**STATE OF CONSERVATION REPORT**
**NAN MADOL: CEREMONIAL CENTER OF EASTERN MICRONESIA**
**SUBMITTED 1 FEBRUARY 2020**

**Executive Summary of the report**

With assurances of gratitude to the World Heritage Centre and the World Heritage Committee, the State Party of the Federated States of Micronesia (FSM) describes its progress in implementing the corrective measures suggested by the World Heritage Committee, relates the time frame for continuing to formulate and implement such measures, and offers a time frame for finalizing a desired state of conservation for the removal (DSOCR) of Nan Madol: Ceremonial Centre of Eastern Micronesia from the List of World Heritage in Danger. It describes the ongoing development of a Sustainable Conservation Plan and the conservation priorities the Plan has identified, which are vegetation management, the formulation and implementation of a site management plan, and the formulation and implementation of a site interpretive plan that will support site management. The implementation and refinement of these plans and vegetation management activities are proposed to continue with support from the U.S. Department of State, U.S. Forestry Service, and U.S. Department of the Interior through October 2022. The State Party aims to have the vegetation management, site management, and interpretive plans sustainably implemented by that time. The State Party notes further that, through the efforts of Cultural Site Research and Management (CSRM) Foundation and the FSM and Pohnpei State governments, it has made arrangements to remove the most pressing threats posed by vegetation to Nan Madol’s OUV, and to engage a qualified team to undertake a heritage impact assessment (HIA) of the construction of a tourism resort on Nahnningi Island, by the end of April 2020.

**Response to the Decision of the World Heritage Committee**

On behalf of the State Party, the FSM National Commission for UNESCO expresses its gratitude for the World Heritage Centre’s letter of 29 July 2019 and its attention to the World Heritage Committee’s Decision 43 COM 7A.43. The State Party thanks the World Heritage Centre and the World Heritage Committee for the opportunity to relate and document its progress toward conserving the World Heritage Site of Nan Madol: Ceremonial Center of Eastern Micronesia. In the response that follows, the State Party describes its progress in implementing the World Heritage Committee’s recommendations, requests, and recommendations of Decision 43 COM 7A.43, and it describes a time frame for the development and implementation of prioritized conservation measures.

The State Party notes that the 2018 Report on the World Heritage Centre/ICOMOS Reactive Monitoring Mission to Nan Madol deferred from formulating a DSOCR for Nan Madol, stating, “it is clearly in the State Party’s interest to define the DSOCR but this has to be helpful and realistic” (p. 25). In accordance with the project timeframes described below, such a DSOCR will be finalized by September 2020. The State Party can attest at this time that the DSOCR will include the removal of the most urgent threats to the site posed by vegetation; the implementation of an ongoing vegetation management plan; the implementation of a site management plan; and the implementation of a site interpretation plan, all of which measures and plans are under development.
The Sustainable Conservation Plan, and Conservation Priorities

The State Party is collaborating with CSRM Foundation, a United States-based, 501(c)(3) non-profit organization, to develop a Sustainable Conservation Plan for Nan Madol. The State Party is grateful for the support being provided to CSRM Foundation by the U.S. Department of State through its Ambassadors Fund for Cultural Preservation (AFCP) Large Grant program. The AFCP’s financial support for the Sustainable Conservation Plan and its implementation is anticipated to total $750,000. The actions, programs, and policies necessary for the sustainable conservation of Nan Madol, and its removal from the List of World Heritage in Danger, would not be possible without the U.S. Department of State’s support.

CSRM Foundation began preparing the Sustainable Conservation Plan in October 2018. The Plan has benefited from the expert observations and suggestions of the 2018 Draft Conservation Plan, prepared by Dr. Christophe Sand, to which the World Heritage Centre refers in its 29 July 2019 letter. The State Party and CSRM Foundation are collaborating to secure further funding, again from the AFCP, for the Sustainable Conservation Plan’s implementation. That implementation project is proposed to start in October 2020 and continue until October 2022, at which point, according to the project goals, Nan Madol’s vegetation management, site management, and interpretive plans will be functioning sustainably.

The Sustainable Conservation Plan addresses the most urgent physical conservation threats to Nan Madol, and the State Party emphasizes that the overall Plan includes a management plan and an interpretive plan. These are the site’s highest conservation priorities and will be reflected in the DSOCR. The State Party aims to implement the management plan and interpretive plan, and to mitigate those threats that most imminently endanger Nan Madol’s OUV, by the end of the October 2020-October 2022 implementation project. Under the current AFCP-funded project—that of designing the Sustainable Conservation Plan—the management plan and the interpretive plan, as well as the DSOCR, are scheduled to be finalized by the end of September 2020.

The State Party takes this opportunity to note that substantial anastylosis would, under current and foreseeable circumstances, be virtually impossible due to the costs of moving and replacing the stones that belong to Nan Madol’s islets and other structures. Uncertainty surrounding the need for anastylosis, the complexities of the cultural environment in which anastylosis would take place, and the clear and overarching priority of managing vegetation—which would be required, in any case, before much anastylosis were possible—make the implementation of an anastylosis program undesirable. Replacing stones would, in many cases, likely involve removing them from soil contexts that may have archaeological significance. Anastylosis at Nan Madol would also have cultural and spiritual implications that would, at the very least, add further dimensions of complexity and risk to the overall goal of conserving Nan Madol. Any efforts to alter the current distributional pattern of stones should be undertaken only after access to islets has been provided in a noninvasive way and should probably be done on an islet by islet basis once management infrastructure can ensure the sustainability and careful documentation of such efforts.

Vegetation Management

As the World Heritage Committee has recognized, the enormous conservation challenges facing Nan Madol force the State Party to set achievable goals in the short- and medium-terms, starting with counteractions of the most urgent threats. Along with the threats posed by a lack of management and interpretation, the State Party, under advisement from CSRM Foundation, understands that vegetation overgrowth is the most pressing issue the State Party must address.
As attested by Kevin Eckert, an International Society of Arboriculture (ISA) Board-certified Master Arborist, mangroves, vines and ground covers, and trees are damaging many of the site’s islets and other structures in ways that might be irreversible or enormously costly to remedy. The State Party is collaborating with Eckert’s organization, Arbor Global, which is acting with the support and on behalf of the U.S. Forest Service, and with CSRM Foundation to refine and implement a vegetation management plan. This process, the first stage of which culminated in the completion of Arbor Global’s “Tree and Vegetation Management Review and Recommendations,” dated 31 October 2019, will reach its next milestone in March 2020, when Arbor Global, with financing from the U.S. Forest Service, will lead a two-week vegetation management training program on Pohnpei. That program will empower and equip representatives from several Pohnpei State government offices and Pohnpei-based private organizations to plan and apply vegetation management procedures at various levels of specialization, from removing mangroves to advanced tree-climbing and –pruning. An ongoing plan for vegetation management will draw on the capacity built by the March training, focusing, in the short and medium terms, on priority areas that have been chosen with Sand’s 2018 Draft Conservation Plan in mind. The results of the March 2019 airborne LiDAR survey, which was done under the auspices of the Sustainable Conservation Plan, have also been advantageous to the development of a vegetation management plan, because they have provided detailed maps of vegetation cover and canopy height at Nan Madol and in almost all of the buffer zone.

With the U.S. Forest Service’s support, CSRM Foundation has determined that the most urgent threat posed by vegetation is that of falling branches and large trees, and the root systems of large trees, such as breadfruit. In the short term—that is, within six months of the 1 February 2020 submission of this letter—and with the application of the knowledge and equipment afforded by the March 2020 training program, the State Party will address these threats first. The State Party expects to be able to remove the most pressing vegetative threats to Nan Madol’s highest-priority islets—Nan Dowas, Peinkitel, Pahn Kedira, Peikapw, and Idehd—by the end of April 2020.

In the short and medium terms, considering the medium term to be six months to 18 months following this letter’s submission, vegetation management will focus on expanding the large tree management program and on mangrove removal. Mangroves are damaging the site by displacing stonework, and their root systems encourage siltation in the canals, which inhibits passage through the canals and allows other plant species to grow.

In the medium and long terms, considering the long term to be the next one to five years, the areas of the site that are being managed for large tree and mangrove growth will be expanded, prioritizing those areas having the greatest OUV and subject to the most pressing threats. Management of vines and herbaceous ground cover will focus on priority areas and expand similarly over time. Short- and medium-term goals will pave the way for long-term goals—for example, clearing mangroves from key canals will improve site managers’ and maintenance workers’ abilities to access and address threats to other parts of the site.

The Management Plan

The sustenance of an effective management plan will demand capacity-building in the FSM, and especially on Pohnpei, for the skills and expertise that will be necessary to managing Nan Madol. The State Party is facilitating this capacity-building by two means especially. The first is by developing a memorandum of understanding (MOU) between Pohnpei State and the College of Micronesia-FSM (COM-FSM) to set a framework by which the latter will be able to provide the training and certification of staff needed to manage Nan Madol.
The second is by arranging for continuing support from the U.S. Department of the Interior and U.S. Forest Service. To that end, officials from the FSM Office of National Archives, Culture and Historic Preservation (NACH) are working with the FSM Office of Legislative Counsel and CSRM Foundation to revise a bill, LB392, to the Pohnpei State Legislature that will establish a Nan Madol Trust. The State Party hopes and expects to introduce that bill by the end of March 2020. Once it is signed into law, the bill will formally establish a framework for the management structure at Nan Madol. It is designed to balance the interests of the FSM government, the Pohnpei State government, traditional leadership, and the local community on Pohnpei, as well as to encourage the transfer of knowledge from the U.S. Department of the Interior and COM-FSM to Nan Madol management. The goal of establishing the Trust is to establish collaborative relationships for Nan Madol’s conservation and management that will last indefinitely.

Though LB392 creates a legal basis for the Nan Madol Trust, the specifics of the Trust’s organizational structure and activities will be defined by the Trust itself, in collaboration with NACH, the parties represented by the Trust’s members, and CSRM Foundation. The State Party is following this approach in order to allow the organizational structure of Nan Madol’s management to adjust to its new responsibilities and to revise its activities in accordance with changing circumstances in the future. Between the submission of this letter and September 2020, the State Party will oversee iterative meetings of the organizations that will be represented by the Trust. The purpose of these meetings is to develop and refine the Nan Madol management plan, which will include a definition of the Trust’s organizational structure. The first of these meetings took place on 22 January 2020, and follow-up meetings are scheduled for March 2020. One outcome of the finalization of the management plan will be the identification of a long-term Property Manager for Nan Madol.

The Interpretive Plan

Traditional leaders, community members, and the relevant government offices, which include the Pohnpei State Tourism Office and the Pohnpei State Historic Preservation Office, are providing iterative feedback on a Nan Madol interpretive plan to CSRM Foundation. Those parties will provide information and expertise regarding the interpretive material that will be presented to Nan Madol’s visitors. In coordination with them, and with due consideration for the design documents and physical plans for the forthcoming Nan Madol Visitor Center, CSRM Foundation is arranging for the design and installation of interpretive devices, including panels, introductory videos, and three-dimensional maps. The interpretive plan will include a visitor itinerary that will suggest a minimally intrusive, but informative and aesthetically outstanding, visitors’ route through parts of the site. Under that itinerary, visitors will move through some of the site’s canals on guided boat tours, minimizing physical disturbance to the site and facilitating visitor flow management.

Other current conservation issues identified by the State Party which may have an impact on the property’s Outstanding Universal Value

In a letter dated 20 December 2019, and in the ICOMOS Technical Review attached to it, the World Heritage Centre informs the State Party of its awareness of the ongoing construction of a tourism resort on Nahningi Island, a small, coral island that is within the buffer zone of the Nan Madol: Ceremonial Center of Eastern Micronesia World Heritage Site. That letter requests that the State Party prepare an HIA, following the 2011 ICOMOS Guidance on Heritage Impact Assessments for Cultural World Heritage Properties, taking account of the tourism resort’s
construction and its impacts on Nan Madol. The State Party is arranging to engage a qualified team with the requisite expertise to develop that HIA. The State Party aims to finalize those arrangements by the end of May 2020.

In conformity with Paragraph 172 of the Operational Guidelines, describe any potential major restorations, alterations and/or new constructions intended within the property, the buffer zone and/or corridors to other areas, where such developments may affect the Outstanding Universal Value of the property, including authenticity and integrity.

Besides the tourism resort on Nahningi Island, for which an HIA is forthcoming, and the construction of a Nan Madol Visitor Center (sometimes termed Nan Madol Information Center), there are no restorations, alterations, or new constructions intended within the World Heritage Site core boundaries that might plausibly affect the site’s OUV. Management zoning within the buffer zone will ensure that the Nan Madol Visitor (Information) Center does not threaten the OUV of the Nan Madol World Heritage Site and that construction will adhere to all relevant FSM and Pohnpei State laws and regulations.

Public access to the state of conservation report
The State Party consents to free and public access to this report via the World Heritage Centre’s State of Conservation Information System.

Signature of the authority

Mr. Augustine Kohler
Secretary-General, FSM National Commission for UNESCO

[Signature] [Date: 01/29/20]
LEFT SIDE ELEVATION

insulated roofing panel
2\"x3\" metal purlins @ 36\" o.c.

ROOF FRAMING PLAN
Report of: Kevin K. Eckert  
ISA Board Certified Master Arborist WE-1785BU

Project: Tree and Vegetation Management Review and Recommendations

Project Site: Nan Madol, Pohnpei, Federated States Of Micronesia

1.0 Introduction

Nan Madol is an historic city complex of stone platforms dated to the 10th through 14th centuries located along the southwest coast of Temwen Island, Pohnpei, Federated States of Micronesia (FSM).

Mangrove trees have encroached upon the central canal system and onto the platforms inhibiting access and obstructing water flow that propagates siltation on restricted sections of the canal. Other tree species, vines and herbaceous vegetation have been planted or naturalized within the platforms such that these sites are visually and physically obstructed and, in some instances, incurring damage caused by this invasive vegetation growth. This unmanaged vegetation has restricted Nan Madol’s current and future value and integrity, and is a significant contributor to its entry into the List of World Heritage in Danger. It has been determined that judicious and technically correct vegetation removal and management will be required to salvage the site and enable managers to enhance its cultural, historical and educational properties. The Nan Madol Sustainable Conservation Plan project team has recommended that a team of arborists on Pohnpei be trained and equipped to help design, then implement, such a plan.

Through the coordination and cooperation of State and Federal agencies including:

- FSM National Archives, Culture and Historic Preservation Office (NACHPO);
- Pohnpei State Economic Affairs Office;
- Pohnpei State Historic Preservation Office (PSHPO);
- Pohnpei State Tourism Office;
- United States Ambassador to the FSM;
- United States Department of Agriculture Forest Service (USFS); and
- Cultural Site Research and Management (CSRM);

Arbor Global (AG), a Hawaii-based arboricultural consulting company with direct experience in tree management in Pohnpei and US Pacific Island Territories, has been retained to conduct a review of the vegetation conditions in select sections of the Nan Madol site and provide recommendations for clearing and management of undesirable vegetation.
Field inspections were conducted on August 12 and 13, 2019 by AG’s Kevin K. Eckert, International Society of Arboriculture (ISA) Board Certified Master Arborist WE-1785BU, under the guidance of Gus Kohler, Pohnpei State Historic Preservation Officer, and in the direct company of Randy Joswa, PSHPO.

