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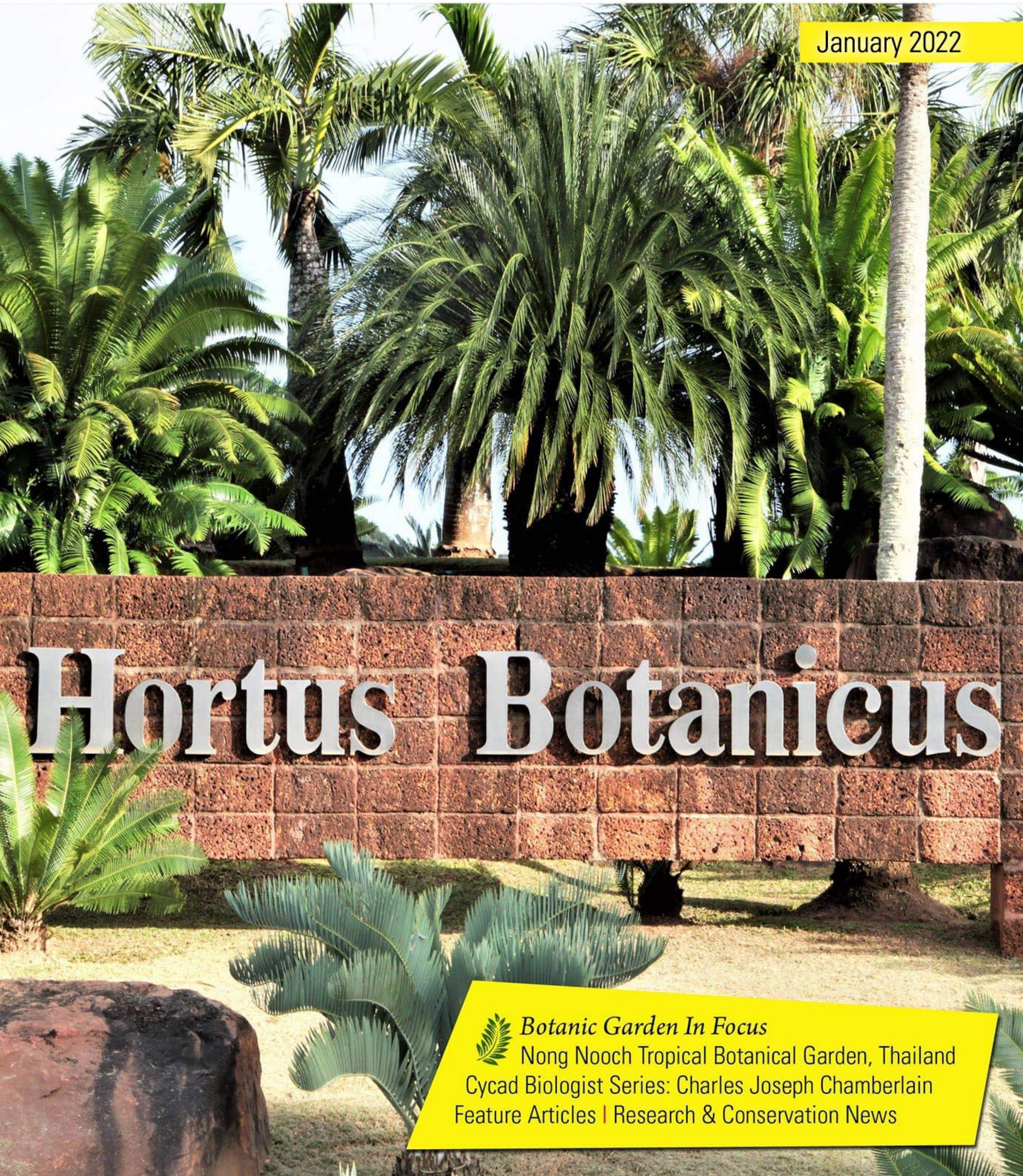
# CYCADS

Official Newsletter of IUCN SSC Cycad Specialist Group

Cycad Specialist Group

January 2022




*Botanic Garden In Focus*

Nong Nooch Tropical Botanical Garden, Thailand

Cycad Biologist Series: Charles Joseph Chamberlain

Feature Articles | Research & Conservation News

*Cycas divyadarshanii* Khuraijam & Rita Singh
Manipur, India. Photo: Anisiya Naorem

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# Cycads

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Cycad Specialist Group
Vol. VI | Issue 1 | January 2022

The Cycad Specialist Group (CSG) is a component of the IUCN Species Survival Commission (IUCN/SSC). It consists of a group of volunteer experts addressing conservation issues related to cycads, a highly threatened group of land plants. The CSG exists to bring together the world's cycad conservation expertise, and to disseminate this expertise to organizations and agencies which can use this guidance to advance cycad conservation.

Official website of CSG:
http://www.cycadgroup.org/



Front Cover photo:
Nong Nooch Tropical Botanical Garden
*Photo by Anders Lindstrom*

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IUCN/SSC CSG Meeting 2015 at Medellin, Colombia

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# MESSAGE

Dear Friends,

*Conservation through collaboration!* This issue of CYCADS presents a new initiative: to network and coordinate the remaining living cycads into a broad set of METACOLLECTIONS – i.e., *collections of collections* – in order to assure not another cycad species vanishes. See the article by Handley *et al.* on page 12. Recent understanding of cycad genetics points a way forward in which every garden, collection, and extant population can contribute to that goal of no further extinctions. This innovative new Consortium partners our Group's expertise with cycads with the networking savvy of Botanic Gardens Conservation International in a novel way.

Our featured cycad collection in this issue is Nong Nooch Tropical Botanic Garden (page 5), which leverages their exceptionally broad holdings to advance cycad conservation horticulture in new and innovative ways. We are glad to include a historical perspective of a pioneering cycad expect, Chamberlain, showing his early contributions to our field. Articles on pollination and ecophysiology show how the expertise of our own era can address more modern conservation challenges.

This issue also marks our first since the pandemic. I am inspired by all of the progress made on cycad research and conservation since that time, in our greatly changed world. I extend my best wishes for further progress, health and goodwill as we move into 2022.

While so many plans had to be delayed, rethought or set aside, I am excited to tell you that solid preparations are underway for the next Cycad Conference in the Philippines in 2023, followed by a Cycad Conference in Cuba in 2025. I hope to see each of you at both!

