# Conservation management of an abandoned copra plantation at Palmyra Atoll, Northern Line Islands, Pacific Ocean

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**SUMMARY**

Coconut palms (*Cocos nucifera*) cultivated for copra are agricultural resources on many of the world's low-lying tropical oceanic islands where they provide sustenance and economic value to human communities. However, coconut palms, when dominant in island plant communities, can outcompete native plants for above- and below-ground resources. Furthermore, when coconut palms displace native plant species preferred by seabirds as roosting and nesting habitats, they may disrupt beneficial nutrient pathways in both marine and terrestrial ecosystems. At Palmyra Atoll, located in the Northern Line Islands, Pacific Ocean, evaluation of three methods for controlling coconut palm seedlings (foliar herbicide application, cut-stem, and cut-stem combined with herbicide) showed that mortality was highest with the cut-stem combined with herbicide application. A comparison of herbicide volumes injected directly into stems of mature palms showed that mortality increased with herbicide volume; an injection of 10 ml of undiluted Roundup Custom™ herbicide (53.8% glyphosate) achieved 100% mortality within 8 months.

## BACKGROUND

Remote, oceanic islands are important reservoirs of biodiversity (McCauley et al. 2013), yet their isolation renders them ecologically vulnerable to the impacts of invasive species (Spatz et al. 2022). Palmyra Atoll ("Palmyra"), located in the Northern Line Islands in the central Pacific Ocean (Figure 1), provides important habitat for seabirds, migratory shorebirds, terrestrial crabs, and marine life. The atoll supports one of the best remaining wet atoll forest ecosystems in the region and the surrounding coral reef is recognised as a regional baseline for intact reef systems (Sala et al. 2008). Despite the present-day integrity of Palmyra's ecosystem, the atoll experiences considerable ecological impacts from past human activities including the introduction of invasive species.

Beginning in the mid-19th century, efforts to farm copra at Palmyra resulted in the displacement of native broadleaf rainforest trees by establishing coconut palm (*Cocos nucifera*) plantations (Young et al. 2017). In the years between 1939 to 1946, the US military had a large presence at Palmyra, including impacts associated with lagoon dredging and land reclamation (Collen et al. 2009) and the unintentional introduction of black rats (*Rattus rattus*) (Wegmann et al. 2012). These events compromised many of the atoll's ecological features, including species abundances and distributions, hydrological systems, and nutrient cycling (Collen et al. 2009; Young et al. 2017).

Today, The Nature Conservancy (TNC) manages a nature preserve at Palmyra within a U.S. Fish and Wildlife Service (USFWS) National Wildlife Refuge. Palmyra is a wholly protected atoll ecosystem with limited infrastructure and no permanent human settlement. Black rats were successfully eradicated from Palmyra in 2011 (Wegmann et al. 2012), after which coconut palms experienced a significant increase in seed germination and seedling survival (Wolf et al. 2018). By 2016, Palmyra's coconut palm population was measured at 2,367,461 seedlings and 32,876 mature trees across the atoll (Struckhoff 2019).

Coconut palms, originating in south-east Asia (Arulandoo et al. 2017), exhibit invasive behaviour at Palmyra Atoll (Young et al. 2017) and on atolls in the Chagos Archipelago (Carr et al. 2021) by competing with native trees for above- and below-ground resources. Furthermore, the displacement of native broadleaf trees by coconut palms limits habitat for tree-nesting seabirds, which in turn limits the distribution and possibly the gross quantity of seabird-transported nutrients (N and P) (Young et al. 2017). Seabirds are one of the most threatened bird groups and their global declines have ecosystem-wide consequences given their important role in cross-system nutrient transfer (Dias et al. 2019). While eradication of invasive predators is a key conservation intervention in seabird-driven island ecosystems (Spatz et al. 2022), the conversion of abandoned copra plantations to habitat conducive to tree-nesting seabirds is similarly important (Carr et al. 2021). Coconut palm removal followed by managed establishment of native trees preferred by seabirds may lead to enhanced distribution and abundance of



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beneficial seabird-transported nutrients, and enhancing this seabird-driven nutrient subsidy may create greater whole-ecosystem resilience for atolls experiencing impacts from climate change (Benkwitt et al. 2022).

In 2019, the USFWS, TNC, and Island Conservation implemented the Palmyra Atoll Rainforest and Reef Resilience Project (PARP), which aims to remove 95% of the coconut palms associated with the abandoned copra plantation at Palmyra and re-establish native broadleaf tree species preferred by seabirds as nesting habitat. Here, we present results from field experiments at Palmyra to test the effectiveness of different methods for controlling mature and immature (“seedling”) coconut palms.