This report provides AG’s general findings, conclusions and recommendations for tree and vegetation management according to conditions at the time of this inspection.

2.0 Inspection and Assessment Procedure

2.1 Preliminary Information Collection
Douglas C. Comer, Ph.D., Principal, CSRM, provided AG an overview of the Nan Madol site including maps, aerial photos, ground-based photos from he and his team’s recent inspection of the site.

Dr. Comer advised that the priority sites and platforms that should be initially inspected and vegetation management plans developed are:

- Canal system that extends from Peiniot islet and passes on the west side of Nandowas, southeast sides of Peikapw and Pahnkedira, and then along the western border of Pahnkedira exiting west into the bay near Pohnkeimw islet;
- Peinkitel;
- Nandowas;
- Idehd;
- Peikapw;
- Pahnkedira; and
- Watershed on Temwen Island
Background and project goals were supported by Dr. Comer’s “Nan Madol Sustainable Conservation Plan Preliminary Report on Threats Posed by Vegetation” prepared by the CSRM Foundation and supported by the Ambassadors Fund for Cultural Preservation, Award Number SLMAQM18GR2224.

Basic considerations for management were guided by a recommendation for vegetation management by Dr. Margie V. C. Falanruw, USFS Natural Resources Technology Transfer Specialist. Pohnpeian names of the plant species were referenced from “Species seen from boat, along foot path from Peinkitel to Nandowas and on Nandowas” prepared by Dr. Falanruw.

Key references used for identification, naming and general description of sites, and from which site drawings were copied was the “Inventory of Islets of Nan Madol (UNESCO 2015 Nan Madol Dossier), An Appendix to the World Heritage nomination of Nan Madol: A Ceremonial Center of East Micronesia” compiled by: Adam Thompson, Helen Alderson and Osamu Kataoka.

Historical vegetation conditions were referenced from “Vegetation cover of Nan Madol World Heritage Property: an assessment of its history” by Christophe Sand, Institut d’Archeologie de la Nouvelle-Caledome et du Pacifique (IANCP), July 2018.

2.2 Field Inspection
Field inspection was conducted along the canals, where accessible, from a boat and on land by foot.
Canals were navigated by boat as far as possible from Peiniot through to the southwestern end of Peikapw when shallow water and vegetation obstructions terminated boat access (blue line on the map below). Access and inspection of the canal area from land was conducted of the areas highlighted in yellow on the map below. During this inspection, neither visual or physical access was practical of the canal area highlighted in red on the map below.

![Canal Inspection Access](image)

Nandowas was easily accessible on land permitting a walk-through and review of vegetation throughout the entire platform and inside the walls.

Idehd, Pahnkedira, Peikapw, Peinkitel, and the watershed on Temwan Island were densely vegetated with visual and physical access restricted by walls, dense vegetation, water barriers and uneven terrain. Vegetation conditions were inspected by walking transects, as able, through each site to enable an understanding of primary vegetation species, density, heights and character.

The watershed site possessed significant access obstacles during this inspection and only viewing from the western border at three access points was practical. Approximate access points are very tentative as maps did not conform to ground conditions and adequate land-based references were not available.

Photographs and notes were recorded at inspection sites.
Recommendations for vegetation removal and cost-effective management have been developed based on AG’s extensive experience with vegetation management on various locations including Pohnpei, Guam, Saipan, American Samoa, Kosrae, Hawaii, Australia, the Mainland US, Costa Rica, Brazil, Guatemala and Southeast Asia.

Vegetation removal methods for initial clearing that were considered included:

- Tree felling using chainsaws,
- Tree felling in parts using rope access,
- Mowing with machines,
- Small tree and vegetation felling using manual hand tools (hand saws, machetes, axes, scythe, loppers),
- Herbaceous vegetation cutting using string trimmers,
- Small woody and herbaceous vegetation cutting using brush saws
- Grubbing up roots with heavy equipment,
- Hand pulling,
- Burning, and
- Animal grazing.

Vegetation management methods that were considered for long-term maintenance were assessed within the structure of an Integrated Vegetation Management (IVM) program approach. IVM is proven as an environmentally sound management approach especially for sensitive sites as are found at Nan Madol. An applicable definition of IVM can be found within the American National Standards Institute (ANSI) A300 (Part 7) – 2018 Standard Practices – Integrated Vegetation Management a. Utility Rights-of-Way that describes “A system of managing plant communities in which compatible and incompatible vegetation is identified, action thresholds are considered, control methods are evaluated, and selected control(s) are implemented to achieve a specific objective. Choice of control methods is based on effectiveness, environmental impact, site characteristics, safety, security and economics.”

In conformance with this definition and approach as applied to the Nan Madol site, AG followed basic steps that are generally outlined with the ANSI Standard in developing a recommended IVM program to manage vegetation after initial clearing is complete. These steps are as follows:

1. Identify the purpose and goal of the IVM program on the site.
2. Establish plans and objectives to establish and maintain the desired site condition.
3. Set tolerance levels and action thresholds for vegetation condition. Tolerance levels are the vegetation conditions that are acceptable and do not unreasonably impact site goals, function and utilization. Action thresholds are vegetation conditions (height and/or density) that trigger action to achieve management objectives. Thresholds consider safety, visual and physical access, site function, appearance, efficacy of control, and economy of management.
4. Identify reasonable management methods, considering biological, manual, mechanical, cultural and chemical. These methods include:
a. Biological: Use of insects, pathogens, competitive plants or animals to control undesirable vegetation establishment or growth.
b. Manual: Use of hand or hand-operated tools to physically remove or manage undesirable vegetation growth.
c. Mechanical: Use of engine-powered tools in a generally non-selective manner to manage undesirable vegetation growth.
d. Cultural: Establish desirable ground covers that prevent, inhibit or manage the establishment or growth of undesirable vegetation.
e. Chemical: Use of herbicides or other compounds (e.g. salt, acetic acid, borax) to control the establishment or growth of undesirable vegetation.

5. Monitor and evaluate site conditions to determine when thresholds are reached.
6. When thresholds are reached, prepare and document prescriptions and application specifications for each of the control methods that are determined suitable for use on the site.
7. Conduct work in conformance with the specification.
8. Monitor application and evaluate results to determine treatment effectiveness. Adjust treatment, including re-treatment if required, to achieve control goals.

3.0 Findings and Conclusions

AG’s general findings are that the canal, and subject stone and coral platforms are being overrun and dominated by various native tree species, naturalized vines and ground covers that are taking advantage of the structures and site conditions to establish and thrive. A significant portion of the canal and Nandowas have been maintained such that they are relatively open and generally accessible visually and physically throughout most of these sites.

Mangrove species were observed to be the primary invasive, damaging tree species growing upon, infiltrating within and obscuring visibility of the platforms and secondary structures throughout the site. In many areas where they were observed to be growing in high density, the roots and expanding trunks of mangrove trees appeared to be separating and dislodging the stones forming the platform structures. Unless it is controlled, this action May destroy the exterior foundation of these platforms as well as disrupt the interior foundation and secondary structures within the platforms.

Through its heavy rooting network, mangrove naturally serves to collect and retain sediments that pass through the system. This function is well documented throughout the range of this plant and significant siltation and expansion of a land mass is a characteristic result of encroachment of this species in many areas. Sedimentation through mangrove encroachment appears to have degraded and obstructed the canal surrounding Pahnkedira where sections of the waterway are impassable due to heavy mangrove encroachment and excessive sedimentation. It is projected that obstruction of access throughout the canal system through heavy vegetation growth and sedimentation is a significant risk if mangrove is permitted to establish and thrive within the canal area.
Evidence provided through reports and photographs show various platforms and canals cleared of vegetation in the early 1960s through early 1980s (Vegetation History in Nan Madol). However, the lack of regular vegetation management on most of the platforms has resulted in the relatively rapid re-establishment of undesirable, invasive vegetation that have grown into dense thickets that are difficult to access visually and physically.

Significant findings and conclusions are organized according to the unique site as follows:

3.1 Canal System
A canal system traverses through the approximate middle of the site from the north at Peiniot in a southwest to west direction exiting in the bay at Pohnkeimw. This canal system is reported to have been the major transport route through the city when it was active. It is also reported to have provided a conduit for the flow of fresh water from the watershed on Temwen Island throughout the city, serving as an important resource for residents during its occupancy.

The canal system is of variable width, estimated to be greater than 25 meters wide in some areas and approximately five meters wide in other areas. It was observed to have a shallow, relatively flat, naturally sandy bottom that was of variable depth, but estimated to be approximately 60 centimeters at mid tide through much of the area. Tide ranges appear to vary from low to high peaks by approximately one meter.

The canal was reasonably navigable to shallow-draft boats relative to mangrove clearance from Peiniot through to the area between Peikapw and Pahnkedira where siltation and mangrove encroachment blocked canal navigation. This siltation and mangrove canal obstruction was observed from that point through to what AG estimated was the area near to the Peinpwe islet. Land-based inspections conducted from remote vantage points indicated that the canal was relatively open from the area near to the Peinpwe islet to the bay past Pohnkeimw. AG was able to access the area at Peinmet and observed that the canal appeared to be relatively open and navigable from Peinpwe through and beyond Pohnkeimw.

Mangrove species were observed encroaching along the edges of the canals throughout the site. The primary mangrove species that were encroaching into the canal and observed on and within platform walls were identified as Rhizophora apiculata, Sonneratia alba, and likely Rhizophora hybrids.

*R. apiculata*, Pohnpeian name of akapa, is native to Micronesia. It is capable of growing to 20 meters in height with diameters exceeding 12 inches. It is ranked as a species of Least Concern on the IUCN Red List of Threatened Species.

*Sonneratia alba*, Pohnpeian name of koatoa, is native to Micronesia. It is capable of growing to over 20 meters in height with diameters exceeding 12 inches. It sends up many pneumatophores that typically range in height of 30 to 100 cm tall. It is ranked as a species of Least Concern on the IUCN Red List of Threatened Species.
Representative views of the general vegetation condition of the canal during this inspection are following:

View from Pohn Mwudok

View from South of Dau

View East of Usen Dau

View East of Peilapalap

View South of Dapahu

View North of Peitaup
3.2 Peinkitel
Peinkitel is an approximately 48 x 130-meter platform built on Temwen Island. There is some discrepancy on the size of this platform with another source sizing it at 63 x 143-meters. However, this will not impact the vegetation management assessment or recommendation. This platform is primarily on land that extends into a very wet and swampy area.
AG observed signs of path clearing for coconut harvesting on this site, but it is generally overgrown with invasive trees and herbaceous vegetation on the walls and especially in the wet areas.

The forest cover on this site is primarily nih (*Cocos nucifera*, English name: coconut palms), mahi (*Artocarpus altlis*, English name: breadfruit), kehma (*Terminalia spp.*, English name: kamani), akapa and keleu (*Hibiscus tiliaceous*, English name: hibiscus). The site has a somewhat open floor within the first approximately 30 meters from the access footpath and within the nih stand. Where the wall was inspected on dry land, a number of large tree species, including mahi and kehma, had become established and appeared to be destroying the wall. The site floor was covered with herbaceous and vine growth. Vines were observed growing up and into trees. As the site dropped into the swamp to its west, keleu and akapa became dominant. Approximately 30 meters from the access footpath and down into the swamp area, the site becomes very difficult to traverse due to exceptionally dense vegetation and unstable ground.
3.3 Nandowas

Nandowas is a 50 x 50-meter islet constructed of long, naturally pentagonal-shaped columns of basalt over a foundation of large basalt boulders. It includes two, walled enclosures. A large stone burial vault is in the center of the interior enclosure. Two stone burial vaults are found in the first interior enclosure on the north and south sides. Various stone pathways, stairs and deteriorating walls are found throughout both interior enclosures. Large trees have been planted or naturalized within both interior enclosures.

Nandowas is a managed site that is being overgrown at the time of this inspection by vines and herbaceous vegetation in sections of the walls and within much of the interior courtyards. A number of various-sized trees, including some large specimens, are growing both outside and within the enclosures. In some instances, the larger trees are in decline and dropping large branches and/or are damaging platform structures through root and trunk growth. These trees show signs of storm damage and/or inadequate or incorrect management that has resulted in their poor health and structural condition such that most of these trees are a current or future detriment to this site. Inadequate management includes the planting of mahi where this large-growing tree can damage structures and/or improper structural and maintenance pruning that has resulted in decay and/or unstable architecture that increases the risk of whole tree or tree part failure and damage or injury, and neglect of invasive vines and vegetation throughout much of the ground and walls.

Platform and Exterior of Outer Enclosure: The vegetation on the platform outside the walls appears to be maintained. However, the exterior walls are significantly overgrown with vegetation including invasive vines. This growth will continue to grow to obstruct more of the visual and physical access to the walls for inspection, maintenance and repair, and may cause damage as it grows larger.

- Front, West Side: There are two nih growing in the front of Nandowas. These palms are close to the wall, but do not appear to be causing any damage to the site. Vines are beginning to encroach on the top of the wall and herbaceous vegetation is establishing throughout the wall structure. This growth will continue to advance and obstruct visual and physical access to the walls for inspection, maintenance and repair, and may cause damage as it grows larger.
• North Side: There are two, small nih growing close to the wall that do not appear to be causing any damage at the time of this inspection. A large tintin (*Heliotropium foertherianum*, English name: heliotrope) is growing on the northwest corner very close to the wall.

![North Wall Vines and Nih](image1.png) ![North Wall Tintin](image2.png)

• East Side: The wall is significantly overgrown with vegetation including invasive vines. This growth will continue to obstruct visual and physical access to the walls for inspection, maintenance and repair, and may cause damage as it grows larger.

• South Side: The wall is significantly overgrown with vegetation including invasive vines and small trees. This growth will continue to obstruct visual and physical access to the walls for inspection, maintenance and repair, and may cause damage as it grows larger. A small mahi is growing off the southeast corner of the platform. It is not causing any structural damage at this time, but is not located in a sustainable location and as it grows larger it is expected to damage the structure and/or fall in strong winds.

![East Wall – Vines](image3.png) ![South Wall – Vines and Mahi](image4.png)

**Interior of Outer Enclosure:** A mixture of tree species of various sizes was observed inside this outer enclosure wall. Large mahi, kehma, nih and weipuul (*Morinda citrifolia*, English name: noni) were observed throughout. The large mahi are generally in decline with significant damage and decay in the tops from heavy winds. The large mahi and kehma that are near to the walls are beginning to cause damage to

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the structure. The weipuul is not a large tree and will likely not create a conflict with the structure. However, these trees are in very poor structural condition due to past removal of their tops and the unmanaged regrowth such that they pose a risk to people within the fall zone. The nih are located such and possess a growth pattern that should not interfere with the structure in the near future.

A heavy, vegetative ground cover was observed throughout the site as well as significant growth of invasive vines and vegetation on the interior of the walls. This growth will continue to advance and obstruct visual and physical access to the site and walls interfering with tourism, inspection, maintenance and repair, and may cause damage as it grows larger.