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# The Cycad Collection at Nong Nooch Tropical Botanical Garden, Thailand

Anders Lindstrom

Nong Nooch Tropical Botanical Garden, Thailand was started in 1954 by Mrs. Nong Nooch Tansacha and has been managed by her son, Mr. Kampon Tansacha for the last 30 years.

The Botanical Garden is situated at sea level to the East of Bangkok in Thailand. The latitude is 12 degrees North of the Equator which equals the position of Nicaragua in the Americas and Sudan in Africa. It has a monsoonal tropical climate, with average annual temperatures ranging from 21˚C to 33˚C all year round. Highest ever recorded was 38˚C and lowest 18˚C. Relative humidity range from 75-85% all year round. The area does not suffer from typhoons or equal strong wind as it is sheltered in the bay of Siam. The geology of the site is low lying beach sand soil with underlying granite/quartzite base.

The total area of the garden is 245 hectare and the average of 5000 visitors/day. The garden hires more than 2000 staff to manage not only the plants and gardens but also the 4 restaurants and Resorts with 280 rooms. Several conference facilities including a large Exhibition Centre with an exhibition area of 5,610 $m^2$. The plant collections consist today of 19266 accessions representing 12639 taxa of a highly diverse assembly of tropical plants.

The main focus of the botanical garden has always been the cycads and palms, but the collection of today host a wide variety of plant groups such as Zingiberaceae, Bromeliaceae, Cactaceae and many family and genera of succulents, orchids, and shrubs and trees. The garden has one of the largest collections in the world of palms, *Heliconia, Hoya* and *Bougainvillea*, with between 60-87% being of documented origin. The palm collection consists of 1567 taxa and of these 199 species are unique to the garden and do not exist in any other botanical garden in the world according to BGCI. Among the interesting palms are the Coco-de Mer, *Lodoicea maldivica* from the Seychelles. The garden has a large number of plants growing and have successfully produced viable seeds. Seeds have been acquired in cooperation with Seychelles authorities and consist of material from both known populations. The main focus on the palm collections are Asian species, especially Indochinese and Indonesian species, but also species from other parts of the world such as the Caribbean and Latin America. Edible and commercially utilised plant groups such as mango, banana, *Guava* and *Annona* collections are extensive, both wild origin as well as cultivars are maintained in field gene bank set ups. These collections are the base of regular research projects to investigate and fingerprint distinct cultivars and their wild ancestry.

The original cycad collection was limited in species and number of plants and also lacking crucial and important data as well as proper horticulture care. A full time Cycad Curator, Anders Lindstrom, was hired in 1993 to amend these issues. The original cycad collection consisted of bought in and donated material from private institutions and botanical gardens. At first, Mr. Lindstrom teamed up with Dr. Si-lin Yang from China and together they did field work in China, Vietnam, Thailand and Laos. Later, he continued study and doing field work on cycads with the late Mr. Ken Hill from Australia. Together they went on several field trips to China, Vietnam, Thailand and the Philippines. Lindstrom expanded his field trips to Indonesia, Malaysia, India, Sri Lanka, Papua New Guinea and the Pacific islands. Several scientific papers were co-authored by Lindstrom and Hill. Lindstrom has continued to do regular field trips to numerous African and South American countries. The collection has expanded from a very modest base towards more scientific based collections. At present, the garden does not sell cycads but are active in exchange of seeds and plant material with both scientific institutions but also dedicated collectors.

The garden is an officially registered CITES nursery under the DOA of Thailand. There are no CITES registered scientific institutions in Thailand, due to the fact that Thai Law under DOA make no such provision. The importance of specialist private collectors cannot be underestimated and many of those collections often hold more and better plant material than most Scientific Institutions which in turn are often limited in space and effort by being less specialized and more generalized in their plant selections.

The often-quoted drawback of private collections is that they are often not a permanent set up and will not be able maintain the plants long term. This drawback is however artificially invented as the dedication for the long-term maintenance in scientific Institutions are as sensitive to the same factors, with dedicated staff leaving and with the counterproductive policies of not sharing plants with others, those plants are forever lost in cultivation. The best scenario is of course to share the responsibility of maintaining healthy living, documented plant collections with all parties interested. Responsible private collectors have more and more realized the long-term value of their collections and often search out ways to donate, share or sell their treasured plants to other parties. As the plants have matured and start coning, the emphasis has changed towards conservation and improvement of horticulture of cycads. The setup of a cycad pollen bank started in early 2000 and has expanded and been improved over the years. The garden is actively participating in Cycad conservation and good examples are the Debao Cycad Conservation project in China that was initiated by William Tang and Anders Lindstrom in cooperation with Liu Nian. Another project was the Ugandan cycad project that involved training and field survey of Ugandan species with emphasis on *Encephalartos whitelockii* and *E. equatorialis*. Close cooperation with Kew Millennium seed bank has resulted in several projects, most notable the cycad germination research that is still on going with Dr. Anna Nebot. Several visiting researchers have conducted and produced numerous scientific and popular papers concerning the plant collections.

**Collected seeds 2014**

| Genus | Taxa | Amount |
|---|---|---|
| Ceratozamia | 7 | 229 |
| Cycas | 36 | 13,928 |
| Dioon | 3 | 20 |
| Encephalartos | 20 | 59,491 |
| Lepidozamia | 1 | 27 |
| Macrozamia | 2 | 46 |
| Stangeria | 1 | 14 |
| Zamia | 32 | 457,877 |
| **Total** | **102** | **531,632** |

**Figure 1**. Total number of hand pollinated seeds produced in 2014 as an example.

1999-2004 Debao Cycad Conservation Project (IUCN/SSC Group/ Nong Nooch, South China Botanical Garden)
2014-2017 Protecting Ugandan Endemic Cycads (Darwin Initiative/ Kew/Nong Nooch/SANBI)

The living cycad collection consist today of one of the largest collections of living and scientifically documented cycads in the world, as the number of taxa and number of plants as well as the area used to grow and propagate this plant group. The genus *Cycas* with 110 taxa and 519 accessions and Zamiaceae with 225 taxa and 654 accessions. The total number of living plants (2020) is 1,415,069 cycad plants as officially registered with Thai CITES nursery regulations.