**ACTION**

Palmyra is among the most isolated atoll ecosystems in the world, located in the Northern Line Islands, equatorial Pacific (5.8885° N, 162.0787° W) Palmyra consists of 38 forested islets (198 ha) adjacent to lagoon, backreef, and forereef habitat (6,277 ha) (Figure 1). To accomplish the management objectives of PARP, we studied the effectiveness of different methods for controlling mature and seedling coconut palms.

**Removing Seedling Coconut Palms:**

We tested three methods for controlling coconut palm seedlings studied at Palmyra: 1) applying glyphosate herbicide to seedling leaves (foliar-herbicide); 2) cutting seedling stems with a machete (cut-stem); and 3) cutting seedling stems with a machete and applying glyphosate herbicide to the cut stem (cut-stem-herbicide).

The foliar-herbicide method involved spraying coconut palm seedling fronds (n = 220) on Sacia Islet (0.13 ha) (Figure 1) with Roundup Custom$^{TM}$ herbicide in an 8% solution (4.3% glyphosate) using a backpack sprayer with a fan-spray wand. Blue marker dye was added to the solution to indicate herbicide application. Approximately 18 ml of herbicide solution was applied to the fronds of each seedling. The study team used personal protective equipment (PPE) to avoid topical exposure to the herbicide. The site was revisited six weeks later, and seedling mortality was assessed by counting the number of live coconut palm seedlings remaining within the study population.

For the cut-stem action, coconut palm seedlings (n = 36,623) on Paradise Islet (Plot 114, 1.9 ha) (Figure 1) were controlled by using a machete to cut off stems sprouting from coconuts, cutting the base of a stem as close to the coconut as possible. The cut-stem method aims to damage the growth tissue (meristematic tissue) in the seedling to prevent regeneration, without the use of herbicide. We found that stem cutting is most effective on seedlings with stems 5-17 cm in diameter at the base (approximately 1-2 years old); cutting larger and older coconut palm seedling stems is more physically challenging. We revisited the site after two weeks and twenty months to count surviving (resprouted) seedlings; both times all surviving seedlings were re-treated using the same method.

In the cut-stem-herbicide action, also on Paradise Islet (Plot 116, 1 ha) (Figure 1), stems of coconut palm seedlings (n = 11,564) were cut in the same manner as described for the cut-stem (without herbicide) study