Large Mahi and Kehma

Large Mahi

Mahi, Kehma and Weipuul Trees North
Interior of Second Enclosure: A mixture of tree species of various sizes was observed inside this second enclosure wall and surrounding the large burial vault in the center. Large mahi, kehma and nih were observed throughout. The large mahi and some of the kehma that are near to the walls are beginning to cause damage to the structure. A kehma near the burial vault possesses a poorly structured double trunk that is susceptible to failure that will increase in risk as this tree gets larger. All but one of the nih are located such and possess a growth pattern that should not interfere with the structure in the near future. One of the nih is growing upon the riser on the north corner near to the burial vault and is damaging the structure.

A vegetative ground cover was observed throughout the site as well as some growth of invasive vegetation on the interior of the walls. This growth should continue to advance and obstruct visual and physical access to the site and walls for tourism, inspection, maintenance and repair, and may cause damage as it grows larger.
3.4 Idehd
This is a small islet, reported to be 42 X 30 meters, located across from Peikpw. It is surrounded by a deteriorating foundation wall and filled with coral and basalt rock. A path bordered with basalt columns extends from the channel for a short distance inward.

Mangrove significantly infiltrates and obstructs the platform foundation along the canal. An opening in the mangrove along the canal provides access to the path. The area around the footpath in the center of the platform is sparsely populated with encroaching vegetation. The remainder of the platform that could be viewed at this time includes variable density of mangrove, a few nih, with some pone (*Thespesia populnea*, English name: portia tree or milo). These small trees averaged approximately 10 to 20 feet in height with diameter observed primarily to be less than two inches to approximately 12 inches.
3.5 Peikapw

Peikapw is approximately 105 x 115 meters. Where accessed, this platform was found to be generally dry with a ground surface of rock and coral. Where accessed, the forest cover on this site was primarily small akapa with some kehma and other species scattered throughout. Larger trees were observed within the site. Where accessed, the site has a relatively open floor due to the dense overstory of trees that restrict light to the ground. Areas of high-density understory were observed where openings in the forest canopy were found. Where the wall was viewed, a number of large tree species, including akapa, keleu, pone and ikoik (*Cordia subcordata*, English name: Hawaiian kou or sea trumpet) were established and appeared to be beginning to impact the wall. Vines were observed growing up and into trees in some locations. A large pwulok (*Xylocarpus granatum*, English name: cannonball tree) was observed growing along the southwest wall.
Forest Stand with Dense Growth at Openings

3.6 Pahnkedira

Pahnkedira is approximately 145 meters along the long, east-west edge x 115 meters along the long, north-south edge. Where accessed, this platform was found to be generally dry with a ground surface of rock and coral.

The forest cover on this site is primarily nih in the southeast half with keleu scattered throughout. It appeared that most of the northeast and northwest half was primarily keleu with the entire perimeter along the southwest and canal dominated by akapa.
The site has a somewhat open floor throughout the northwestern half due to the dense overstory of trees that restrict light to the ground. However, areas of dense keleu restrict access as do heavy undergrowth where holes in the canopy permit light to reach the forest floor. Where the wall was viewed, a number of large tree species, including akapa and keleu were becoming established and were beginning to impact the wall. Vines were observed growing up and into trees in some locations.
3.7 Watershed on Temwen Island

The watershed appears to begin in the area between Temwen Nanwei Road and Lehiak Road and extends downslope approximately 800 meters through the valley to empty into the Nan Madol site in the area between Pedenieng and Sapwenleng platforms. Where accessed, the upper and midlevel of the watershed was found to have very steep, vegetated slopes on the southwest side that dropped into the bottom drainage area where standing water and swampy areas were encountered. Cultivated taro patches were observed in the upper and midlevel areas. LIDAR indicates that the opposite side of the watershed also possesses very steep slopes.

Watershed Location: CSRM Foundation LIDAR Survey Map

Upper Watershed area, where accessed, was found to possess primarily nih and keleu. The stand was generally composed of trees scattered in clumps. Keleu was approximately six inches and greater in diameter and approximately 25 feet tall. Vines were growing up and over small trees. The ground was very swampy with taro patches found within the area.
Mid-Level Watershed area, where accessed, was found to densely vegetated primarily by keleu with kehma scattered throughout. Keleu was approximately two inches and greater in diameter and approximately 20 to 30 feet tall. Kehma was approximately two to eight inches in diameter and approximately 30 feet tall. The ground was very swampy. Signs of significant pig rooting along the banks of the wet area were observed.

Lower Watershed area, where accessed, was found to be densely vegetated primarily by keleu with areas of large akapa. Keleu was approximately two inches and greater in diameter and approximately 15 to 30 feet tall. Akapa was observed over 10 inches in diameter and up to approximately 50 feet tall in some instances. The ground area that was accessible was relatively dry and was observed to transition into a more swampy ground as it approached the canal.
3.8 Vegetation Removal Methods for Initial Clearing

Various vegetation removal methods for initial clearing were considered with AG’s findings and conclusions as follows:

3.8.1 Tree felling using chainsaws is a practical and appropriate method to cost-effectively remove trees to a low stump and process large (> eight-inch diameter) and medium-sized trees (> two-inch diameter). Removal should be accomplished using standard tree felling, limbing and bucking techniques. Cut debris will require handling and transport to a disposal site.

3.8.2 Tree felling in parts using rope access is a practical and appropriate method to most safely remove trees to a low stump and process large (> eight-inch diameter) trees that cannot be felled from the base due to obstacles or hazards that could endanger people or damage site structures. Removal can be conducted using standard rope access tree climbing with arborist fall protection equipment, and rigging tree parts with ropes and equipment trees. Cut debris will require handling and transport to a disposal site.

3.8.3 Mowing with machines that employ flail-type mowers mounted on articulated booms may be a practical and cost-effective method for cutting and mulching small trees (< four inches diameter) and vegetation at the dry-land portions of Peinkitel or other land-accessible sites, but are not likely a practical method to be applied to manage vegetation on the sites that are surrounded by waterways and swamp. Accessing most sites in swamp would require swamp mats and significant disruption along access routes. The structure of the platform may be damaged by the machines and stone and large rocks that comprise these structures would hinder mowing operations.

Cut debris are generally chopped by the mower head into small pieces and scattered on the site as a low, mulch ground cover that will quickly bio-degrade. No handling or transport of cutting debris is required.

3.8.4 Small tree and vegetation felling using manual hand tools (hand saws, machetes, axes, loppers) is a practical and appropriate method to most safely
remove trees and vegetation to a low level and process small (< two-inch diameter) trees and vegetation. Removal should be accomplished by cutting the target tree or vegetation as low to the ground as possible and parallel to any slope. The stump of woody vegetation must be left flat to minimize the risk of tripping and impaling by a sharp, protruding stump. Cut debris will require handling and transport to a disposal site.

3.8.5 **Herbaceous vegetation cutting using powered string trimmers** is a practical and appropriate method to most safely remove non-woody (herbaceous) vegetation. String trimmers are powered by gasoline or battery-operated engines and use a spinning head at the bottom of a long shaft. The head uses a rapidly spinning monofilament string that uses centrifugal force to cut through herbaceous vegetation easily and efficiently. Removal of herbaceous vegetation with powered string trimmers will permit fast removal of the top of target vegetation close to the ground level without damaging site structures. This technique will not control the root system of treated vegetation resulting in relatively fast regrowth for most species and regular re-treatment. Cut debris is generally chopped by the string trimmer into small pieces and scattered on the site as a low, much ground cover that will quickly bio-degrade. No handling or transport to a disposal site is usually required.

3.8.6 **Small woody and herbaceous vegetation cutting using brush saws** is a practical and appropriate method to most safely remove small (< two-inch diameter) woody and dense, heavy-stemmed (e.g. clumping and large grasses) herbaceous vegetation. Brush saws are powered by gasoline engines and use a rapidly spinning blade or cutting wheel head at the bottom of a long shaft to cut through small woody and herbaceous vegetation easily and efficiently. Removal of target vegetation with brush saws will permit fast removal of the top of target vegetation close to the ground level. This technique will not control the root system of cut vegetation resulting in relatively fast regrowth for most species and regular re-treatment. Cut debris will require handling and transport to a disposal site.

3.8.7 **Grubbing up roots with heavy equipment** is not likely a practical method to be applied to manage vegetation on these sites. Although grubbing up vegetation by the roots is very effective at removing the entire target plant and minimizing regrowth, it is very disruptive and sometimes damaging to a site due to the requirement for heavy equipment and the damage to the substrate caused by the uprooting operation. The stone and coral platforms are not considered appropriate sites for application of this equipment.

3.8.8 **Hand pulling** of early establishing mangrove sprouts and small, very low-density, undesirable vegetation is a practical and appropriate method to most safely and effectively remove small plants that are not well established in the substrate. This method is labor intensive, but effectively removes target vegetation.
vegetation and eliminates the risk of regrowth of that individual. Skill levels and safety risk of this method are low permitting easy procurement of a diverse labor force.

3.8.9 Burning is not likely a practical method to be applied to manage vegetation on these sites as it would likely not be effective on target vegetation. Burning effectively removes the top of small vegetation and disposes debris through incineration. However, AG does not believe that site and vegetation conditions are appropriate or conducive to this control method. Burning also requires public, fire management and regulatory considerations that result in application challenges that would likely render this method difficult if not impossible on this site. Burning may be practical to dispose of piles of cutting debris.

3.8.10 Animal grazing is not likely to be a practical and cost-effective method for removing target vegetation within these sites. Grazing effectively removes the top of small vegetation, but animals do not control the root systems and target plants rapidly resprout. Due to the terrain and vegetation conditions, goats would likely be the best option, but would require regular management and restriction to avoid them from leaving a site. Goats would effectively remove and dispose herbaceous and small woody vegetation, and may girdle larger trees by eating the lower bark. However, the rocky terrain, walls and other obstacles on-site may restrict their movement and effectiveness. Further, dropping of wastes by animals may create other management problems on these sites.

3.9 Vegetation Methods for Long-term Maintenance
Various vegetation control methods for long-term maintenance and management were considered within the scope of an IVM program. AG’s findings and conclusions on each of the IVM considerations for the Nan Madol site are as follows:

3.9.1 Identify the purpose and goal of the IVM program on the site: AG understands that the purpose and goal of this vegetation management program is to safely, cost-effectively and in an environmentally sound manner, remove and then manage and control undesirable, invasive trees and vegetation that damage or are capable of damaging the facilities and obstruct physical and visual access for tourism, inspection, maintenance and repair of the general site and structures.

3.9.2 Develop plans and objectives to establish and maintain the desired site condition: AG understands that its recommendations will provide and document a management plan that includes recommended methods to maintain the desired navigable portions of the canal, foundation walls of the platforms and designated areas within the platforms free of obstructive and damaging trees and vegetation. Further, this plan should provide for establishment and maintenance of a sustainable community of desirable tree
species within designated areas to enhance cultural practices of the residents, educational opportunities for Pohnpeians and visitors, and facilitate tourism through conformance with the guidance of the World Heritage Committee to recover and maintain Nan Madol’s “integrity and authenticity” insofar as it has been adversely impacted by vegetation.

3.9.3 Set tolerance levels and action thresholds for vegetation condition: AG’s extensive experience with IVM program design and management find that establishing and conforming with reasonable, technically supportable tolerance levels for acceptable vegetation conditions are critical to support a successful IVM program. Action thresholds should be set as appropriate for each site that will trigger conduct of the most cost-effective, safe and environmentally sound vegetation management method in a timely period.

3.9.4 Identify reasonable management methods: AG has reviewed and considered various management methods including biological, manual, mechanical, cultural and chemical. AG finds that the following management methods are most appropriate to be considered to most safely, cost-effectively and in an environmentally sound manner meet management objectives:

- **Biological:** The use of insects, pathogens or animals to control undesirable vegetation is not currently practical on this site due to various challenges that include efficacy, cost and management.

- **Manual:** Use of hand or hand-operated tools to physically remove or manage undesirable vegetation growth can be accomplished through hand pulling of small plants that are not strongly attached to the substrate, use of secateurs or loppers to clip off the above-ground portion of small, woody plants, or the use of secateurs, handsaws or chainsaws to prune trees that are retained or planted in conformance with the management plan to maintain a compatible height and architecture.

- **Mechanical:** Use of small, engine-powered tools, such as string trimmers and brush saws, in a generally non-selective manner to manage undesirable vegetation growth. Larger mowing equipment will not meet project goals or restrictions due to their size and potential site impacts except possibly within sites on Temwen Island where this equipment can easily and cost-effectively access and conduct treatments.

- **Cultural:** Establishing desirable ground covers that prevent, inhibit or manage the establishment or growth of undesirable vegetation may be compatible in certain applications. For example, where excavation and reconstruction of platforms is conducted, installation of a geo-textile material beneath the substrate to prevent vegetation establishment could be conducted. Other cultural methods, such as cultivation of crops that would manage undesirable plants or alternate land uses are not compatible with site goals at this time.
• Chemical: Use of herbicides or other compounds (e.g. salt, acetic acid, borax) to control the establishment or growth of undesirable vegetation should be compatible and effective for vegetation management on this site. The use of hand applicators to selectively and judiciously apply carefully selected herbicide solutions to target vegetation in conformance with manufacturer’s directions, industry standards and practices has been demonstrated to most cost-effectively, safely and environmentally soundly manage undesirable vegetation.

3.9.5 Monitor and evaluate site conditions to determine when thresholds are reached: AG’s extensive experience with IVM program design and management finds that regular, competent and diligent monitoring of site conditions to identify changes and threshold conditions in a timely manner is critical to support a successful IVM program.

3.9.6 When thresholds are reached, prepare and document prescriptions and application specifications for each of the control methods: AG’s extensive experience with IVM program design and management finds that preparing technically appropriate prescription and specification documents that actively guide the control method for the site are critical to support a successful IVM program.

3.9.7 Conduct work in conformance with the specification: AG’s extensive experience with IVM program management finds that conformance with the treatment specifications applicable for the site and control method must be followed by application personnel to ensure application efficacy, safety and environmental protection.

3.9.8 Monitor application and evaluate results to determine treatment effectiveness: AG’s extensive experience with IVM program management finds that follow-up inspections and assessments during treatment and of treatment efficacy afterwards are critical to ensure satisfactory application and control.

3.10 Disposal of Cutting Debris: The debris resulting from tree and vegetation management must be properly disposed after cutting. Some species can regenerate from cuttings increasing tree management challenges, but generally tree cutting debris only create an unsightly, obstructive or otherwise objectionable element on a site. The challenge in Nan Madol is that:

- Disposal on the platforms may be restricted due to the magnitude of debris generated during initial clearing and the visual obstruction resulting; and
- Physical access of equipment to deposit and transport debris is very restricted by site conditions.

Common alternatives for cutting debris disposal include:

- Cut into small pieces and scatter on the site;
- Cut into pieces and windrow debris into small piles on the site;
Piling and burning on-site;
Transport the cutting materials off-site to be disposed by:
  o Chipping (AG understands that chippers are available);
  o Piling on another, approved site;
  o Dumping at a sanctioned green waste dump.

4.0 Recommendations

Based on AG’s findings and conclusions as described above, the following recommendations are offered:

4.1 Establish Nan Madol’s vegetation management purpose and goal for its IVM program as follows:
This vegetation management program should be designed and implemented in conformance with IVM standards and practices to remove and then manage and control undesirable, invasive trees and target vegetation as safely and cost-effectively as practical, and in an environmentally sound manner. Undesirable, invasive trees and target vegetation are defined as those that damage or are capable of damaging the structures and/or obstructing physical and visual access for tourism, inspection, maintenance and repair of the general site and structures.