Cycad pollinators are for most part or perhaps exclusively host specific, at least to genera of cycads, that translates to the different genera of cycads that now exist are on separate continents and thus the natural pollinators are only found on the same continent. By cultivating cycad genera from other continent than Asia the garden supports no natural pollinators for those cycads. In fact, the garden is rather isolated from any natural Thai cycad population and as such the garden does not have any natural cycad pollinators.

Consequently, no cycads set seeds, with the exception of *Stangeria*, without man made controlled hand pollination. This is crucial as the large number of seeds produced at the garden can be sure that they are not hybrids as no open pollination can take place. The seeds produced are pure or documented hybrids done on purpose.

Mass production has on many occasions been suggested to be an important tool to curb the commercial treat to many cycads. If seeds and plants are available then the market will be less inclined to remove large plants from the wild, is the common notion. The reality is as usual much more complicated. Large cycads take considerable time to grow into large sizes and it is often not commercially viable to grow, as the production time is considerable. Species are priced based on rarity and on the sizes of the stems. Many collectors of cycads are not plant fanatics as such, but are drawn to the high prices and status symbol that large cycad plants command. The garden has free land grown cycads of most genera and over 60 species for several years, these plants, some rare others not so rare are now starting to grow into size. These plants will be used as mother stock for future production from both seeds and divisions and will be commercialized to curb the demand for large cycads as landscape plants and also large-scale seed production for commercial use and to support the conservation of the cycads left in the wild.

Some species of less tropical origin has been moved to a property in Northern Thailand where the cooler winters are more suitable to the selected species. These plants are now starting to cone and the gardens are now able to propagate these from seeds. With no natural pollinators for these African genera the seeds can be confidently pure to species and population. The species involved are mostly the waxy blue leaved *Encephalartos* species, these are the very same species that are most thought after and consequently more inclined to be removed from the wild instead of grown from seeds. Some species are unfortunately it is too late as their wild populations are extinct or nearly so but by producing non hybrid seeds of these species the hope is that these species will survive in cultivation and perhaps one day the resulted seedlings might be used for reintroduction back in to the wild.

Different genera of cycads are all cultivated within the garden and the following breakdown goes into some details on our experiences with each genus. Almost all described species in the genus *Cycas* are represented. Several species are not known in cultivation elsewhere, such as *Cycas falcata, C. zeylanica, C. montana, C. javana* and *C. sundaica*. The garden has been successful in producing seeds from hand pollination of 80% of all species in the genus *Cycas*. Notably *Cycas javana, C. aculeata, C. papuana, C. badensis, C. glauca* and many other species. The climate at the garden seems to be suitable for all species but some species have not coned, most likely due to the lack of a cool spell, species like *C. revoluta* and *C. taitungensis* has never coned.

Every described species in the genus *Macrozamia* is cultivated in the garden. Several species seem to suffer from the high humidity in the rainy season and we have had severe problem with fungal attacks on the young leaves. However, so far, a large number of species has coned and we successfully produced viable seeds. Notably species such as *Macrozamia mcdonnelii, M. stenomera* and *M. cardiacensis* has coned and produced viable seeds.

Both species of *Lepidozamia* grows and cones, we can see that L. peroffskyana is suffering from the tropical climate and succumb to fungal attacks. Both species in the genus *Bowenia* and *Microcycas* as well as *Stangeria* are all growing excellent and we regularly produce viable seeds.

Several species in the genus *Ceratozamia* seem to be on the borderline of their climate preference. *Ceratozamia zaragosae* has never coned and *C. matudae* cones only rarely. Broad leaved species such as *C. europhyllidia, C. whitelockii* and *C. miqueliana* are coning regularly. Also, some rarer species such as *C. zoquorum, C. beccerae, C. alvarezii, C. vovidesii* are also coning and producing seeds.

Surprisingly, considering the often-high altitude habitat of many *Dioon* species we grow and cone every described species. *Dioon tomasellii* and *D. sonorense* as well as *D. argenteum*. *Dioon* seems to be very adaptable not only to the tropical climate but also to the excess of rain and humidity. We have had *D. caputoi* coning from seed grown plants in less than 10 years.

The majority of *Zamia* species are thriving in cultivation. Especially the tropical rainforest species and many South American species. We are regularly producing seeds of *Z. restrepoi, Z. disodon* and *Z. manicata* as well as *Z. roezlii* and *Z. lecointei.* Also, Central American species such as *Z. onan-reyesii, Z. sandovallii* and all the species in the *Z. skinneri* complex are thriving and coning. Species that we had problem in cultivating are *Z. wallisii* and *Z. oligodonta*, most likely related to their cool cloud forest habitat preference. Other problem species such as *Z. chigua* and *Z. macrochiera* seems to suffer from the high PH and we can only keep this species in pots with highly acidic soil mixes. Most species have coned, including those problem species mentioned before but we have so far failed to produce viable seeds of some species, such as *Z. urep* and strangely enough *Z. lindenii.* These two species are now part of a project to determine pollen viability and proper hand pollination techniques in order to produce seeds. We grow a complete collection of *Encephalartos* with the exception of *E. relictus.* Most species are growing very nicely but a large number of species seems not to be able to cone, most likely related to the lack of cooler temperatures.

Photo: Simon Lavaud

Such as *E. longifolius, E. horridus*, and *E. transvenosus* seems to not thrive in the tropics, with slow growth and no coning, other species such as *E. trispinosus, E. lehmannii* and *E. arenarius* only cone rarely. However, all tropical species are doing excellent with coning and seed production of *E. whitelockii, E. ituriensis, E. equatorialis, E. laurentianus, E. sclavoi, E. kisambo* doing very well. All the seasonal deciduous species such as *E. delucanus, E. schmitzii, E. flavostrobilus, E. schajeseii, E. marunguensis* and *E. poggei* are also thriving with annual coning. High altitude species such as *E. ghellinckii* are struggling but are alive after more than 20 years.