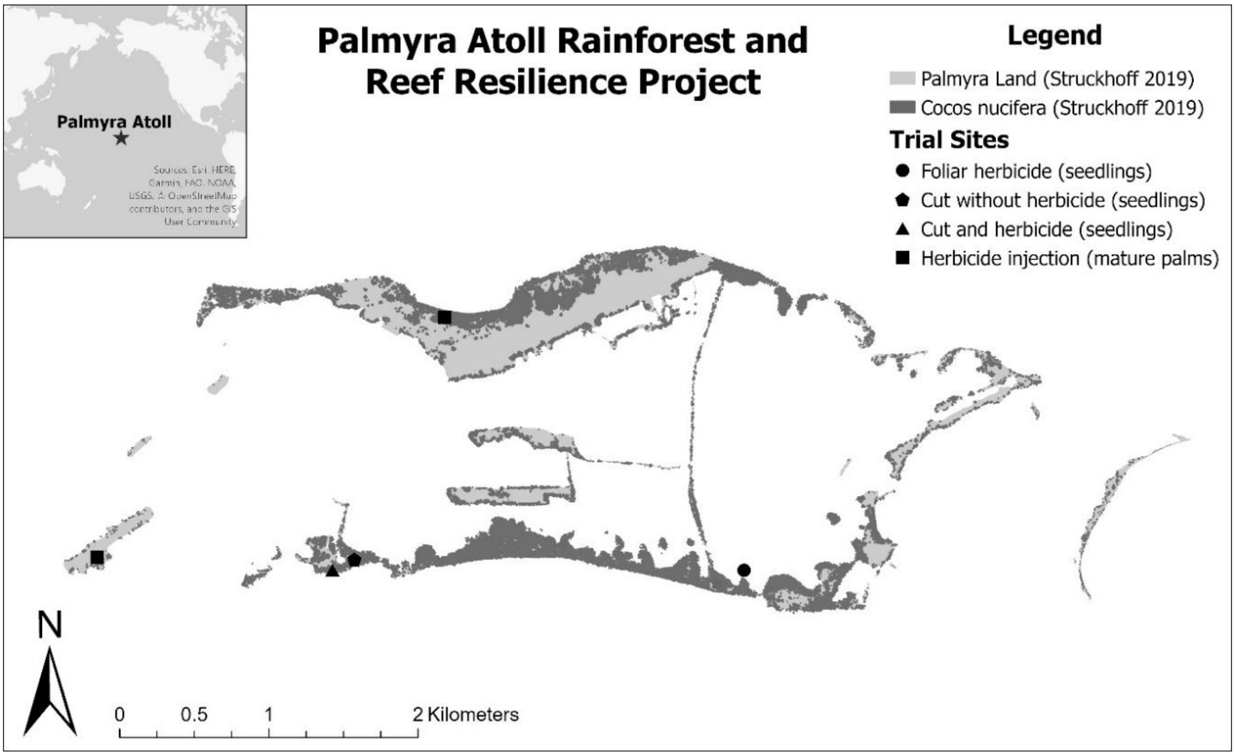


**Figure 1.** Map of Palmyra Atoll with coconut palm distribution and trial site locations.



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and then treated with Roundup Custom™ in an 8% solution (4.3% glyphosate). Consistent with the foliar herbicide application study, blue marker dye was added to the herbicide solution and appropriate PPE was used. We revisited the site after two weeks and twenty months to count surviving (resprouted) seedlings; both times all surviving seedlings were re-treated using the same method.

**Removing Mature Coconut Palms:**

To determine the appropriate dosage of Roundup Custom™ (53.8% glyphosate) for high-efficacy control of mature coconut palms, we assessed the effectiveness of three herbicide application rates on mature coconut palms at two locations at Palmyra: Cooper Island and Sand Island (Figure 1). We injected different volumes, 6 ml (n = 57), 8 ml (n = 83), and 10 ml (n = 72), of Roundup Custom™ into the central cylinder of coconut palm stems. We used battery-powered drills fitted with six-inch long (15 cm) 7/16" bits to bore holes in the stems and used a syringe to inject herbicide, allowing for herbicide uptake by vascular bundles within the central cylinder. Treatments were randomly assigned to coconut palms in the study sites and untreated coconut palms adjacent to the study sites were observed as controls for the treated trees. Treated coconut palms were monitored monthly for eight months and given a health ranking of 0-4, as follows: '0' indicates a dead palm; '1' indicates a palm that will likely die before the next monthly monitoring period, all remaining fronds drooping or dead; '2' indicates a palm that has a thin canopy with over half the fronds dead or drooping; '3' indicates a palm that has more yellow and dead fronds than typical but still has 50% or more of the fronds green and erect; and '4' indicates a normal, healthy palm with all fronds green and erect.

Health rank values were averaged by tree for each sample period (0-8 months) and the results were analysed with Kruskal–Wallis tests for differences between the treatments (6 ml, 8 ml, 10 ml) for each sample period.

## CONSEQUENCES

**Immature Coconut Palm Control**

*Foliar-herbicide:* After six weeks, all 220 seedlings treated with the foliar-herbicide method survived (Table 1). No further monitoring of this method was carried out.

*Cut-stem:* At the initial two-week assessment, 6,250/36,623 seedlings treated with the cut-stem method had survived and were retreated using the same method. After 20 months, 20,743/36,623 treated seedlings had survived, which equates to a mortality rate of 43.4% for the study population treated with the cut-stem method.

*Cut-stem-herbicide*: At the initial two-week assessment, 209/11,564 seedlings treated with the cut-stem-herbicide method had survived and were retreated using the same method. After 20 months, 3,880/11,564 treated seedlings had survived, which equates to a mortality rate of 66.4% for the study population treated with the cut-stem-herbicide method.

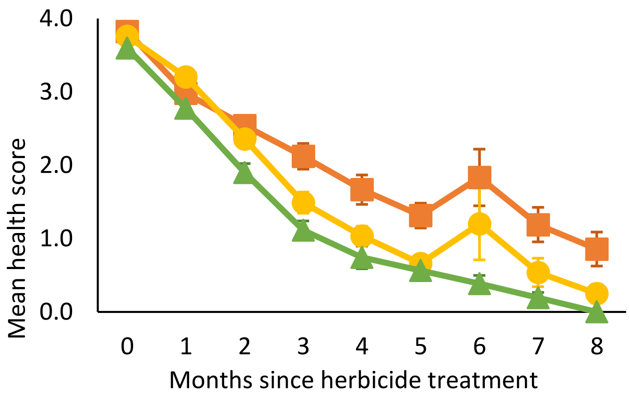


**Figure 2.** Coconut palm health scores ranging from 0 (dead) to 4 (normal, healthy) associated with three glyphosate herbicide treatments for mature coconut palms over an eight-month observation period. Different herbicide dosages are represented by the following shapes: orange square = 6 ml, yellow circle = 8 ml, green triangle = 10 ml. Sample sizes are provided in Table 2. Error bars represent the standard error in health scores.