4.2 Tolerance levels and action thresholds for vegetation condition should be established as follows:
- No obstructive or potentially damaging vegetation shall be permitted to establish and thrive on or encroaching upon the platform foundation.
- No woody vegetation shall be permitted to establish and thrive within the managed platform sites except for specified, managed trees that provide cultural, educational or protective shade.
- Herbaceous groundcovers that are approved within the site plan shall be maintained as designated and such that they do not unreasonably interfere or inhibit visual or physical access, maintenance, repair or aesthetics.

Action thresholds should be set as follows, but may be modified with cause and demonstrated technical justification based on enhanced safety, cost-effectiveness and environmental impacts:
- All woody vegetation observed to be establishing on platform foundations or within the platform that is not designated as a retained, managed tree shall be removed before they grow to a height of one meter.
- A management plan shall be developed and followed for all managed tree species that are permitted to be retained within the platform. This management plan shall establish the desired and maximum height and crown spread for each protected tree. An inspection and management cycle shall be established for each designated tree that will enable short and long-term management of that tree according to maintain its desired size and condition cost-effectively and arboriculturally correctly.
• A management plan shall be developed and followed that establishes an appropriate height for all herbaceous groundcovers, including a threshold height where maintenance shall be conducted. Various groundcover species possess various optimum heights and these heights shall be established and maintained as appropriate for that species.

4.3 Removal Methods

4.3.1 Develop a Tree Retention and Replacement Program:
Identify tree species that are desirable to be planted on the platforms that will provide shade, cultural, historical and/or educational opportunities, or other approved and compatible uses of these sites. Develop a plan to place these trees on the platform at a strategic location to provide the desired function(s) without damaging the structure over the long-term.

• Develop a plan to procure and install these trees on these sites as soon as practical, coordinated with the undesirable tree removal program. All tree selection, installation and structural pruning prescriptions and work should only be conducted by or under the direct supervision of qualified arborists with demonstrated knowledge and skill to successfully conduct this work.

In conjunction with the selection and siting of desirable trees described above, identify and clearly mark trees that are currently thriving, possess strong architecture, are strategically located to provide desired amenity values, and will not damage the structure. These trees should be retained and managed over the short or long-term to provide shade, cultural, historical and/or educational opportunities within the site. As more desirable trees establish and grow it may be designed and/or desired to remove these retained trees.

• Develop a plan to prune and structure these retained trees to commence as soon as practical. All pruning prescriptions and work should only be conducted by or under the direct supervision of qualified arborists with demonstrated knowledge and skill to successfully conduct this work.

4.3.2 Akapa Removal: Initial removal of established akapa should be conducted as follows:

• Using a hand-lopper tool capable of pruning woody stems of two inches diameter, cut akapa prop roots as close to the substrate level (sand, soil or rocks/coral) and then remove the root by cutting it as high up as safely practical to separate it from the subject tree. Handsaws should be available to support this removal.

• Using chain saws, remove larger roots and fell the remaining tree. To ensure safe operations with chainsaws and tree felling and processing (limbing and bucking), it is critical that all workers who handle, operate and maintain chainsaws and conduct any phase of tree
felling and processing be qualified through training and demonstrated proficiency in the standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017 and recognized industry standards and practices.

4.3.3 **Keleu, Kehma, Mahi and Other Undesirable Tree Species Removal**: Initial removal of established, undesirable trees species should be conducted as follows:

- Identify a program of progressive removal of these undesirable trees without creating unfavorable conditions on the site, such as excessive heat from loss of shade.
- Removal of all undesirable trees should be conducted over a period of two to three years, or other approved time frame, in concert with the replacement and retention program described above to minimize adverse impacts resulting from removal of the current tree overstory.
- Target trees that can be safely and practically felled from the ground without causing damage to structures should be removed using chain saws and correct tree felling and processing standards and practices. Hand saws should be available to support this removal.
  - To ensure safe operations with chainsaws and tree felling and processing, it is critical that all workers who handle, operate and maintain chainsaws and conduct any phase of tree felling and processing be qualified through training and demonstrated proficiency in the standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017 and recognized industry standards and practices.
  - Where these trees are on dry ground, stumps should be cut as low as practical, parallel to the ground level.
  - Where these trees are in standing water that are not open water (such as the watershed stream, canal, bay, or estuary) or a ditch used to transport irrigation water or is located such that runoff or irrigation water may flow onto agricultural land, stumps should be cut so that the cut portion is flat and remains approximately six inches above the projected high tide water level.
  - If these trees are in standing water that is open or an irrigation ditch or is located such that runoff or irrigation water may flow onto agricultural land, stumps should be cut as close to the substrate level (sand, soil or rocks/coral) as safely practical so that the cut portion is flat and minimizes the risk of tripping and impalement.
- Target trees that cannot be safely and practically felled from the ground without causing damage to structures should be removed through rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
o To ensure reasonably low risk and effective tree climbing, rigging and chainsaw operations, it is critical that all workers who conduct any phase of this work be qualified through training and demonstrated proficiency in the applicable standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017 and recognized industry standards and practices.

- Where permitted according to label directions, whenever trees are felled that are capable of resprouting, use a paint brush applicator to apply a solution of seed oil with the ester formulation of the herbicide triclopyr (e.g. Garlon 4). The mix should be 80% seed oil and 20% triclopyr ester. The herbicide solution should be carefully painted onto the freshly cut surface of the stump to achieve complete coverage of the cambium and phloem of the cut surface of the tree stump with small amounts of solution permitted to run down the side of the stump.

4.3.4 Vine and Herbaceous Vegetation Removal: Using hand-pump backpack applicators and depending on the species of undesirable plants requiring control, selectively apply a water-based solution of herbicide to the target plants. The herbicide solution must be applied in conformance with label directions at a low volume and rate such that it minimizes the risk of off-target movement of significant amounts of the solution. Herbicide shall be specified based on its efficacy on the target plants and based on credible research demonstrating their human safety, relatively fast degradation in the environment and low level of movement in the soil when properly applied. Herbicides with active ingredients recommended by AG include, but are not limited to various combinations and solutions of glyphosate, metsulfuron methyl, sulfometuron-methyl, triclopyr and imazapyr. Actual solutions should be prescribed based on target and non-target vegetation conditions.

4.3.5 Vine and Herbaceous Vegetation Removal – Herbicide Use Not Permitted: Where herbicide use is not permitted by label directions or will interfere with site management goals or objectives (primarily aesthetic), powered string trimmers may be used to cut vine and herbaceous vegetation.

To ensure safe operations with string trimmers, it is critical that all workers who conduct any phase of this work be qualified through training and demonstrated proficiency in the applicable standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017, the manufacturer’s operation instructions, and recognized industry standards and practices.
4.3.6 Peinkitel and Other Land-Accessible Sites: If flail-type mowers mounted on articulated booms are available, it is recommended that sites on Temwen Island with dense populations of small trees (<four-inch diameter), vines, woody and herbaceous vegetation that are desired to be removed consider these mowers.

The footpath to Peinkitel and access to other sites would require modification to provide access for a small mowing machine. Cut debris is generally chopped by the mower head into small pieces and scattered on the site as a low, mulching ground cover that will quickly bio-degrade. No handling or transport to a disposal site is required.

To ensure safe operations with this equipment, it is critical that all workers who conduct any phase of this work be qualified through training and demonstrated proficiency in the applicable standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017, the manufacturer’s operation instructions, and recognized industry standards and practices.

4.3.7 Nandowas Large Tree Management: The large broad-leaved trees (mahi, kehma, weipuul and tintin) at Nandowas should all be removed and replaced over the next five to ten years due to their poor structure and/or current and future damage to the structure. One of the nih, within the central enclosure that is damaging the structure, and two small nih on the north, exterior wall, should be removed within the next two to three years.

To ensure safe operations using rope access tree climbing, rigging, chainsaws and tree felling and processing, it is critical that all workers who conduct any phase of tree felling and processing be qualified through training and demonstrated proficiency in the standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017, the manufacturer’s operation instructions, and recognized industry standards and practices.

Platform and Exterior of Outer Enclosure:
- Remove the Tintin in the northeast corner within the next one year. This tree can be felled from the ground using standard tree felling practices.
- Remove the two nih along the north wall within the next two years. These trees can be felled from the ground using standard tree felling practices.
- Remove the mahi in the southwest corner within the next two years. This tree can be felled from the ground using standard tree felling practices.
• Remove the small trees that are establishing within the wall structure. These trees can be cut with loppers or hand saws.
• Using a paint brush, hand-pump backpack applicator or squirt-bottle applicator, selectively apply a solution of seed oil with the ester formulation of the herbicide triclopyr (e.g. Garlon 4) to the freshly cut stumps of these plants. The mix should be 80% seed oil and 20% triclopyr ester. The herbicide solution must be applied in conformance with label directions at a low volume and rate such that it minimizes the risk of off-target movement of significant amounts of the solution. The herbicide solution should be carefully applied onto the freshly cut surface of the stump to achieve complete coverage of the cambium and phloem of the cut surface of the tree stump with small amounts of solution permitted to run down the side of the stump.
• Using a hand-pump backpack applicator, selectively apply a water-based solution of herbicide to the target plants growing on the wall. Herbicide solutions recommended for this application should include a mix that contains active ingredients of glyphosate, sulfometuron-methyl and triclopyr with a surfactant added. The herbicide solution must be applied in conformance with label directions at a low volume and rate such that it minimizes the risk of off-target movement of significant amounts of the solution.

Interior of the Outer Enclosure:
• Remove the large mahi trees that possess dead and broken tops, within the next one year. Removal should be conducted using rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
• Remove the large kehma tree near the front entrance that is in contact with the wall within the next one year. Removal should be conducted using rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
• Remove the multi-stem trees on the north and south sides of this area, within the next one year. Removal should be conducted using rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
• Conduct crown reduction pruning on the remaining trees throughout this area within the next one year to reduce weight and risk of whole tree or large tree part failure. All pruning work should be conducted using rope access climbing and rigging methods using hand saws, chainsaws and correct tree pruning and rigging standards and practices. All pruning work should be conducted by or under the direct supervision of qualified arborists with demonstrated knowledge and skill to successfully conduct this work and in conformance with the most recent version of the ANSI A300 (Part 1) Pruning Standard Practices.
• Identify tree species that are desirable to be planted on this site that will provide shade, cultural, historical and/or educational opportunities, or other approved and compatible uses of these sites. Develop a plan to place these trees on the platform at a strategic location to provide the desired function(s) without damaging the structure over the long-term.
  o Develop a plan to procure and install these trees on these sites as soon as practical, coordinated with the undesirable tree removal program. All tree selection, installation and structural pruning prescriptions and work should only be conducted by or under the direct supervision of qualified arborists with demonstrated knowledge and skill to successfully conduct this work.
• Using a hand-pump backpack applicator, selectively apply a water-based solution of herbicide to the target plants growing on the ground and wall within the next one year. Herbicide solutions recommended for this application should include a mix that contains the active ingredients of glyphosate, sulfometuron-methyl and triclopyr with a surfactant added. The herbicide solution must be applied in conformance with label directions at a low volume and rate such that it minimizes the risk of off-target movement of significant amounts of the solution.

**Interior of Second Enclosure:**
• Remove the large mahi and kehma trees that are growing against the western wall that are damaging that wall within the next one year. Removal should be conducted using rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
• Remove the double-stem kehma in front of the burial vault within the next one year. Removal should be conducted using rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
• Remove the nih in front of the burial vault that is damaging the structure within the next one year. Removal should be conducted using rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
• Conduct crown reduction pruning on the remaining trees throughout this area within the next one year to reduce weight and risk of whole tree or large tree part failure. All pruning work should be conducted using rope access climbing and rigging methods using hand saws, chainsaws and correct tree pruning and rigging standards and practices. All pruning work should be conducted by or under the direct supervision of qualified arborists with demonstrated knowledge and skill to successfully conduct this work and in
conformance with the most recent version of the ANSI A300 (Part 1) Pruning Standard Practices.

- Identify tree species that are desirable to be planted on this site that will provide shade, cultural, historical and/or educational opportunities, or other approved and compatible uses of these sites. Develop a plan to place these trees on the platform at a strategic location to provide the desired function(s) without damaging the structure over the long-term.
  - Develop a plan to procure and install these trees on these sites as soon as practical, coordinated with the undesirable tree removal program. All tree selection, installation and structural pruning prescriptions and work should only be conducted by or under the direct supervision of qualified arborists with demonstrated knowledge and skill to successfully conduct this work.

- Using a hand-pump backpack applicator, selectively apply a water-based solution of herbicide to the target plants growing on the ground and wall within the next one year. Herbicide solutions recommended for this application should include a mix that contains the active ingredients of glyphosate, sulfometuron-methyl and triclopyr with a surfactant added. The herbicide solution must be applied in conformance with label directions at a low volume and rate such that it minimizes the risk of off-target movement of significant amounts of the solution.

4.3.8 Watershed Management: Tree removal and recovery of the water flow within the watershed should be conducted as follows:

- Tree removal should be conducted over a period of two to three years, or other approved time frame, to adequately distribute costs, permit a more stable transition to the desired condition and minimize adverse impacts (e.g. erosion, rapid regrowth of invasive vegetation) resulting from large-scale removal of the current tree overstory.

- A corridor of approximately 20 meters in width should be cleared during each annual operation, starting in 2020, to clear the primary drainage area. Each year, an additional 20 meters of approximately 10 meters on each side of the primary drainage, should be cleared to widen the area until the optimum clearance is procured to restore and manage the desired drainage flow.

- Target trees that can be safely and practically felled from the ground should be removed using chain saws and correct tree felling and processing standards and practices. Hand saws should be available to support this removal.
  - To ensure safe operations with chainsaws and tree felling and processing, it is critical that all workers who handle, operate and maintain chainsaws and conduct any phase of tree felling and processing be qualified through training and demonstrated
proficiency in the standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017 and recognized industry standards and practices.

- Where these trees are on dry ground, stumps should be cut as low as practical, parallel to the ground level.
- Where these trees are in standing water that are not open water (such as the watershed stream, canal, bay, or estuary) or a ditch used to transport irrigation water or is located such that runoff or irrigation water may flow onto agricultural land, stumps should be cut so that the cut portion is flat and remains approximately six inches above the projected high tide water level.
- If these trees are in standing water that is open or an irrigation ditch or is located such that runoff or irrigation water may flow onto agricultural land, stumps should be cut as close to the substrate level (sand, soil or rocks/coral) as safely practical so that the cut portion is flat and minimizes the risk of tripping and impalement.

- Target trees that cannot be safely and practically felled from the ground should be removed through rope access climbing and rigging methods using chain saws and correct tree felling, rigging and processing standards and practices.
- To ensure reasonably low risk and effective tree climbing, rigging and chainsaw operations, it is critical that all workers who conduct any phase of this work be qualified through training and demonstrated proficiency in the applicable standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017 and recognized industry standards and practices.

- Where permitted according to label directions, whenever trees are felled that are capable of resprouting, use a paint brush applicator to apply a solution of seed oil with the ester formulation of the herbicide triclopyr (e.g. Garlon 4). The mix should be 80% seed oil and 20% triclopyr ester. The herbicide solution should be carefully painted onto the freshly cut surface of the stump to achieve complete coverage of the cambium and phloem portions of the cut surface of the tree stump with small amounts permitted to run down the side of the stump.