*Horticulture*

The majority of the cycad collection are grown in raised brick beds, filled with excellently drainage soil. The beds have no bottom, so the cycad roots can and are growing though the layer of good top soil into our sandy natural soil. The soil mix ratio is half part sand, 1 quarter of compost and 1 quarter of coarse gravel. The main difference is the regular top dressing that we do. For tropical *Zamia* and *Ceratozamia,* we top dress with a mix of chopped coconut husk and coconut coir, it nicely keeps the moisture in the soil and suppresses the weeds. For *Macrozamia* and most *Encephalartos* and *Dioon*, we have a layer of coconut coir mixed with coarse sand. Humus rich soil mixed with sand is used for seedlings and newly rooted suckers.

*Hand pollination*

A number of techniques has been used over the years and we are constantly improving our techniques. The two main ways are either with pollen mixed with water or pollen used dry. The "wet "method is very straight forward, with pollen mixed with water and inserted with a medical syringe into the receptive female cone. This method is used with a number of species in several genera; however, we have found that several species seems to resent this method and must be pollinated by using the dry method only. *Cycas* with their open group of megasporophylls are always pollinated dry and also all *Ceratozamia* and *Macrozamia* are pollinated with the dry method only. *Encephalartos* species such as *E. ferox, E. whitelockii* and *E. ituriensis* seems to be successful by using either way but other species such as E. turneri, *E. poggei* and *E. marunguensis* must be pollinated by the dry method only. In the genus *Zamia* we have found that there are species that can be pollinated by either way but some are only dry pollinated such as *Z. roezlii* and *Z. sandovallii.*

The garden has been the host of the International Conference of Cycad Biology in 2002 and organized two workshop/ conferences in Cycad Horticulture in 2017 and again in 2019.

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Photo: Simon Lavaud

Charles Chamberlain (left) and William Land (right), a friend and colleague from the University of Chicago. Chamberlain was a renowned sharpshooter and trained marksmen in WW1, hence the medals. A photograph given to Dennis Stevenson by Chamberlain's grandson.

# Charles Joseph Chamberlain (1863–1943), pioneering American cycad biologist

Roy Osborne & Dennis Wm Stevenson

In acknowledging the ground-breaking work of cycad biologists who preceded our generation, we have recently prepared short biographical sketches of Friedrich Anton Wilhelm Miquel (1811–1871), Johann Georg Christian Lehmann (1792–1860), Eduard August von Regel (1815–1892) and Ferdinand Jacob Heinrich von Mueller (1825–1896). These four articles are presently in press in "Encephalartos", Journal of the Cycad Society of South Africa. In this paper, we are privileged to introduce to you Professor Charles Chamberlain, American pioneer in cycad biology.

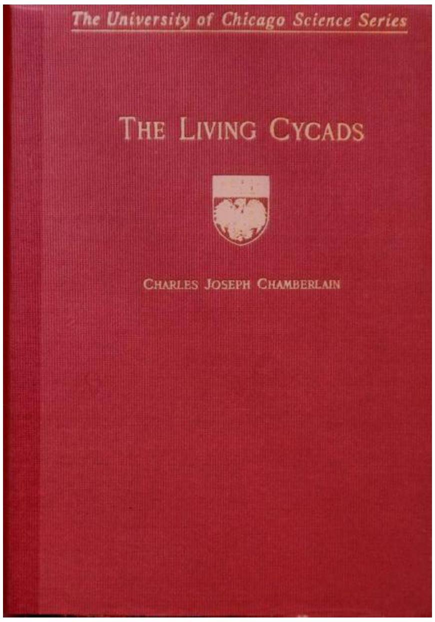
Born on 23 February 1863 near Sullivan, Ohio, Chamberlain was educated at Oberlin College, Ohio, the oldest coeducational liberal arts college in the United States, and at the University of Chicago, Illinois, an Institution which was to become the prominent feature of his life. He was the first recipient of a Ph.D. degree in Botany from the University, where he was a valued employee, being appointed Associate Professor in 1911 and full Professor in 1915.

Chamberlain was innovative in applying zoological microscopic techniques to the study of plant material, especially in his work on cycad anatomy and morphology. In addition to organising and directing the botanical laboratories at the University, he created in the world's foremost greenhouse collection of living cycads, containing specimens from Cuba, Mexico, Australia and South Africa in a plant collection that remained unsurpassed until a decade after his death.

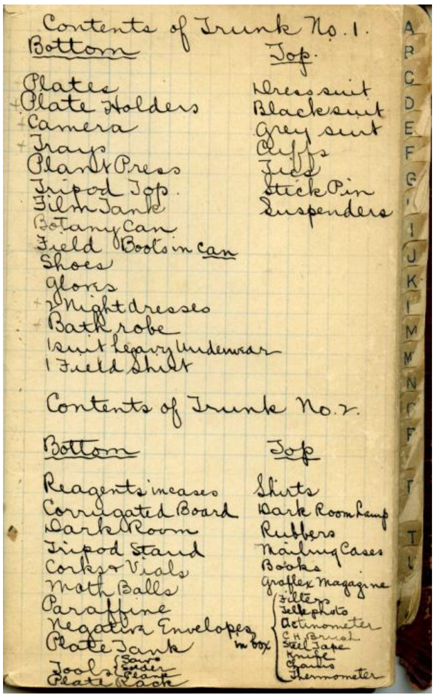

Charles Chamberlain with part of his cycad collection in the Garfield Park, University of Chicago, glasshouse. A photograph given to Dennis Stevenson by Chamberlain's grandson.

During the first two decades of the 1900s, Chamberlain travelled by extensively – by ship, by rail and even on horseback. Funded by grants from the American Botanical Society and the University of Chicago, he went first to Florida then onto Cuba, seeing *Zamia* and *Microcycas* in the wild, then twice to Veracruz, Mexico, where he saw *Dioon* and *Ceratozamia*. Those excursions were followed by his major and challenging round-the-world trip, commencing by boat from the USA to the Sandwich Islands, onwards to Fiji, New Zealand and then Australia. Arriving in Sydney, he lost no time in exploring the local cycads and other aspects of flora and fauna. He then travelled almost the full length of the Queensland coast, from Brisbane in the south to Cairns in the north. During that time, he saw all four genera of Australian cycads. After that, he went once again by boat, this time via Perth to South Africa, where he spent time in Natal, the Eastern Cape and Cape Provinces, becoming familiar with *Encephalartos* and *Stangeria*, before leaving for London and then home to Chicago. In total, he saw all known cycad genera and some 30 different species, making field notes, taking photographs, collecting material for microscopic studies and arranging for live plants to be shipped to Chicago for the greenhouse collection.

