommended six years ago [36], would be far more likely to result in a sustainable solution and could be accomplished with a fraction of the funds that have been spent on other *C. micronesica* conservation strategies. If this advice had been followed when the scientific community first published these recommendations [34,41], and trees were adequately protected from the non-native insect herbivory, *C. micronesica* may never have required listing for protection under the ESA. Resistance during and resilience following Typhoon Mawar could have been no worse than during Typhoon Paka. A large proportion of available conservation funds should therefore be dedicated to classical biological control programs, which would automatically reduce the remaining secondary threats. Successful biological control will enable the surviving population to begin the road to recovery and the species could be de-listed from the ESA.

We recommend the cessation of salvage projects designed to translocate unhealthy *C. micronesica* trees from federal construction sites. The funds could more effectively support species recovery if they were instead invested into *in situ* conservation plots to conserve an equivalent number of living *C. micronesica* trees within the forests adjacent to construction sites. Conservation of existing forests rather than establishment of new salvage projects increases the chance of success and lowers the risk of negative consequences of conservation actions [42]. The surviving trees on Guam are not healthy, but have a greater chance of sustained survival compared with trees stressed from either translocation or when used as sources for asexual propagation by stem cuttings. One negative consequence in the first large-scale translocation project was an irruption of the native *A. marianarum* stem borer as a direct response to the added stress of transplantation. This translocation further threatened *in situ C. micronesica* trees surrounding the site because it promoted local stem borer regeneration. Thus, shifting the emphasis to better management of *in situ* conservation plots for living trees adjacent to construction sites is a better alternative to salvage of trees within the construction sites.

Ensuring meaningful engagement by knowledgeable scientists is a pervasive recommendation within the extensive contemporary conservation and restoration literature [42-46]. Involving scientists with a credible understanding of the biology and ecology of *C. micronesica* and *A. yasumatsui* would ensure inclusion of up-to-date conservation advice regarding the unique and evolving circumstances and enable ongoing research and monitoring of the cycad population's response to different interventions. Much of the evidence for decision-making derived from peer-reviewed journal publications has been ignored in recent years, and evidence-based decisions have even been reversed in some cases. Direct plant mortality of the ESA-protected plants has been the result.

The Guam case study was positioned in 2003 to serve as an example of how to manage the threats to an endemic *Cycas* population after an island is invaded by *A. yasumatsui*. Most cycad species are threatened by land conversion and poaching [47], so the Guam case study stood out as unique at the time [48]. These facts indicated every lesson learned from Guam would benefit future conservation decisions during the *A. yasumatsui* invasions of other islands. For this reason, the call for more dedicated research to enable adaptive management of biological control was suggested by treating the newly invaded island as a "natural experiment" [48]. Decision-making under uncertainty is a foundation of endangered species conservation, and relying on formal expert knowledge is one way to manage uncertainty and adapt decisions based on results of ongoing research and monitoring [49-51]. Unfortunately, success has been elusive and the conservation efforts that have been funded over two decades have done little to control the primary threats to species persistence. The islands of Japan that comprise the endemic range of *Cycas revoluta* Thunb. have been invaded by *A. yasumatsui* in recent months. Local *C. revoluta* conservationists are unable to rely on any tangible lessons learned from the 2003 invasion of Guam because most of the conservation funding has been invested into efforts that do not address control of the specialist insect herbivory.

CONCLUSION

The island of Guam has not experienced direct landfall of a major tropical cyclone since the 2003 *A. yasumatsui* invasion. The lessons learned from the 2023 Typhoon Mawar may improve ongoing conservation decisions to better prepare for this guaranteed recurring event. The use of a transparent, inclusive multi-scale process for prioritizing conservation goals is needed. The Guam conservation community cannot expect a different result for *C. micronesica* if the decision-makers continue to do the same thing. Despite the 2015 ESA listing of *C. micronesica*, the Guam population exhibited 36% mortality during the first five years of being protected under the ESA. Moreover, the *A. yasumatsui* invasion of Guam has adversely impacted the natural resilience of *C. micronesica* to tropical cyclone damage. The most sustainable solution is establishment of classical biological control of the armored scale population and continued monitoring and management of the remaining herbivore threats. To our knowledge, no serious funding has been invested into the multi-species biological control program that the scientific community has recommended since 2005, yet millions of dollars have been spent on salvage projects that we have repeatedly discouraged because they have minimal conservation impact. Maintaining the Guam status quo approach, whereby evidence generated by the scientific community is not properly utilized to inform the decision-making process, means that avoidable tree mortality will continue in a manner that poses a major threat to the persistence of *C. micronesica*.

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