4.3.9 Disposal of Cutting Debris: The debris resulting from tree and vegetation management should be disposed in the most cost-effective and site-appropriate manner. Given restrictions on-site, AG recommends that:

- Wherever practical, cutting debris be cut and piled in small windrows on discrete locations within the platform. Debris should be cut into pieces to permit tight packing of piles that facilitate rapid decomposition. Piles should be restricted to rows no longer than 4
meters by one meter wide by 0.5 meters high.

- Where retention and disposal on-site is not practical, cutting debris should be deposited on small barges and transported to a nearby site to be chipped.

4.4 Long-Term Management Methods

4.4.1 Akapa Management: Maintaining designated sites clear of akapa establishment should be accomplished by ground crews that regularly traverse each site, identify akapa trees that are sprouting, hand-pull these plants and properly dispose. It is recommended that this monitoring be conducted on a three-month frequency that can be adjusted based on findings of establishment cycles of these species on this site.

4.4.2 Keleu, Kehma, Mahi and Other Tree Species Management: Maintaining designated sites clear of establishment of tree and other woody plants should be accomplished by ground crews that regularly traverse each site on a six-month basis, identify trees and woody plants that are sprouting and conducting a management method as appropriate for the condition and character of the target plant. Treatment methods can include:
- Hand-pulling and properly disposing plants that are not well-rooted and easy to extract; or
- Using secaters or loppers, clipping off the above-ground portion of the target plants and treating the remaining, freshly cut stump with an 80% seed oil and 20% triclopyr ester herbicide solution in conformance with label directions; or
- Using a hand-pump backpack applicator or squirt-bottle applicator, to selectively apply a water-based solution of herbicide in conformance with label directions to the target plants. The herbicide solution must be applied at a low volume and rate such that it minimizes the risk of off-target movement of significant amounts of the solution. The actual herbicide solution shall be prescribed based on the species of undesirable plants requiring control.

4.4.3 Vine and Herbaceous Vegetation Management: Using hand-pump backpack or squirt-bottle applicators, depending on the size of the plant and area of coverage required, selectively apply a water-based solution of herbicide to the target plants. The herbicide solution must be applied in conformance with label directions at a low volume and rate such that it minimizes the risk of off-target movement of significant amounts of the solution. Herbicide shall be specified based on its efficacy on the target plants and based on credible research demonstrating their human safety, relatively fast degradation in the environment and low level of movement in the soil when properly applied. Herbicides with active ingredients recommended by AG include, but are not limited to various combinations
and solutions of glyphosate, metsulfuron methyl, sulfometuron-methyl, triclopyr and imazapyr. Actual solutions should be prescribed based on target and non-target vegetation conditions.

4.4.4 Vine and Herbaceous Vegetation Management – Herbicide Use Not Permitted: Where herbicide use is not permitted by label directions or will interfere with site management goals or objectives (primarily aesthetic), powered string trimmers may be used to cut and maintain vine and herbaceous vegetation at the desired height.

To ensure safe operations with string trimmers, it is critical that all workers who conduct any phase of this work be qualified through training and demonstrated proficiency in the applicable standards and practices in conformance with the most current version of the American National Standard for Arboricultural Operations (ANSI) - Safety Requirements Z133-2017, the manufacturer’s operation instructions, and recognized industry standards and practices.

4.4.5 Management Pruning of Retained and Replacement Trees: Crown reduction pruning, where recommended, requires that subject trees be pruned to appropriately reduce the ends of branches and the tops of the trees as specified. Pruning cuts must be made in conformation to the most recent version of the ANSI A300 Pruning Standard. This reduction in the height of trees and/or ends of long branches should clear obstacles and obstructions, and has been demonstrated to significantly reduce the risk of whole tree or tree part failure. The primary advantage is that desirable subject trees that may be too tall, wide or otherwise in conflict with infrastructure or site safety can be retained and provide amenity values to the site.

Structural pruning of young, developing trees require that subject trees be pruned to promote strong and directional architecture consistent with the natural form of the subject tree, desired tree function and site restrictions. Pruning cuts must be made in conformance with the most recent version of the ANSI A300 Pruning Standard. Development of strong and appropriate architecture during tree development results in safer, more structurally sound trees that better provide the functional and amenity value desired as well as reduce future maintenance and safety risks.

Please contact Kevin K. Eckert at keckert@arborglobal.com with any questions regarding this inspection, assessment or recommendations.
Nan Madol Introductory Vegetation Management Training Program

Training Goal: Develop sustainable workforce and management team capable of safely, cost-effectively and technically correctly remove, manage and control trees and vegetation in diverse and sometimes difficult sites.

Training Objective: Provide active leaders and service providers with instruction and supervised practice in the standards, procedures, practices and processes required to successfully remove, control and manage trees and vegetation on this important site.

Training Modules: Arbor Global has identified eight (8) unique work types required to effectively remove, manage and control trees and vegetation at the Nan Madol site. These work types, their respective general training components, and recommended minimum tools, equipment and materials, are as follows:

1. Mangrove cutting/pulling: In waterways/canals
   - Trainee: Instructor Ratio (maximum): 12:1
   - Minimum Training Time Projected: 4 hours
   - Selection and care of tools: Personal Protective Equipment (PPE), Loppers, Machete, Hand saw, Chainsaw (separate class with specialized team)
   - Proper cutting technique
     - Small plants
       - (propagules and seedlings): hand pull
       - (<1.5” diameter): lopper/machete (careful not to leave punji sticks)
     - Moderate-sized plants (2” – 4” diameter): hand saw/machete (careful not to leave punji sticks)
     - Large plants (> 4” diameter):
       - Cut aerial roots at ground level with loppers, hand saw or machete (careful not to leave punji sticks)
       - Remove aerial roots as high as possible with loppers or hand saw
       - Remove large trunks (> 4” diameter): chainsaw

2. Brush cutting: dry land platforms
   - Trainee: Instructor Ratio (maximum): 12:1
   - Minimum Training Time Projected: 4 hours
   - Selection and care of tools: PPE, Loppers, Machete, Hand saw, Chainsaw (separate class with specialized team)
   - Proper cutting technique
     - Small plants (<1.5” diameter): lopper/machete (careful not to leave punji sticks)
     - Moderate-sized plants (2” – 4” diameter): hand saw/machete (careful not to leave punji sticks)
     - Large plants (> 4” diameter):
       - Cut aerial roots at ground level with loppers, hand saw or machete (careful not to leave punji sticks)
       - Remove aerial roots as high as possible with loppers or hand saw
       - Remove large trunks (> 4” diameter): chainsaw
3. **Herbicide treatments**
   - Trainee: Instructor Ratio (maximum): 8:1
   - Minimum Training Time Projected: 8 hrs
   - Selection and care of tools: PPE, Battery electric drill, Machete, Hand-squirt bottle, Hand-pump backpack applicator
   - Materials review: herbicides and adjuvants handling and mix
   - Treatment techniques:
     - Drill and treat (Habitat Aquatic Herbicide)
       - Moderate mangrove (4’ – 6” diameter) that can be left to die
     - Frill and treat (Habitat Aquatic Herbicide)
       - Large mangrove (> 6” diameter) that can be left to die
     - Cut surface treatment (Habitat Aquatic Herbicide or triclopyr/mineral oil)
       - Resprouting species (hibiscus, Terminalia, Thespesia, Cordia, other resprout species) that are cut
     - Low-volume foliar (glyphosate-triclopyr- Sulfometuron-methyl/Metsulfuron Methyl)
       - Small woody vegetation (<1/2” diameter), vines and herbaceous areas desired bare ground

**Pruning practices:**
   - Trainee: Instructor Ratio (maximum): 8:1
   - Minimum Training Time Projected: 8 hrs
   - Selection and care of tools: PPE, Hand saw (folding or 13” curved), Secateurs
   - Structural pruning of young trees
     - Selection and care of tools: Hand saw, Secateurs
     - Pruning techniques for young tree architecture: 5 steps to pruning
     - Materials: Small trees (4’ to 6’ tall)
   - Maintenance pruning of mature trees
     - Selection and care of tools: Hand saw, Secateurs, Pole pruner/saw
     - Pruning techniques for crown reduction
       - Lifting
       - Obstacle clearance
       - Crown cleaning

**Tree Climbing**
   - Trainee: Instructor Ratio (maximum): 4:1
   - Minimum Training Time Projected: 16 hrs
   - Selection and care of tools and equipment: PPE, Harness, Arborist’s rope, Lanyard, Carabiners, Split tail, Throwline and weights, Handsaw, Pole saw and pruner
   - Standards and practices
     - Selection, inspection and use of saddles, ropes, lanyard, throwline, handsaw, pole saw/pruner, snaps, carabiners, redirects, and split tails.
     - Tying and proper application of important knots: Blake's hitch, figure 8, bowline, running bowline, anchor hitch, sheet bend, clove hitch in middle of rope, clove
hitch in end of rope locked with 2 half hitches, girth hitch, basket hitch and double fisherman’s loop.
  o Pre-climb tree and site inspection.
  o Development of a safe, effective work plan and conduct of a job briefing.
  o Rope installations using a throwball or rope throw.
  o Procedures for tree entry using bodythrust and ascenders.
  o Tree entry and final tie-in for fall protection.
  o Advancing the climbing line in the tree.
  o Maneuvering in the tree, including safe limb walking techniques.
  o Setting and using redirects for maneuvering and working in challenging conditions while consistently ensuring proper fall protection.
  o Safe, controlled descent

Chainsaw Safe Operation and Basic Cutting
  • Trainee: Instructor Ratio (maximum): 8:1
  • Minimum Training Time Projected: 8 hrs
  • Selection and care of tools and equipment: PPE, Chainsaws, Chainsaw tool kit
  • Standards and practices
    o Choosing the right chain saw;
    o Chainsaw safety features;
    o American National Standard (ANSI) Z133.1 Safety Requirements;
    o First aid supplies required for chainsaw use;
    o Selection, use and care of Personal Protective Equipment;
    o Chainsaw care and maintenance toolkit;
    o Proper, safe transport and storage;
    o Inspection, field care and maintenance, including importance of proper fuel mix and bar oil;
    o Chain tension and sharpening;
    o Proper starting procedures: ground and leg lock;
    o Safe operation practices and procedures, including avoiding kickback; and
    o Proper cutting techniques: stance, top cut, undercut, kickback prevention

Tree Felling
  • Trainee: Instructor Ratio (maximum): 8:1
  • Minimum Training Time Projected: 8 hrs
  • Selection and care of tools and equipment: PPE, Chainsaws and tool kit, Tree Felling tools
  • Standards and practices
    o OSHA 1910.266(h)(2) Manual Felling;
    o ANSI Z133.1 Safety Standard;
    o Work Planning - Site and tree inspection, and tools and equipment;
    o Felling techniques (notches, hinges, plunge cuts, and back-cuts);
    o Avoiding and addressing felling challenges (lean, hang, barber chair);
    o Limbing and bucking
Tree planting practices

- Trainee: Instructor Ratio (maximum): 8:1
- Minimum Training Time Projected: 8 hrs
- Selection and care of tools and equipment: PPE, Tree planting tools, equipment and materials
  - Standards and practices
    - Tree selection
    - Site preparation
    - Transport and handling tree
    - Digging pit
    - Preparing tree
    - Installation of tree
    - Backfill pit
    - Mulch
    - Water
    - Establishment care

**Brush disposal**: Brush disposal will be part of the cutting training, but is separated here given the significant consideration and planning required to mobilize and conduct this important task.

Woody plant material that is cut should be taken away from cutting sites. Small amounts of material may be left on site to bio-degrade, but monitoring and observations on other sites have found that the mulched material often decomposes slowly, resulting in long-term adverse impacts, which have been observed to continue sometimes years after removal. There is minimal dispersal and sometimes slow decomposition of plant remains that results in smells of hydrogen sulfide associated with rotting plant material, bacterial mats, and algal blooms.

- Options
  - Movement and disposal off site
  - Burning
  - Piling or windrowing minor amounts of material
Article

Airborne LiDAR Reveals a Vast Archaeological Landscape at the Nan Madol World Heritage Site

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Abstract: An airborne LiDAR survey of the Nan Madol World Heritage Site and adjacent Temwen Island revealed a complex, irrigated cultivation system, the first found in the Central and Eastern Caroline Islands. This informs the goals of the sustainable conservation project, funded by the U.S. Department of State Ambassadors Fund for Cultural Preservation, that inspired the survey, and expands understanding of Nan Madol and its place in the network of Pacific island interaction and trade. Fieldwork verified the presence, across Temwen, of low, wet, cultivable areas, many of which are connected by water channels or separated by earthen berms. The berms themselves may also have been cultivated. In complexity, labor investment, and organization, the system is comparable to Nan Madol itself, the largest archaeological site in Micronesia, with structures on about 100 artificial islets built of stone and coral on a reef flat. Constructed over a millennium, Nan Madol was the seat of the Saudeleur Dynasty, which persisted from about 1200 to 1600 CE. The cultivation system appears to have been able to provide ample food for consumption, feasting, and redistribution or trade. If the landscape alteration described here proves to date to the time of the Saudeleur Dynasty, it will offer many avenues of research into the economic basis of Nan Madol’s regional dominance.

Keywords: LiDAR; Micronesia; Pohnpei; Nan Madol; hydrology; water management; remote sensing; archaeology; cultivation; site conservation

1. Introduction

An airborne LiDAR survey of the UNESCO World Heritage Site of Nan Madol and Temwen Island has revealed a vast archaeological landscape consisting of a network of cultivation features connected by a complex water management system. This landscape is adjacent to the core area of Nan Madol.

The LiDAR survey was completed to inform a sustainable conservation and management plan that is funded by the U.S. Department of State and conducted by Cultural Site Research and Management (CSRM) Foundation. Data products and models generated from the LiDAR data will guide the physical conservation and management of Nan Madol and enhance site interpretation. They also enrich understanding of the scope, organization, and influence of the Saudeleur Dynasty, which ruled from Nan Madol. The revealed features have the potential to inform the chronology and pattern of
human settlement and occupation of Pacific islands. This discovery and further research are expected to open many avenues of inquiry.

While the Temwen cultivation system has not been physically dated, it has been examined on the ground. There are reasons to believe that it is coeval with Nan Madol. The labor investment necessary for forming and maintaining this vast and complex network parallels what would have been required for the construction of Nan Madol itself. While more research is needed, for example, to determine the cultivars being grown, the cultivation techniques used, and the periods of use, the discovery of this landscape of cultivation features suggests ways in which Nan Madol’s economic strength may have contributed to a position of great influence on Pohnpei and in Micronesia, incentivizing populations of Micronesian atolls to maintain regular economic, social, and cultural links with Nan Madol via sophisticated sailing technologies and navigational techniques.

1.1. Project and Site Overview

In 2016, Nan Madol was inscribed onto the World Heritage List and simultaneously placed on the List of World Heritage in Danger. In 2018, the U.S. Department of State awarded a large Ambassadors Fund for Cultural Preservation grant to the CSRM Foundation to develop a Sustainable Conservation Plan that, when implemented, will provide the basis for removing or mitigating threats to the site by means of physical interventions and ongoing management and interpretation of Nan Madol.