"The Living Cycads" makes fascinating reading. Part One of the three-part volume deals with his travels. His struck up warm and ongoing friendships with many people in all the countries he visited and clearly spent time in the company of high-ranking officials and other persons of influence; in anticipation of such occasions, he had packed formal attire in his baggage.

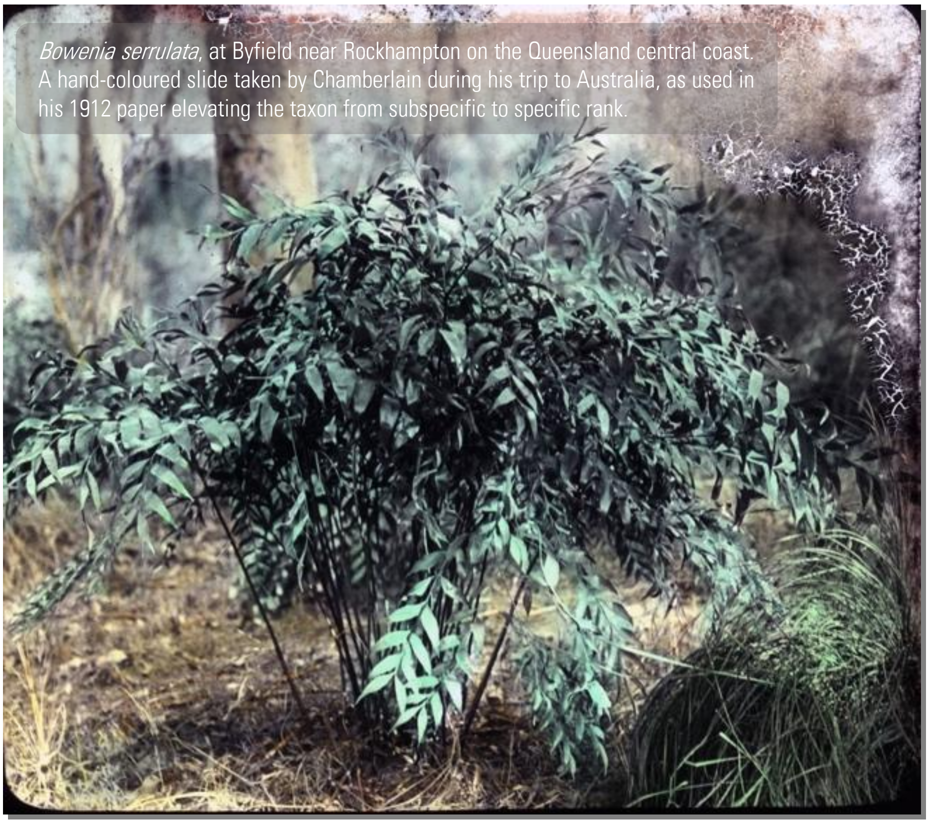



Chamberlain's popular book "The Living Cycads" (1919). In Part One he recounts his worldwide travels in search of cycads. Part Two deals with morphology and anatomy while Part Three covers evolutionary and phylogenetic aspects.


Contents of Trunk No. 1.
Bottom — Top.
Plates — Dress suit
Plate Holders — Black suit
Camera — Grey suit
Trays — Cuffs
Plant Press — Ties
Tripod Top. — Stick Pin
Film Tank — Suspenders
Botany Can
Field Boots in can
Shoes
Gloves
2 Nightdresses
Bath robe
1 suit heavy Underwear
1 Field Shirt

Contents of Trunk No. 2.
Bottom — Top
Reagents in cases — Shirts
Corrugated Board — Dark Room Lamp
Dark Room — Rubbers
Tripod Stand — Mailing Cases
Corks & Vials — Books
Moth Balls — Graflex Magazine
Paraffine — Filters
Negative Envelopes — Actinometer
Plate Tank — Steel Tape
Tools — Knife
Plate Rack — Thermometer

Handwritten inventory of the contents of Chamberlain's two trunks packed for his trip to Australia and South Africa. Note the formal attire packed in the upper layer of trunk #1. From the notebook given to Dennis Stevenson by Chamberlain's grandson.


*Bowenia serrulata*, at Byfield near Rockhampton on the Queensland central coast. A hand-coloured slide taken by Chamberlain during his trip to Australia, as used in his 1912 paper elevating the taxon from subspecific to specific rank.

During his second visit to Mexico, he describes the forest flora at Tierra Blanca, on the Veracruz-Oaxaca border, while searching for *Dioon spinulosum* in … "a forest of Spanish cedar, mahogany, ceiba, various kinds of rubber and occasionally ebony. Orchids, bromeliads, ferns and other plants weigh down the branches of the trees until they break off, so that one may collect this epiphytic vegetation without the labor of climbing".

In Australia, Chamberlain was much taken with *Macrozamia moorei*… "which is abundant at Springsure, about two hundred miles west of Rockhampton, just on the Tropic of Capricorn. It has a massive trunk, seldom more than eight or ten feet in height, but often fifteen inches or even two feet in diameter. The grass was dry and brown but the cycads looked fresh and vigorous with dark-green leaves and a wonderful display of cones". In South Africa, he describes how he was taken by James Wylie's Zulu guide to see the single extant specimen *Encephalartos woodii* … " about ten miles from Mtunzini in the midst of the *Stangeria* and *Encephalartos brachyphyllus* [*E. ngoyanus*]." In another, he tells of the excitement of finding *Encephalartos latifrons* in the Trappes Valley near Grahamstown.


*Zamia pygmaea* in habitat. A hand-coloured slide taken by Chamberlain during a trip to Cuba, named by him at the time as *Zamia kickxii*.

Chamberlain produced several important textbooks. With John Coulter he wrote the *Morphology of Gymnosperms* (1910), followed by his popular text *The Living Cycads* (1919), then his *Methods in Plant Histology* (1932), and finally his *Gymnosperms, Structure and Evolution* (1935). His publications I the field of cycad taxonomy relate to two species: in 1912 he elevated *Bowenia serrulata* (from William Bull's 1878 subspecies rank) to species, while in 1926 he described *Zamia monticola* from Guatemala, both papers published in the *Botanical Gazette.*

Chamberlain married Martha Life in 1888 and they had one daughter. After his wife passed away in 1931, he married another Martha, Martha Lathrop.