**Mature Coconut Palm Control**

All three treatment volumes resulted in health declines by the end of the eight-month study (Figure 2). However, the individuals in the 10 ml treatment group experienced the fastest decline in health and achieved 100% mortality (loss of all fronds and drupes) after eight months. Kruskal–Wallis test for differences between treatments indicated the treatments were all

**Table 1**. Number of coconut palm seedlings before and after each treatment and estimated efficacy of three control methods. [1]Initial assessment occurred six weeks after treatment. [2]Initial assessment occurred two weeks after treatment.

| Method | Pre-treatment | Initial survival after treatment | Survival 20 months after treatment | Final treatment effectiveness (mortality) |
|---|---|---|---|---|
| Foliar herbicide application | 220 | 220[1] | N/A | 0.00% |
| Cut-stem | 36,623 | 6,250[2] | 20,743 | 43.36% |
| Cut-stem-herbicide | 11,564 | 209[2] | 3,880 | 66.45% |



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significantly different from one another from month one to month seven of the study period (p-values ranging between 0.01 and 0.0003; Table 2). Over the eight-month sample period, the average control tree health score was 3.8 (n = 10), suggesting a strong treatment effect on the study population.

**Table 2.** Results distributions from Kruskal–Wallis tests for differences in the efficacy of three glyphosate herbicide treatments for mature coconut palms: 6 ml, 8 ml, 10 ml.

| Time period (month) | n | H statistic | p-value |
|---|---|---|---|
| 0 | 212 | 4.37 | 0.11 |
| 1 | 157 | 10.23 | **0.0060** |
| 2 | 208 | 9.15 | **0.010** |
| 3 | 136 | 16.49 | **0.00026** |
| 4 | 139 | 11.32 | **0.0035** |
| 5 | 169 | 11.00 | **0.0041** |
| 6 | 48 | 10.70 | **0.0047** |
| 7 | 78 | 10.94 | **0.0042** |
| 8 | 61 | 5.85 | 0.54 |

## DISCUSSION

Our results indicate the cut-stem-herbicide treatment is the most effective method tested for controlling immature coconut palms, although a third of the seedlings survived after treatment. For mature coconut palms, our results indicate glyphosate herbicide injection is an effective control method, with the 10 ml treatment achieving 100% control.

Since 2019, the cut-stem-herbicide and 10 ml glyphosate injection methods have been implemented by PARP field teams to control immature and mature coconut palms, respectively. By the end of 2022, PARP achieved control of over 1.1 million coconut palms across 115 ha of land at Palmyra, requiring approximately 6,000 person-hours; controlling immature coconut palms accounts for 90% of the effort.

Experimental restoration of native trees for seabirds in abandoned copra plantations has also been implemented in the Chagos Archipelago, with successful restoration of three 10-ha plots within the Diego Garcia island group (Carr 2010). Building on the success of the Diego Garcia Project, PARP is the first ecosystem-wide conservation-focused managed conversion of an abandoned copra plantation to a native-tree-dominated forest.

We acknowledge the undeniable importance of coconut palms to island and coastal communities as a highly useful resource and as a cornerstone of cultural practice (Foale 2003). With PARP and the methods development studies presented here, we are not challenging the cultural significance of the coconut palm, nor are we challenging the agricultural propagation of coconut palms via the global copra industry. We are, however, highlighting the opportunity to restore atoll ecosystem function where coconut palm monocultures from abandoned copra plantations no longer provide socioeconomic benefit. A deeper analysis of this opportunity space is warranted yet lies outside the scope of this study.

**Implications for managers considering conservation-based control of coconut palms on atolls:**

The coconut palm control methods developed at Palmyra are customised to the atoll's unique attributes, opportunities, and limitations and are informed by the studies described here with learnings applied to an adaptive management approach. We recognise that Palmyra's remoteness, largely intact native ecosystem, and lack of human settlement are a rare mix of island attributes, and similar conservation actions in other geographies will need to tailor methods to local circumstances. Studies (Diu 2016; Tsui & Chu 2008) suggest the acute application of glyphosate herbicide to control coconut palms, as described in this study, should result in negligible environmental consequence. However, in other geographies, mechanical control of coconut palms (chainsaw or larger forestry machinery) may be the preferred approach. Funding, regulatory restrictions, proximity to human settlements, the cultural, economic and sustenance value of coconut palms, workforce availability and skillset, accessibility to control sites, prevalence of invasive species, and the integrity of the island ecosystem are key factors to assess in determining the best site-specific approach for conservation-based management of abandoned copra plantations.

After removal of abandoned coconut palm plantations, the re-establishment of native broadleaf trees preferred by seabirds for nesting and roosting is essential for maximising the beneficial seabird-derived nutrient subsidy to the island and near-shore marine ecosystems (Benkwitt et al. 2019, 2022; McCauley et al. 2012). Reforestation can occur via natural recruitment from existing seed banks, natural seed dispersal, and from planting (Jeffery 2014).

Environmental monitoring is a critical part of any conservation intervention as it demonstrates the ecosystem response to the management action. Managers planning similar management actions should consider designing before-after-control studies to quantify changes to forest composition, seabird abundances and distribution, nutrient concentrations in land and sea habitats, water quality, and coral reef health.



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