Nan Madol is in Pohnpei State, one of the four state groupings of approximately 600 small islands that constitute the Federated States of Micronesia (FSM). Each of these groupings is arranged around one of the FSM’s four volcanic, or high, islands. The island of Pohnpei, which is approximately seven degrees north of the equator, provides 336.7 square kilometers of the total 345.5 square kilometers of Pohnpei State. A reef and many smaller islands surround Pohnpei’s main island. Among these smaller islands is Temwen Island (1.81 square kilometers). Pohnpei’s topography is extremely rugged, and it is one of the wettest places on Earth, receiving four to five meters of rain each year [1].

The World Heritage Site of Nan Madol covers 0.767 square kilometers. The site’s buffer zone, which is recognized and monitored by UNESCO, is 6.64 square kilometers (Figure 1). Temwen Island, a volcanic caldera, is within this buffer zone. It connects to the main island of Pohnpei via a short causeway, constructed in 1986.

Nan Madol is considered the largest archaeological site in Micronesia, and some have argued that it contains the earliest stone architecture in the Pacific [2]. The site consists of approximately 100 anthropogenic islets, built of basalt and coral, on the reef flat that extends from Temwen Island’s southeastern shore into the ocean. Canals of seawater separate the islets, many of which feature stone and coral structures on top of them. In addition to their sizes, number, and location on the reef flat, the islets and structures are notable for the sizes of some of the basalt boulders used to build them and for the columnar, or prismatic, shape of thousands of the basalt pieces. This columnar quality is natural, and allowed for the stacking and laying of basalt pieces without having to shape them first.

Archaeological investigations indicate that the bulk of Nan Madol’s islets and structures were constructed from approximately 1200 to 1600 CE [2–15]. Oral histories support these dates and associate Nan Madol, at least in its later stages, with the Saudeleur Dynasty. According to these accounts, the Saudeleurs, who ruled over the entirety of Pohnpei, were overthrown by an invasion of 333 warriors. This invasion was led by a warrior hero named Isokelekel, who came from an island to the east of Pohnpei [16,17]. Some have interpreted this as referring to Kosrae, another of the FSM’s high islands.

A good deal of ethnographic, ethnohistorical, and archaeological research has focused on Pohnpei [3,6,7,17–24]. In 1967, Betty J. Meggers and Clifford Evans, of the Smithsonian Institution, cleared vegetation and conducted excavations at several islets that had been identified by Saul Riesenber as having had specific or noteworthy functions. Some islets, for example, served as residences or burial places for Saudeleur elites, while others hosted rituals that enhanced the Dynasty’s socio-political cohesion. Meggers and Evans’s work supported Riesenber’s ethnohistoric research [25].
Riesenber’s considered the Saudeleur Dynasty “a highly developed socio-political system that permitted the planning of the structures, organization of manpower to build them and to raise and feed the mass of labor necessary for construction” ([24], p. 5). Subsequent research has corroborated this interpretation, with many other researchers noting the high level of social complexity implied by the construction of Nan Madol [2,4–8,10,14,15,22,23,26,27]. Riesenber’s comment about the necessity of feeding laborers anticipates the findings on Temwen Island reported here.

![Figure 1. A regional map showing the location of the UNESCO World Heritage Site of Nan Madol and its buffer zone.](image)

1.2. Project Objectives

The goal of the CSRM Foundation project is to develop a Sustainable Conservation Plan that will identify steps needed to remove Nan Madol from the List of World Heritage in Danger. This includes recommending physical interventions to mitigate threats to the site. Chief among these threats are (1) destructive vegetation; (2) siltation of the canals between islets, which has encouraged an environment that nurtures destructive vegetation and makes accessing the islets difficult; (3) erosion of islets and damage to structures caused by tidal action and storm surges (both of which become more destructive as the sea level rises); and (4) human activities that damage islets and structures. To be sustainable, conservation measures must include an interpretive plan and a management plan, which are necessary to site maintenance after initial treatments have been made.

LiDAR data was collected in order to assess the condition of Nan Madol’s islets and structures; to assist in the identification of vegetation that threatens the structural integrity of the site; and to model Temwen Island’s hydrology, in order to understand how it might be contributing to the siltation of the site’s canals. Siltation and the proliferation of vegetation have progressed to such an extent that today, visitors can see little to suggest why Nan Madol was once called “The Venice of the Pacific.” LiDAR’s potential for distinguishing among vegetation, ground, and other features, and for yielding
precise elevation measurements, figured prominently into the CSRM Foundation’s decision to collect the data that led to this paper.

CSRM Foundation planned and oversaw the airborne LiDAR survey of Nan Madol and Temwen Island, which took place on 11 and 12 March 2019. It was undertaken by Aerial Surveying Inc., a Hawaii-based company specializing in LiDAR acquisitions. CSRM Foundation oversaw the preliminary data processing, much of which was done by Aerial Surveying Inc., and either oversaw or did all the data processing and analysis that followed.

As anticipated, it proved possible to classify and process the LiDAR data to develop several kinds of useful models. Some models reveal the landscape of Temwen Island and Nan Madol beneath the vegetation that blankets them, while others display the vegetative canopy itself. This was pertinent to the conservation objectives of the LiDAR survey, but it also resulted in the detection of the cultivation features on Temwen Island that are discussed below. In addition to providing the kinds of research opportunities mentioned above, these features are likely relevant to a myriad of archaeological and conservation-related matters, such as the original selection of the construction site for Nan Madol, the socio-economic system in which the islets emerged, and the alteration of Temwen hydrology that has contributed to the siltation of Nan Madol’s canals.

1.3. Terminology

As the rest of this paper will reinforce, visual inspection of the LiDAR-derived products; fieldwork; and consultation of the literature on Pacific island archaeology, anthropology, and cultivation and agriculture indicate that the features revealed by the LiDAR survey described here were created by people to enhance Temwen Island’s capacity for food production through the intensive cultivation of select species. But important details, such as which crops were grown in which areas and what methods were used to cultivate them, have not been ascertained with certainty. For that reason, the terms we use to describe the features revealed by LiDAR are empirically descriptive and nontechnical. For example, it is likely that the earthen berms described in Section 3 were used to cultivate certain crops, while the low, wet areas occurring between such berms were planted with others. Both berms and wet areas could be called fields, but that term has technical connotations we will avoid here.

The word agriculture is especially connotation laden, particularly in archaeology. Though its application to the features discussed here would be defensible, we opt for the arguably more general term cultivation.

2. Materials and Methods

In this section, we describe the methods of LiDAR data collection and analysis and the field methods used for validating the LiDAR data and ground-truthing the features visible in the LiDAR imagery.

2.1. LiDAR Data Collection

The LiDAR data were collected with a (full-waveform) ALIS560 sensor mounted to a Britten-Norman Islander, a small, two-engine, fixed-wing aircraft. The surveyed area (Figure 2) is 8.69 square kilometers and covers all of Temwen Island and Nan Madol. Mean flight altitude was 457.2 m, mean ground speed was 46.3 m per second, the scan angle was 60° (±30°), and the total swath width was 577 m. There was total coverage between scan lines, making the overlap percentage 100%. The data was output as WGS84 UTM Zone 57N, with elevations measured in meters above mean sea level (MSL), and using EGM2008 as the geoid model. The survey yielded 108.55 million recorded data points or returns. Each return consists of a 3D (x, y, z) spatial measurement, along with several other measurements, including intensity of return and red, green, and blue reflectances, that will be useful for future analyses. The mean number of returns per square meter was 11.93.
2.2. LiDAR Data Analysis

The combined point cloud for the entire region of interest was classified into ground and non-ground returns via the LP360 commercial software package, which is commonly used within the LiDAR community. The mean number of returns classified as having been reflected from the ground itself (called ground returns) was 2.7 per square meter. Once the point cloud was classified, it was used to create a Digital Terrain Model (DTM), a bare-earth representation of the ground surface, with 0.5-meter post spacing. This DTM took the form of a georeferenced raster data product (sometimes referred to as a 2.5D product, as opposed to the original point cloud itself, which is 3D; see [28]) with 0.5 × 0.5-meter cells (Figure 3). LP360 was used to create the DTM as well.

Multiple products derived from the DTM were generated to highlight the archaeological features. We briefly describe seven of them here. The first derived product is a composite shaded relief image composed of 32,310 individual shaded relief products that were generated using a highly parallelized custom application written in C++. Azimuth angles from zero to 359 and elevation angles from 0 to 90, which effectively represent a solar illumination dome over the region of interest, were used to ensure that subtle terrain features that might be visible only under specific geometric conditions could be highlighted. The shaded relief results of each azimuth and elevation angle combination were summed and then divided by the total number of products used, creating a normalized output. This derived product can be generated using standard commercial and open-source GIS software packages through relatively straightforward Python scripting, but the process would likely be very time consuming due to the single-threaded nature of those applications, unless some batch job orchestration system, taking advantage of multiple CPU cores, multiple computers, or both, was used. That is one reason why simpler versions of this product, like the multidirectional hillshade discussed below (Figure 4), are generally created instead.
SVF evaluates how visible each cell in the supplied terrain model would be with respect to Temwen Island and Nan Madol. As discussed in Section 4.1 Conservation Objectives, this product is particularly useful for identifying potentially harmful vegetation. This tool proved particularly important for revealing the intricate patterns of flat areas, berms, and water channels on Temwen Island, many of which are subtle, low-relief features.

The second derived product is a Sky-View Factor (SVF) image [29] that was generated using a highly parallelized custom application written in C++. Instead of using a solar illumination dome (top-down), SVF evaluates how visible each cell in the supplied terrain model would be with respect to its neighbors (bottom-up) and assigns it a score between zero and one. While both composite shaded relief and SVF use the concept of a dome around a point of interest, SVF can sometimes be more effective at highlighting subtle landscape features. The custom application mentioned above is not required to create the product; the developers of SVF provide software on their website [30].

The third derived product is a multidirectional hillshade that was generated using the Hillshade function in ArcGIS Pro. A subset of the Surface functions, the multidirectional hillshade generates grayscale 3D terrain representations that combine light from six different directions, enhancing the visibility of terrain features. This tool proved particularly important for revealing the intricate patterns of flat areas, berms, and water channels on Temwen Island, many of which are subtle, low-relief features.

The fourth derived product is an estimated canopy height raster. It was generated by calculating the differences between the digital surface model (DSM, derived from the so-called first returns) and those provided by the digital terrain model (DTM, which is often called the bare earth model, derived from the ground, or last, returns). It models the estimated height of the vegetation canopy that covers Temwen Island and Nan Madol. As discussed in Section 4.1 Conservation Objectives, this product is particularly useful for identifying potentially harmful vegetation.

The fifth derived product is a raster of flow directions from each cell to the steepest downslope cell, generated with a traditional eight-direction (D8), pour-point flow modeling algorithm. This product can be represented as a 3D scene. It provides a visual model of the hydrology of Temwen Island and Nan Madol.
In preparation, six priority areas were selected for inspection (Figure 5). These areas were selected chiefly on the basis of two criteria: Including particularly evident and representative examples of the features visible in the LiDAR data, and being relatively lightly covered by vegetation. The latter criterion was important to the performance of the Global Navigation Satellite System (GNSS) equipment used for verification and validation, which must have a relatively unobstructed view of the sky to achieve the most precise measurements possible (GNSS systems use global positioning system satellites as well as other constellations of positioning satellites). Temwen itself is almost entirely covered by thick vegetation, but we placed one of our areas of interest, Area 6, within Nan Madol's islets are discernible.

The sixth derived product is a stream network created by analyzing the DTM with a Flow Accumulation tool, which reveals the number of upslope cells that flow into each cell. The product included in this paper has a threshold value of 100, presenting a model that only includes cells with more than 100 cells flowing into them. This threshold is a common choice as a default threshold for exploratory stream network analysis. The resulting model highlights real and potential streams and watercourses.

The seventh derived product, based on the DTM, simulates a sea level 1.4 m above MSL. It shows the impact that the higher sea level would have on low-lying terrain. All values below 1.4 m MSL in the DTM were set to that value, after which a new SVF image was generated to highlight subtle terrain features. The DTM was then colorized, emphasizing variability between 1.4 and 10 m MSL, and overlaid on the SVF image.

2.3. Identification of Areas of Interest for Field Verification

Fieldwork to verify the presence and ostensible cultivation function of the features revealed by the LiDAR, and to validate and calibrate the LiDAR elevation measurements, was scheduled for 16–29 June 2019. In preparation, six priority areas were selected for inspection (Figure 5). These areas were selected chiefly on the basis of two criteria: Including particularly evident and representative examples of the features visible in the LiDAR data, and being relatively lightly covered by vegetation. The latter criterion was important to the performance of the Global Navigation Satellite System (GNSS) equipment used for verification and validation, which must have a relatively unobstructed view of the sky to achieve the most precise measurements possible (GNSS systems use global positioning system satellites as well as other constellations of positioning satellites). Temwen itself is almost entirely covered by thick vegetation, but we placed one of our areas of interest, Area 6, within Nan Madol,
where some of the islets are relatively clear of vegetation. This allowed us to fully exploit the GNSS system’s precision and gather highly accurate geospatial measurements (see Section 3.1 for details). For later analyses, many of which will be relevant to the Sustainable Conservation Plan, these data will be quantitatively compared with the LiDAR data, to verify and validate the elevations measured for Nan Madol’s islets.

![Image of six areas of interest chosen for field verification of the features revealed by LiDAR and for validation and calibration of the LiDAR data.](image)

**Figure 5.** The six areas of interest chosen for field verification of the features revealed by LiDAR and for validation and calibration of the LiDAR data.

Another area of interest, Area 1, was chosen because it appeared, in the LiDAR data products, to play critical roles in the current hydrology on Temwen Island and downstream in Nan Madol. Areas 2–5 were chosen on the basis of the first criterion mentioned above.

2.4. Field Verification

Georeferenced LiDAR-derived images, such as the shaded relief product described in Section 2.2, were loaded on iPads and used to navigate to the six areas of interest through the ArcGIS Collector application. Preparing these maps for use in the application was done with ArcGIS Online. ArcGIS Collector also allowed the fieldwork team to add point, line, and polygon features to the maps loaded onto the iPads while in the field. Another application, the GPS Camera 55 Field Survey, automatically recorded the location, elevation, time acquired, and direction of each photo taken with the iPads, and it allowed the team to add notes to the photos.

Pohnpei State Historic Preservation Office (HPO) personnel and Temwen Island landowners were informally surveyed for information about archaeological feature locations. HPO personnel used machetes to clear vegetation from parts of the areas of interest. Without clearing vegetation, discerning and identifying the cultivation features under Temwen’s profuse plant growth would have been extraordinarily difficult. HPO and Pohnpei State Department of Land personnel identified the owners of the parcels of land where the areas of interest were located. The HPO was instrumental in getting landowner permission to access and clear vegetation from the parcels. The GNSS system was used to collect data not only for validating and calibrating the LiDAR data (in future analyses), but also to confirm and record the locations of features visible in the LiDAR-derived products. Because
the system records precise geospatial data in three dimensions, these data were used, and can be used further in the future, to verify and compare not only the shapes and locations of the Temwen features in horizontal, plan view, but also in terms of their elevations and profiles.