He died in Chicago, Illinois on 5 February 1943, just a few days before his 80th birthday.

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Figure 1. Ranger Eliah Hlungwani holds seeds of *Encephalartos dyerianus* at the Lillie Flora Nature Reserve in Limpopo, South Africa. The reserve protects the sole extant wild population of this Critically Endangered species.

# Global Conservation Consortium for Cycads: Accelerating conservation of cycads on a global scale

Vanessa Handley, M. Patrick Griffith, John Donaldson, Tim Gregory and Cristina Lopez-Gallego

Nearly two decades have elapsed since publication of the *Cycads Status Survey and Conservation Action Plan* (2003). The Plan included a robust slate of proposed actions which have since been actively pursued (*see Griffith & Vovides, this issue*). However, despite this increased emphasis on conservation, the intervening years have borne witness to an ongoing – at times intensified – global decline in cycad populations. This apparent paradox speaks to the complexity of the issues at hand and the lag time in efficacy of conservation measures. It also highlights the need for greatly accelerated action.

CSG leadership has eloquently sounded this alarm (*see Gregory & Lopez-Gallego, Cycads 3(1))* while acknowledging the need for increased funding, dissemination of expertise to regional practitioners and coordination of conservation efforts. In response to this call for direct action, a Global Conservation Consortium for Cycads (GCCC), has been launched. As a joint effort of the IUCN Cycad Specialist Group (CSG) and Botanic Gardens Conservation International (BGCI), the objective of the GCCC is to enhance durable conservation of global cycad diversity through integrated ex situ and in situ actions.

To this end, GCCC members will work in concert with national and regional government agencies, non-governmental organizations, indigenous communities, landowners, and other interested parties to accomplish the long-term conservation of genetically diverse and representative populations of cycads. This will entail both traditional approaches (i.e. land protection, ex situ collections) and emerging methodologies (i.e. genetically informed metacollection management, integration of private holdings, conservation credit systems with local communities).

The administrative arm of the GCCC is the Consortium Steering Committee; currently composed of CSG leadership and chaired by a rotating Consortium Lead Institution. In collaboration with partners at BGCI, this team is tasked with developing and implementing an overall workplan for the GCCC.

While the Consortium Steering Committee will provide broad, strategic leadership, a slate of Regional Steering Committees will directly guide and coordinate conservation hubs. Hubs are envisioned in Africa, Asia, Central & South America, Caribbean & Mexico, and Oceania. Membership from diverse geographies will ensure that the work of the Consortium is global in scope and representative of key diversity hotspots. With logistical and administrative support from the Consortium Lead Institution, the Regional Steering Committees will develop regionally appropriate objectives.

An additional, more granular level of GCCC participation will be that of the Species Steward. Ideally at least one Species Steward will be identified *for every cycad of conservation concern*. Species Stewards will be botanic gardens (or, when appropriate, individuals) that manage an in situ population and/or an ex situ collection of high conservation quality for one or more priority species. For participating gardens, the collective accessions of a stewarded species constitute the "metacollection" for that taxon - a living resource potentially distributed across multiple institutions but managed collaboratively for research and conservation purposes.

In this manner, each network of Species Stewards will assume responsibility for management of their focal species – and serve as a force for accelerated conservation action. In general, an institutional lead will be designated within each, to facilitate annual tracking and reporting. In serving as a lead, an institution will be expected to stimulate conservation efforts for the target species and, as feasible, conduct allied research and fundraising. Engagement in direct conservation action will be a critical, near term objective for priority taxa. In short, the goal is to move beyond basic metacollection management and to a) enhance genetic representation through acquisition and exchange and b) enhance conservation impact. The desired outcome is to not only secure cycad collections for perpetuity but to greatly increase their conservation value. As applicable, re-introduction strategies will be developed and implemented in parallel.

Since there will be attendant metacollection data management and data security burden, we are pleased to announce that BGCI is developing a module for their global PlantSearch platform that will provide database support to the GCCC and other conservation consortia.

To support the administrative costs associated with launching the GCCC, Montgomery Botanical Center (MBC), working with the Morton Arboretum, has secured funding through the US Institute of Museum and Library Services. In conjunction, MBC has stepped forward to serve as the initial Consortium Lead Institution and CSG members Patrick Griffith and Vanessa Handley have agreed to serve as, respectively, GCCC Project Leader and GCCC Chair & Coordinator for the launch phase. Throughout 2021 virtual meetings will be held across regions to introduce the GCCC and encourage broad participation. In the meantime, we invite broad participation – CSG members would be particularly valued on Regional Steering Committees - and welcome feedback and suggestions. The deep expertise and passion of CSG members will be integral as we mobilize to enhance the action initiated with the 2003 Plan. Collectively we can implement the next phase of an ambitious, coordinated, and action-oriented conservation strategy for cycads!

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CYCADS

*Macrozamia stenomera* L.A.S.Johnson Photo: Bret Dalziel

# Cycad Garden Networks: History, Foundations, and the New Path Forward

M. Patrick Griffith and Andrew Vovides

An ambitious goal laid out in the *Cycad Status Survey and Action Plan* (Donaldson, 2003) was "comprehensive coverage of cycad taxa in genebanks." The text of that goal (10.2.1; ibid, page 59) is worth quoting in depth:

> "Although the few gardens now involved have built up collections of many threatened species, there are still species that are not in genebanks and there are inadequate backup collections. Such backup collections are crucial to deal with natural disasters and mishaps. Additional gardens need to be encouraged to develop genebanks, even if they focus on only one or a few species. There is a special need to develop genebanks within cycad range states because it will be easier to maintain mutualisms in these collections and they can form part of local conservation programmes. The facilities and expertise that exist in the current network of gardens involved in cycad conservation can form the framework for a broader network of gardens".

Aims were clearly articulated in that text to assure cycad survival through a worldwide network of gardens. Action steps on that page specifically call upon botanic gardens to work with the Cycad Specialist Group to set up genebanks and facilitate exchange of duplicate plants. Botanic Gardens Conservation International (BGCI) was specifically tasked to partner with the CSG to identify gaps in coverage for these assurance collections, and facilitate communication among gardens worldwide. BGCI's PlantSearch tool has greatly facilitated in identifying plants and garden holdings.