3. Results

Products derived from the LiDAR data set not only prove themselves useful for preparing the Nan Madol Sustainable Conservation Plan, but also revealed, to all appearances and in accordance with Pohnpei’s larger archaeological context, a sophisticated and extensive landscape of cultivation features hidden under Temwen Island’s vegetation. Ground verification supported this interpretation. Along with notes and georeferenced photos, GNSS measurements confirmed and recorded the shapes, layouts, and locations of the features.

3.1. GNSS Accuracy

Precise cartographic data was gathered using Trimble GNSS receivers supplied by the Spatial Observation Laboratory for Archaeological Research (SOLAR) at Johns Hopkins University. A Trimble R10 receiver was used as a base station and a Trimble R2 as a rover. Differential correction of the rover data was performed using Trimble GPS Pathfinder Office software. All points collected in Area 6, which proved to offer good access to the sky, had accuracy estimates of zero to five centimeters after post-processing. On Temwen Island, where vegetation is far denser, precision was often compromised (Table 1). However, elevations obtained in areas with less tree cover have accuracies comparable to those of the measurements obtained during the LiDAR survey.

Table 1. Estimated horizontal accuracies, after post-processing, of the Global Navigation Satellite System (GNSS) points collected on highly vegetated Temwen Island.

<table>
<thead>
<tr>
<th>Percentage (%)</th>
<th>Accuracy Range (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.38</td>
<td>0–5</td>
</tr>
<tr>
<td>2.06</td>
<td>5–15</td>
</tr>
<tr>
<td>3.86</td>
<td>15–30</td>
</tr>
<tr>
<td>12.16</td>
<td>30–50</td>
</tr>
<tr>
<td>24.66</td>
<td>50–100</td>
</tr>
<tr>
<td>22.29</td>
<td>100–200</td>
</tr>
<tr>
<td>14.08</td>
<td>200–500</td>
</tr>
<tr>
<td>0.50</td>
<td>&gt;500</td>
</tr>
</tbody>
</table>

3.2. LiDAR Analyses and Models

Quantitative analyses of the LiDAR data, which were mostly restricted to statistical characterizations of the distributions of elevation measurements, and visual analysis of the products derived from it yielded several conclusions. Visualizations of the LiDAR data products display the structural integrity of Nan Madol’s islets and the structures on them. The islets’ and structures’ outlines are clear. Many islets have been visibly, profoundly affected by periodic inundations associated with normal and extreme tidal cycles and storm surges. Many structures, even on relatively intact islets, have evidently been damaged not only by inundation, but also by vegetation on the islets and in the canals between them. The siltation of the canals seems to be related to this process (Figure 6). This phenomenon has been noted previously by several observers on the ground [31,32] (but see also [33]). Certain products make visible the extent and density of mangrove growth in and near Nan Madol.
Figure 6. A multidirectional hillshade overlaying a colorized DTM. Some islets and structures have visibly better structural integrity than others do. This product also reveals the extent and density of mangrove growth (the polygon encompassing an area of mangrove encroachment along Nan Madol’s southwestern edge is meant to be expository, not comprehensive). The blue line denotes one of Nan Madol’s principal canal systems, which runs past several of the largest and best-preserved islets.

Some of the LiDAR-derived data products, and in particular the inundation-simulation product described in Section 2.2, make it possible to quantitatively and visually model phenomena that threaten Nan Madol, such as normal and extreme tides and storm surges (Figures 7 and 8). By continuing to work with these models and to use LiDAR elevations calibrated with the precise elevation measures collected with the GNSS system, these models can be made more accurate. With more accurate models, better assessments of conservation threats associated with wind and water can be made.

Data products that include canopy height calculations allow for the mapping and easy identification of high vegetation, which poses special threats to Nan Madol, such as falling branches and trees (Figure 9). These products allow us to identify potentially harmful species, and even especially threatening individual plants.
Figure 7. LiDAR-measured elevations on Pan Kediera (H1–H4) and in the main canal running past the islet (H5).

Figure 8. An inundation-simulation model: A DTM visually flooded to 1.4 m on SVF with 5.0 vertical exaggeration.
which are normally hidden from satellite, aerial, and ground-level view by thick vegetation, (Figure 10)—these terrace-like systems, proceeding downslope and transitioning into systems of parallel, alternating low areas and berms on flat ground, were revealed. By clearing vegetation—for example, along a 70-meter transect in western Temwen (Figure 10)—these terrace-like systems, proceeding downslope and transitioning into systems of parallel, alternating low areas and berms on flat ground, were revealed.

3.3. Field Verification of LiDAR-Derived Models

Other data products make the complex system of cultivable areas and water channels across Temwen Island clearly visible (Figures 10 and 11). In addition to simply revealing these features, which are normally hidden from satellite, aerial, and ground-level view by thick vegetation, these products make immediate suggestions about how the cultivation and hydrological systems on Temwen Island functioned and how they might relate to Nan Madol.

Inspection and verification on the ground confirmed the presence of low areas, separated by earthen berms and connected to one another by channels, that allow water to collect in them. The channels that connect these areas allow water to flow from one area to the next. Because they collect water, these low areas are conducive to the growth of certain plants: In several of the areas inspected on the ground, vegetation in the low, wet areas and water channels was distinct, in terms of density and species present, from that on the earthen berms that separate them. This suggests their potential use in the past as wet fields or pondfields for crops such as taro. Water continues to flow, at least after heavy rain (which is common on Pohnpei), through some of these low areas and the channels that connect them. The berms separating these low areas and crossed by the channels may have been cultivated as well, perhaps with cultigens that prefer drier conditions. Such cultivation on raised mounds or platforms has been noted on Pohnpei and elsewhere in Oceania [34,35].

Low areas, water channels, and berms separating them are found on both flat and sloped areas. Systems of low areas, channels, and berms on the sloped areas manifest in the LiDAR-derived products as terrace-like. By clearing vegetation—for example, along a 70-meter transect in western Temwen (Figure 10)—these terrace-like systems, proceeding downslope and transitioning into systems of parallel, alternating low areas and berms on flat ground, were revealed.

![Figure 9. Estimated canopy height and density at Nan Dowa. Note that the model shows three trees with heights between 17.8 and 28.1 m. As height is an important selection criterion for vegetation removal, models like this one will be important tools for vegetation management.](image-url)
Fieldwork confirmed that the earthen berms, terrace-like features, and many of the lower areas below and around them are roughly rectangular and elongated in plan. At their highest points, the earthen berms that were observed on the ground are approximately 0.5–1.25 m high. The observed terrace-like features are approximately 0.25–1.25 m above the next terrace-like feature or low area. With one possible exception, described below, observed berms and terrace-like features have no retaining walls or other non-earthen support. The margins between them and the lower areas around them, and between one terrace-like feature and the next, are sloped. Aside from these slopes, many of the berms and low areas are level and spacious: One especially large berm in north-central Temwen,
not surveyed on the ground, can be seen in the LiDAR to cover approximately 2800 square meters, or about 0.7 acres.

![Figure 11](image)

**Figure 11.** A multidirectional hillshade of the central area of Temwen Island, revealing its complex cultivation system.

LiDAR-derived flow direction (Figure 12) and flow accumulation models (Figure 13) of Temwen Island show how the cultivation system features influence the landscape’s hydrology. They suggest how the Temwen water management system might have functioned while it was in use, how Temwen’s overall topography and hydrology formed a basis for the cultivation system, and how the system interfaced with Nan Madol. Field observations verified that the earthen berms between low areas act as retaining walls for water, altering the natural flow directions that would be expected from the underlying topography. Some channels were observed bringing water from low areas at higher elevations to low areas at lower elevations (Figure 10). Some channels flow past several low areas along their course, suggesting a spatial and water management scheme integrating many areas of cultivation.

In the southwestern part of the island (in Area 4), a wall of basalt boulders, with a similar but smaller wall built on the retained earth behind (roughly east of) it, was found. These were the only potentially constructed stone features found during field verification. As detectable in the LiDAR data, the larger of the two is about 29 m long. Downslope (roughly west) of these walls were more earthen terraces and channels. These walls could be naturally formed, by volcanic activity, but they appear anthropogenic, and monumental structures are not uncommon on Pohnpei, even outside Nan Madol. Throughout Pohnpei, retaining walls for terraces are typically rock faced (for example, in Awak and Wene; see [36,37]).
4. Discussion

This section discusses the relevance of the LiDAR-derived products to the ongoing conservation planning and activity at Nan Madol. It proceeds to address some of the many implications of the discovery of the Temwen Island cultivation system for understanding and research at Nan Madol, on Pohnpei, and in the region. Current knowledge and ongoing inquiry about the site and its local and regional contexts will be reflected in an interpretive plan, which will constitute part of the larger Sustainable Conservation Plan.
4.1. Conservation Objectives

As mentioned in Section 1.2, salient conservation threats to Nan Madol include disturbance to islets and structures by wind and water, the siltation of the site’s canals, and vegetation overgrowth. The LiDAR data set presented here will help design measures to counter each of these.

4.1.1. Stabilization of Islets and Structures

Imagery and other data products that were generated from the LiDAR data set will be used to prioritize and guide physical interventions for stabilizing Nan Madol’s islets and structures. Models derived from the data set provide convenient and quantifiable means for assessing the physical integrity of archaeological features. The use of the LiDAR’s precise elevation measurements to assess and forecast vulnerability to sea level change and acute threats such as storm surges is an example (Figures 7 and 8).

Prior archaeological fieldwork suggests reasons for the differential preservation of Nan Madol islets that is apparent in the LiDAR models. The findings from this fieldwork indicate that the human occupation of areas offshore of Temwen Island predated the artificial islets and monumental structures that comprise Nan Madol [5,6,8,23]. Nan Madol’s most intact, and many of its most notable, islets and structures lie along a southwest–northeast axis. These are the islets most visible in Figure 6. Athens, drawing upon his excavations and surveys at the islets [3,22,23], posits the presence of natural islets along that axis that predated Nan Madol’s islets. He suggests that the augmentation of these natural islets with basalt and coral rubble inspired the construction of other, later islets both nearer to shore and farther seaward (Figures 7 and 8).

Later survey and excavation by Ayres of islets closer to the Temwen Island shore show—on the basis of pottery content and architectural form—that those islets are older than ones closer to the outer reef edge. In the inland islets, very little columnar rock is used in construction. Ayres and geologist G. Goles confirmed that most of the construction boulders used in the inland islets were from the adjacent Temwen lava flows (see [38]). Also, at the islet called Daahheidik, for example, a concentration of pottery, shell ornaments and food remains was found in a reef sand deposit buried beneath the islet construction. Many of the sherds were water-rolled, indicating either marine reworking of a sand reef islet or materials left as a result of a reef-flat occupation in houses on pilings. This suggested that dwellings on the reef flat predated the development of major artificial islets. This would be consistent with earlier Lapita and post-Lapita residential locations known from Melanesia. Between the idea of marine reworking of a sand reef islet and that of reef-flat occupation in houses on pilings, Ayres favored the latter as a working hypothesis. In any case, he did not think that the use of basalt boulders to construct the artificial islet foundations was necessarily linked to sea level change [6,7]. Columnar basalt was used as facing on some of the earlier islets, but might have been placed later to enhance the islets’ prestige.

Athens [23] and others [6,7,13,21,39,40] tell us that Nan Madol’s islets differ greatly in construction technique, features, pattern and shape, and the oral accounts associated with them. In Figure 6, the islets along the southwest–northeast axis display the greatest structural integrity and are at higher elevations above MSL than are those to the landward and seaward. These islets have been identified by numerous ethnographers, ethnohistorians, and archaeologists as the most significant with regard to the roles they played in the Saudeleur socio-political system (see e.g., [16,20,41,42]). That these islets are relatively well preserved is consistent with the construction scenarios offered by Athens and Ayres. Such assessments assist in supporting decisions about prioritizing islets and structures for conservation treatments. These treatments could include vegetation removal and physical stabilization of structures. Erosion has caused deflation of both inland and seaward islets, and most of the landward islets have been damaged by siltation and tidal flooding [39,40]. These damaging influences make an exact count of islets difficult; only one new islet has been recorded since the 1970s.
4.1.2. Hydrology and Siltation of Nan Madol’s Canals

The development of the landscape of cultivation features on Temwen Island altered the island’s hydrology and the flow of water into and through the canals at Nan Madol. As a result, rainfall runoff into Nan Madol may be lower than what would be expected on a natural Temwen Island landscape. This may have been the case even while the cultivation system was being maintained. At present, there can be little doubt that water flow through the network of water channels is blocked because of the degradation of the network, due to causes such as heavy vegetation on Temwen Island, historic landscape modifications, and ground disturbance by pigs.

With physical treatments such as vegetation clearance and targeted maintenance of the water management system, it may be possible to increase the flow of runoff into and through Nan Madol’s canals. This would offer a minimally invasive way of clearing silt, which is linked with problematic vegetation overgrowth, from the canals. The LiDAR data set will continue to be used to model the hydrology and vegetation of Temwen Island and Nan Madol to assess the feasibility of testing such treatments.

4.1.3. Vegetation Management

LiDAR models show the location and density of mangroves (Figure 6). These models will be used to guide the clearance of mangroves from selected areas. Priority areas include the canals that skirt the most notable of Nan Madol’s islets. Ideally, mangroves will not be completely removed from these canals but allowed to remain in place along the canals’ edges, much as they often do along the banks of natural rivers. Removing mangroves completely could destabilize the walls of the islets along which the canals flow. Mangroves also provide some protection from tidal cycles and storm surges and serve important ecological roles. Allowing the mangroves to grow unchecked, however, impedes water flow through the canals, encouraging siltation and further overgrowth, as well as making the canals impassable.

Other LiDAR models have been created to highlight trees likely to fall or from which limbs might drop (Figure 9). Falling trees and limbs have damaged structures and the islets themselves at Nan Madol. These models will be used during the initial removal of threatening vegetation.

The LiDAR imagery shows a large area in the ravine on the south side of Temwen Island that has been used in recent decades as a field for growing swamp taro. This large field is now almost completely abandoned; local residents say that many members of the family that once grew swamp taro there have left Pohnpei. The remaining few members now grow taro only in an area adjacent to the house in which they live. Clearing this area of vegetation might assist efforts to further document the Temwen cultivation system as well as to increase water flow into Nan Madol.

4.2. Implications and Interpretation Objectives

LiDAR has revealed a massive and complex cultivation system on Temwen Island. It is this advantage of LiDAR, that it can reveal whole archaeological landscapes hidden under heavy vegetation, that has led to its comparison with radiocarbon dating as a groundbreaking technological advance in archaeology. By virtue of its abilities to provide data sets that can reveal an enormous range of archaeologically relevant features and are, geospatially, not merely representative but nearly complete, the importance of LiDAR is difficult to overstate (see [43,44]). Further LiDAR surveys, not only of other parts of Pohnpei but of other Pacific islands, could contextualize the Temwen system and offer new synoptic perspectives.

In plan, the low, water-collecting areas; water channels; and berms on Temwen are similar to the systems of terraces described by Sand in New Caledonia, which he writes are “considered as the most elaborate of the Western Pacific” ([45], p. 167). Within that system, associated with the Traditional Kanak Cultural Complex from the second millennium CE, he documents terraces, water channels, and pondfield sites. In describing the construction and use of these systems, Sand cites Captain James
Cook’s observation that “not an Inch [sic] of ground is lost” ([46], p. 538). The system has been described as “certainly the most technically complex pondfield irrigation within Melanesia” ([47], p. 80; cited in [45], p. 167). Such complexity is in accord with what is observed in the LiDAR images of Temwen Island. The Temwen system also bears a resemblance to some Polynesian terracing systems, including the Kohala field system on Hawai’i Island [48] and recently described slope terraces on Tutuila in American Samoa [49].