In 2010, important steps were taken to begin this network of gardens in support of cycads in a way that matched the vision of the 2003 Action Plan. Dr. Andrew Vovides convened a symposium on cycads at the 4th Global Botanic Garden Congress in Dublin, which formalized a call to establish a Botanic Gardens Cycad Collections Consortium as part of the IUCN SSC (BGCI, 2010). The establishment of that network in early 2011 accomplished two of the action steps laid out by the 2003 Action Plan: it (1) communicated among cycad gardens, and (2) it provided an overall gap analysis of global *ex situ* cycad collections, which was presented at Cycad 2011 in Shenzhen (Vovides *et al.* 2018).

This network of cycad gardens has also been leveraged for many research outcomes. For example, the Jardín Botánico Francisco Javier Clavijero in Xalapa, Veracruz, Mexico holds the Mexican National Cycad Collection with over 90% of native cycads represented, plus species from other world genera on display. Mexico comes in second worldwide for native cycad diversity after Australia (Vovides, 2000), and thus the Xalapa collection contributes significantly to such networked efforts. Most of the living cycad collection at the Clavijero Botanic Garden is bar coded, (see Nicolalde-Morejón *et al.* (2011)) and many of these cycads have contributed to molecular phylogenetic studies (Caputo *et al.,* 1991; Moretti *et al.,* 1993; González & Vovides, 2002, 2012; Hill *et al.,* 2003; Bogler & Ortega, 2004, among others). More recently, some controversial cycad complexes have also been solved by analysing leaflet anatomical traits (Pérez-Farrera *et al.,* 2014, 2016; Vovides *et al.,* 2016, 2018, 2020), emphasizing that older traditional methods such as anatomy very often compliment modern molecular analyses.

Another important conservation strategy emphasized in the 2003 Action Plan is conservation through propagation with plant sales coupled with habitat protection and reintroduction. This creates an incentive to conserve cycad habitats that are generally on marginal lands not suited to agriculture. Rural farmers, assisted by a botanic garden, will make an effort to protect habitats when an income is assured through plant propagation and sales, even though this system is not free of problems (Tang *et al.,* 2018).

With this foundation and progress towards the action steps agreed upon in 2003 (Donaldson, 2003), the stage is now set for engaging cycad collections at a greater scale and scope, in alignment with our Cycads 2050 plan – *that no cycad species goes extinct.* A new US Federal grant (see Handley *et al.,* this issue) funds active facilitation of the exact goals presented in the Action Plan. As a partnership involving the CSG, BGCI, and a number of botanic gardens, it meets the vision from decades past exactly. We are excited to have a clear path forward for cycad collections!

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*Zamia lindenii* Regel ex André in natural habitat, Ecuador. Photo: Simon Lavaud

# Emerging insights into the ecophysiology of dioecy in cycads: a call for research

Sophia Gosetti, Christopher P. Krieg & Katherine A. McCulloh

Cycads are one of the most endangered plant groups on the planet, with more than 65% of species threatened with extinction (IUCN, 2003), yet many aspects of their biology are poorly understood. For example, cycads are dioecious, meaning there are male and female individuals, and although dioecy has been hypothesized to lead to divergent selective pressures for reproduction, much is unknown about the ecophysiological implications of dioecy in cycads (Krieg *et al.,* 2017). Additionally, cycads are in a unique phylogenetic position because they are one of the first dioecious vascular plant groups (Nixon *et al.,* 1994) and the earliest diverging seed plant lineage with complete dioecy (i.e. strict sex separation and without hermaphroditism).

Research on dioecy in cycads is crucial to understand how males and females in early seed plants allocate resources to various functions, such as growth, defense from herbivory, and reproduction. Because resources in the environment are limited, allocation to each of these processes competes with one another, thus creating trade-offs within an individual plant (Fig. 1). When reproductive effort is separated between sexes, as in dioecious systems, then the selective pressures acting on allocation-related trade-offs are also separated. One example of a possible trade-off is the relationship between reproductive structures like cone production, and vegetative growth like the number of leaves an individual can support, as both processes require energy from the plant. If one sex allocates more of its energy to reproduction than the other sex, then it is possible that other aspects of growth may be reduced in one sex more than the other (Fig. 1). Indeed, similar observations have been made in some cycads, where reproductive individuals of both sexes of the species *Zamia skinneri* increased their number of leaves the year before cone production (Clark & Clark, 1988), which is consistent with reproduction being a generally very costly process (because leaf photosynthesis is the main way to acquire and store carbon). In the same study, females did not grow new leaves up to two years after reproduction, indicating that there may be a higher energy cost for females, so much so that they could not afford new leaf growth after reproductive events (Clark & Clark, 1988). Despite evidence for some morphological differences (e.g., leaf number) between males and females, little is known about the actual carbon costs for growth and reproduction in either sex or allocation patterns across any cycad species.

Recent research suggests that divergent selective pressures on reproductive traits in males and females may have contributed to physiological differences between the sexes in cycads (Krieg *et al.,* 2017), and to their pollination biology (Terry *et al.,* 2007, 2012). For example, many cycad species are pollinated by insects that distribute pollen from male plants to female plants (Tang, 1987; Terry *et al.,* 2007). In order to attract pollinators, many cycads undergo periods of thermogenesis (heating of cones before and during pollen shedding) to emit volatile compounds thought to attract pollinators (Suinyuy *et al.,* 2010, 2013). In some species, male cycads can undergo greater degrees of thermogenesis than females, but the consequences thermogenesis may have on resource allocation are not well understood. It seems plausible to posit that if heating a cone for thermogenesis requires large amounts of energy, then there might be a concurrent increase in carbon acquisition (e.g. via increased photosynthesis) to gather and/or store the energy needed for thermogenesis. Plants can increase their photosynthetic carbon uptake in a variety of ways, including increasing the total number of leaves and/or increasing the photosynthetic capacity per leaf. The observations of leaf growth in *Zamia skinneri* prior to reproduction may indicate that one-way individual plants are increasing their carbon uptake is by increasing their total leaf area. However, it remains unclear if increasing the total number of leaves and/or increasing the photosynthetic capacity per leaf are mechanisms to 'pay' for the costs associated with reproduction.

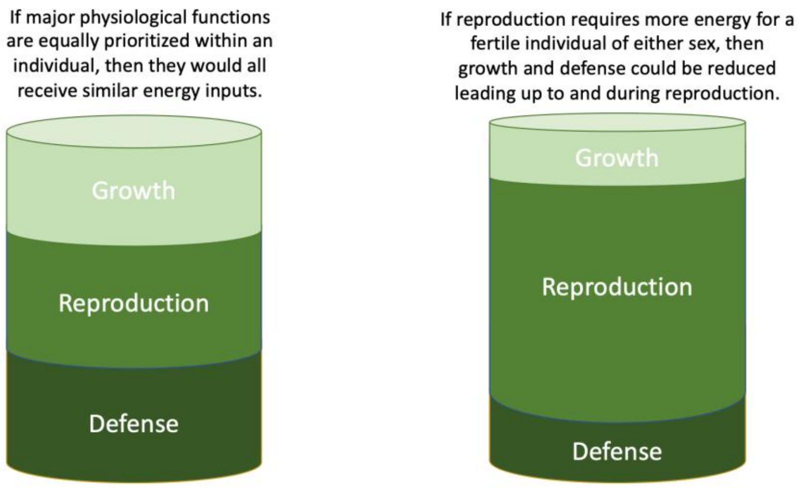


**Figure 1.** Potential consequences of disproportional resource allocation to reproductive effort on other important processes.

There are clear gaps in our knowledge of ecophysiological differences between males and females, as well as between sterile and fertile individuals of the same sex. Future research should focus on the extent to which nutrient uptake and allocation differ between males and females, as well as their stress tolerance, and if these processes change with phenology and reproductive status within each sex. If males and females differ in key ways such as in their resource requirements for reproduction, then a single habitat may be better suited for one sex to reproduce than the other, and potentially impact population dynamics. Furthermore, if males and females differ in their responses to environmental stressors (which remains entirely unexplored in cycads), then males and females may respond differently to climate change. Ultimately, a better understanding of the ecophysiological trade-offs associated with dioecy in cycads may help conservation practitioners form effective plans for their conservation and possibly the conservation of other plant groups, if connections can be made between the trade-offs in cycads and those in other dioecious plant groups.


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*Cycas siamensis* Miq. Photo: JS Khuraijam

# Pollination Ecotypes in the African cycad *Encephalartos ghellinckii*

Terence N. Suinyuy

In response to the call for global efforts to study the different pollination systems in cycads (Chemnick *et al.,* 2002), a recent study on pollination of *E. ghellinckii* showed that this species consist of two pollination ecotypes that are adapted to two pollinator assemblages (Suinyuy and Johnson, 2020). *Encephalartos ghellinckii*, a South African endemic is a medium-sized cycad with an erect or reclining trunk that grows in diverse habitats on rocky slopes and grasslands and occurs singly and in clumps. The species exhibit morphological variation with some isolated mountain populations occurring at *c.* 1500–2700 m a.s.l. often called the giant form, and scattered lowland populations that occur at *c.* 500–900m a.s.l. called the dwarf form (Jones 1993; Grobbelaar, 2004).

A recent study revealed that cone odour profiles of mountain *E. ghellinckii* are characterized by emissions of(3*E*)-1,3-octadiene and *cis-β*-ocimene, while cone emissions in lowland populations are dominated by camphene (Suinyuy & Johnson, 2018).The beetles *Metacucujus goodei*, an undescribed species of Lobariidae and *Platymerus* sp. occur in cones of mountain plants, whereas an undescribed Erotylidae sp. nov. are common in both mountain and lowland populations (Suinyuy & Johnson, 2018). Despite the variation in odour composition and pollinator assemblages between the different morphological forms, there are no molecular data to support recognition of the two forms as separate species.

Pollination studies revealed that the mountain plants are pollinated by *M. goodei* and the Lobariidae beetle while the Erotylidae *sp. nov.* pollinates both mountain and lowland plants (Suinyuy and Johnson, 2020).Evidence for pollination ecotypes is supported by the differential response of *M. goodei*, Lobariidae, and Erotylidae sp. nov. to patterns of cones thermogenesis and cone volatile emissions in the mountain and lowland plants (Suinyuy and Johnson, 2020). Thermogenic episodes in pollen-shedding cones of *E. ghellinckii* in the mountain were associated with the arrival and departure of insect pollinators dominated by *M. goodei* in the afternoon. In mountain plants, Lobariidaebeetles and Erotylidae sp. nov.that also occur in the lowland populations had lower levels of activity during peak thermogenic episodes in pollen-shedding cones when compared to *M. goodie* activity. Field and laboratory bioassays showed that *M. goodie* from mountain plants and Erotylidae *sp. nov.* from lowland populations were attracted cone odours and cones from the host plants and local regions. The study contributes to knowledge in understanding the role of cone thermogenesis in pollination in *Encephalartos* spp. and can be useful in resolving the phylogeny of *E. ghellinckii* that exhibit morphological variation.

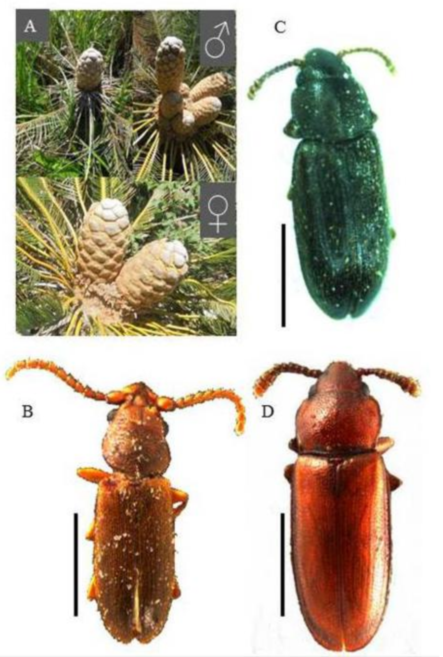


Figure 1. A) Male and female cones of *Encephalartos ghellinckii*, B) *Metacucujus goodie* and C)Lobariidae that pollinate cones of *E. ghellinckii* in mountain populations; D) Erotylidae sp. nov. that pollinate cones of *E. ghellinckii* in mountain and lowland populations. Scale bar = 10 mm (Suinyuy and Johnson, 2020).

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