As mentioned in Section 3, retaining walls for terraces on Pohnpei are typically rock faced [37]. That Temwen’s cultivation features are almost entirely earthen is therefore unusual. This is perhaps explained in part by the paucity of surface rock on Temwen Island. There is a notable exception about half a kilometer to the east of the abovementioned walls, where a profusion of basalt boulders lies on and near an approximately south-facing slope down to the lagoon. (These boulders could have been rolled down the slope into Nan Madol.) The basalt walls are at the head of a ravine that runs down to the northwestern edge of Nan Madol, the same ravine mentioned in Section 4.1.3. This ravine might have brought fresh water to a point at which it could have been relatively easily collected by the site’s inhabitants. The flow of water through the ravine and into the site might also have encouraged water flow through the site itself, potentially clearing sediment from the canals (Figure 13).

The LiDAR models presented here provide the first view of an intensive cultivation system, including water control features, of such scale in the Central and Eastern Caroline Islands. This finding is relevant to ongoing discussions of the development of social complexity throughout the Pacific. Previous localized archaeological surveys and excavations on Pohnpei documented terraces and alignments that were interpreted as agricultural features [34,50–54], some with water control mechanisms (see [34], p. 151). Yet a large, complex system with integrated water channels had not been posited.

Without the view provided by LiDAR, archaeologists who have done research on Pohnpei, and in particular at Nan Madol, have generally emphasized the importance of breadfruit (see e.g., [55], p. 85), yams, and reef fish, with taro contributing little to the Pohnpeian diet. Though the role of bananas is acknowledged, it is understudied, likely because of their lack of prestige in the traditional food system or their limited archaeological visibility [56]. None of these foods can be effectively preserved once harvested, with the exception of breadfruit, and less commonly banana, which can be fermented [34,55–57]. This makes year-round cultivation and harvest of crops necessary. Food security has long been seen as having shaped Pohnpeian culture (and Micronesian culture more broadly) in several defining ways, including by encouraging the improvement of inter-island connections [53,58] and social systems that emphasize the production of large amounts of food for feasting [18,54,59]. But food production on a scale made possible by the cultivation system described here has not been previously suggested.

The Temwen cultivation system can be considered landesque capital in the sense used by Håkansson and Widgren: A choice of agricultural techniques that serve important economic, social, and ritual purposes [60]. The term was originally used by Sen to refer simply to capital goods that replace land (as opposed to laboresque capital, which replaces labor) [61]. In this strictly economic sense, too, the Temwen system fits the concept: Spriggs maintains that irrigated systems for growing taro can generate yields at least four times higher than what is possible with swidden agriculture ([62], cited in [63]).

The concept of landesque capital has been used by geographers and anthropologists to explore food storage as it relates to exchange in the service of food security and the prestige economy. Under certain conditions, for example, concentrations of landesque capital could have generated tradable surpluses of foods such as taro [64,65]. Such tradable surpluses would have constituted wealth, or, as Bayliss-Smith and Hviding put it, “social and nutritional value to be saved, accumulated, and later mobilized” ([64], p. 425).

Without extensive archaeological fieldwork or the application of technologies like LiDAR, it can be easy to overlook the physical evidence even of large investments in landesque capital. In 1568, the first Europeans to arrive at the island of Guadalcanal, in the Solomon Islands, saw a planned
agricultural landscape. In 1610, a Captain de Queirós, on his way to Vanuatu, wrote to the King of Spain that he had observed gardens “artificially severed (divided) into beds, bordered, and paled (fenced)” ([66], p. 221; quoted in [63], p. 75). Yet when Europeans next recorded what they saw on Guadalcanal in the nineteenth century, there was little trace of terracing or irrigation [63]. It was only in 2000 that an archaeologist, David Roe, discovered remnants of stone walls, terraces and irrigated fields [67]. On Vanuatu, Bayliss-Smith and Hviding have examined historical documentation by de Queirós that engineered landscapes for taro production existed in the Tavai, Apuna, and Raovi valleys and their inland catchments [63].

The existence of the Temwen system supports the hypothesis of Ayres et al. that Temwen Island served as an agricultural area to support Nan Madol, and that evidence of agricultural intensification would be found there ([40], p. 9). To investigate this, Ayres and colleagues conducted fieldwork in 2011 that documented several features, such as stone walls that were suspected to have been an element of terraces. They report finding 13 boulder alignments thought to be related to terracing, seven stone platforms or enclosures, and four stone walls, as well as other agricultural features, such as yam enclosures and breadfruit fermentation pits ([40], p. 42; [52], p. 60).

These findings were preceded by others that are consistent with the interpretation of the Temwen Island features as relating to cultivation and possibly coeval with Nan Madol’s fluorescence. Ayres and Haun found water control features, terraces, enclosures, pits, and walls in Pohnpei’s Awak Valley [36] (see also [37]). Many of these features are agricultural. Among them are terraces along stream courses that the researchers suggested might be wet terraces for taro cultivation.

5. Conclusions

The LiDAR survey discussed here was done to advance the goals of the U.S. Department of State-funded Sustainable Conservation Plan for Nan Madol. Chief among these goals is to ameliorate threats to the Nan Madol World Heritage Site so that the site can be removed from the List of World Heritage in Danger. The discovery of an extensive and sophisticated cultivation system influences decisions that must be made about conservation treatments and a site management plan. This management plan will provide for site monitoring, cyclical maintenance, interpretation, facilities, visitor services, and site and visitor protection.

It is likely that the Temwen system revealed by LiDAR is contemporaneous with the islets and structures of the Nan Madol World Heritage Site. The system is comparable to the islets and structures of Nan Madol in terms of the complexity and magnitude of the effort that would have been required to build and maintain it. The investment of labor, for example, and the level of social organization necessary to construct and maintain the Temwen system would appear to be similar to what would have been required to construct and maintain Nan Madol. If the Temwen system is a creation of the Saudeleur Dynasty, it emphasizes the high level of social organization associated with the dynasty; regardless, it suggests many avenues for future research.

The LiDAR models presented here comprise the most convincing evidence thus far for a formal, complex cultivation system incorporating an intensive network of growing areas and water management features in the Central and Eastern Carolines. This is the region of Micronesia thought to have been initially settled by Lapita-descendant communities. Further investigations on Temwen Island, and comparative studies, will be needed to determine how this development might inform the chronology and pattern of human interaction among the islands in the region.

Dateable samples from the field system might prove informative not only regarding how the development of the field system and that of Nan Madol’s islets and structures compare chronologically, but also where a model for the field system might have originated. Athens states that the pottery found at Nan Madol is best described as belonging to the Late Lapita Plain Ware pottery tradition, which he considered to be unlike pottery found elsewhere in Micronesia, based on shape and decorative technique: A simple globular form for pots and bowls, “with perhaps some rim notching or punctuation” ([5], p. 29). He sees this form and decoration persisting over the centuries, despite changes in temper.
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(p. 26). Athens further states that Late Lapita Plain Ware is found only in the southeast Solomon and New Hebrides islands (the latter now Vanuatu; see also [24]). Lebot’s observation that the kava sub-species found on Pohnpei is most similar to that on Vanuatu and the Bismarcks constitutes another link between Pohnpei and that region [68].

Comparative studies in the future could also address the spread of stone architecture through the Pacific. As Carson notes ([69], p. 2), “the stone city of Nan Madol in Pohnpei has long been regarded as the ‘Venice of the Pacific,’ with its canals leading through a labyrinthine network of long-abandoned stonework architecture, but rarely is this discussed in relation to the other monumental stonework traditions that developed throughout Micronesia and the Pacific all about the same time.” McCoy and colleagues have presented evidence that Nan Madol’s stone architecture is among the Pacific’s oldest ([2], p. 295). It remains to be determined how Nan Madol might be related to the spread of Pacific stone architecture, and how the discovered landscape of cultivation features might further this line of inquiry.

The cultivation system reported on here could be an important reference for future research on the development of such systems in the Pacific. Though oral histories indicate that Nan Madol received food as tribute from across Pohnpei, the resident population could not have been adequately fed by food grown or obtained on site. The site itself could not have produced enough food for food-focused ritual and feasting. To the degree that it provided food, and food security, to Nan Madol, the Temwen cultivation system carries enormous implications for the site.

The Temwen system would appear from our inspection on the ground to have formed wet fields suitable for growing taro. Soil testing, including analyses of pollen samples, phytoliths, and plant macroremains, is likely needed to confirm this. Devoting a substantial proportion of the Temwen system to taro would have resulted in an enormous and relatively secure store of food. Such a supply of taro could have been tapped not only for redistribution or trade [64], but also for feasting that enhanced the prestige of the rulers. If a suitable method can be devised to preserve or store it, food constitutes a form of wealth: Food is essential and, contingent on the preservation or storage method, it can be reapplied or reallocated. Under certain circumstances, it can be traded for, among other desirable materials and objects, prestige goods (some of which are themselves foods).

A deeper understanding of the Temwen cultivation system and its relation to Nan Madol requires research on how the system functioned: How the features were built or maintained, and how they harmonized with cultivation methods and environmental dynamics. This calls for studies such as sampling and analyzing the construction of the features, investigating the chronology of the Temwen system’s development and how it relates to Nan Madol’s growth, and comparing Temwen with early field systems in other parts of the Pacific. Comparison or analogy with traditional Pohnpeian cultivation methods, following Carson’s method in Samoa [70], could also be informative.

Detailed knowledge of the Temwen system will allow future researchers to draw conclusions about Nan Madol’s food security and wealth; how these advantages contributed to the site’s development, construction, and maintenance; and the economic and political strategies of Nan Madol’s rulers. With its socio-political, ritual, and economic importance, Nan Madol may have served as a symbol of affluence and stability to other islands and atolls in the region. As such, in times of need, such as those triggered by typhoons or droughts, Nan Madol may have been looked to by regional neighbors or clan members from elsewhere in Micronesia for aid or trade. This idea is supported by Petersen’s argument that the presence of members of clans on numerous islands and atolls across Micronesia created a network of support and trade for voyagers and clan members in need [58]. If such a model holds, then the food security and wealth that supported Nan Madol would have made it an important node at the center of regional social and economic networks.

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By Bill Jaynes
The Kaselehlie Press

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Pohnpei, FSM—Dr. Douglas Comer and his son Jake of the Cultural Site Research and Management (CSRM) Foundation have studied and advised on restoration projects in such exotic World Heritage sites as Macchu Picchu in Peru, Petra in Jordan, and many other historic sites around the world including in Ireland, Sudan, and Turkey. For just over a year now they have brought their skills and expertise to Nan Madol in Pohnpei in an effort to prepare the Nan Madol World Heritage Sustainable Conservation Plan and to move toward the implementation of that plan.

Nan Madol is a UNESCO World Heritage site, a designation it attained in 2016. It also is on the List of World Heritage in Danger sites. Built, beginning in approximately 1200 and occupied until about 1500 during the Saudeleur dynasty, Nan Madol is a series of 99 artificial islets off the south-east coast of Pohnpei that were constructed with walls of basalt and coral boulders. The islets harbor the remains of stone palaces, temples, tombs and residential domains.

Funded by the U.S. State Department Ambassador’s Fund for Cultural Preservation Large Grant Program in support of and in collaboration with the Federated States of Micronesia (FSM) State Historic Preservation Office (FSM SHPO), the Comer’s have embarked on a four year consultancy, providing recommendations for recovery of the historic site and working with stakeholders to build a sustainable management plan for the site. Implementation of plans developed during the first two years will begin during the second two years.

“In essence, the outcome of the first two-year program will be to provide a plan for the interventions needed to arrest natural processes and human activities that are inflicting progressively more serious damage on the Nan Madol World Heritage Site,” Dr. Comer wrote in a progress report to Augustine Kohler of FSM SHPO.

The results of the LiDAR study have been especially important to the planning process. LiDAR stands for Light Detection and Ranging. It is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. LiDAR can be used to gather all sorts of data including topography underneath covering vegetation and types of vegetation.

CSRM’s report to Kohler says that the LiDAR data that was collected on March 11, 2019 by aircraft has proven to be enormously informative in:

- Assessing the state of preservation of islets and structures;
- Determining heights of islets, structures, and structural remains on islets;
- Assessing vulnerability of islets and structures to tidal cycles, including “king tides,” and storm surges;
- Modeling the hydrology of Temwen Island and its possible influence on the silting of the Nan Madol canals;
- Modeling for vegetation management and removal, including identifying trees that might fall in storms or loose limbs that damage archaeological features, and proximity of trees to structures with root systems likely to damage structures,
- Mapping mangroves and assessing density;
- Modeling inter-islet hydrology.

Dr. Comer says that the current biggest threat to the site is vegetation, particularly trees that fall and topple structures or whose roots undermine and potentially destroy them. Mangrove trees and sprouts in the channels contribute to another problem which is silting. He says that analysis of LiDAR data suggests that the degradation of the ancient agricultural fields on Temwen Island because of rooting by pigs and the dense vegetation that now chokes channels that once connected the fields have introduced so much silt on the coral reef that islets and structures are almost completely covered by it.

Arrangements are currently being made for personnel representing the United States Forest Service to train 16 people on Pohnpei in March 2020 to carry out the selective mangrove removal from key canals at Nan Madol, and to manage vegetation. Those tasks will be undertaken in ways that remove vegetative threats and make them visible to visitors at Nan Madol, while maintaining the shade necessary for a comfortable experience.

Dr. Comer says that in the last several decades Nan Madol has been cleared of vegetation twice without much regard for what is good clearing and what is bad clearing. It made the sites visible to visitors but, of course, all of the vegetation came back as if it had never been cleared. Any plan for sustaining Nan Madol will require thoughtful consideration of the type and purpose for any clearing and continued maintenance.

When the proper vegetation has been cleared, there will be better water flow to ameliorate the problem of silting, thereby deepening the channels and making them more accessible by shallow draft boats for tourism purposes and even facilitating the purpose of removing cleared vegetation.

CSRM is certainly not working alone and has spent a significant amount of time building networks and getting stakeholder feedback. They are currently working on a set of Memoranda of Understanding with several local groups, organization, and with government, in order to continue the process along and to help make it sustainable. Those will be announced at a later date as parties are still in discussion and some MOUs have not yet been signed, though they appear to be imminent.

Dr. Comer says that certainly CSRM’s primary focus and task is the development and implementation of a preservation plan but along the way, they have made some noteworthy archaeological discoveries through analysis of LiDAR data that have led to some anthropological insights into the community of Nan Madol. One of those is the previous existence of the highly advanced agricultural fields on Temwen island which must certainly have served as a focal point for the thriving community that both supported the work force and motivated workers to provide it.

A great deal of work is certainly left to be done and never ending work into the future will be required if the sacred site of Nan Madol is to be preserved. It is hoped that helping to make Nan Madol a more attractive site for visitors while simultaneously protecting it from those visitors will generate the revenue through entry fees in order to pay for that work into the future.

“I don’t know if it will work,” Dr. Comer said, “but it’s worked in other places around the world. I don’t see why it wouldn’t work here.”