MECHANICAL CONTROL OF MICONIA CALVESCENS: EFFICACY OF CONTROLLING AN INVASIVE SPECIES WITHOUT CHEMICAL OR BIOLOGICAL INTERVENTION

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Abstract. Worldwide, biodiversity loss threatens the availability of ecosystem services and, by extension, the economies that rely on these services. *Miconia calvescens* is among the most ecologically devastating invasive alien species (IASs) in the Pacific Islands region, where it has expanded its invasive range to include Hawaii, New Caledonia, and parts of the Society Islands, French Polynesia, including the islands of Tahiti, Moorea, Raiatea, Tahaa, Huahine, and Mehetia. In Tahiti, over two-thirds of native forests have been overtaken by *M. calvescens*. In Moorea, an island roughly 20 km northwest of Tahiti, individuals and volunteer groups have used novel control techniques in an attempt to contain the spread of *M. calvescens*. The purpose of this study was to quantify the effectiveness of a novel manual control technique for *M. calvescens*, wherein a seedling is uprooted and hung upside-down from a tree to dry. Relative water content (RWC) was used as a proxy for plant health. Tests were conducted in pairs, with a control group hung using twist ties as fasteners to prevent specimens from falling to the ground. A treatment group was hung without fasteners. The treatment group was found to fall at a significantly higher rate than the control group. Specimens in the treatment group that fell and were recovered were compared with their control counterparts and found to have significantly higher RWCs, indicating they may be less likely to die and more likely to resprout. This study supports the use of biodegradable fasteners, which could be distributed at trail heads to encourage community involvement in controlling *M. calvescens* on the island of Moorea.

Key words: Miconia calvescens*; invasive alien species (IASs); invasive plant; management strategies; French Polynesia; Mo'orea; control technologies; community engagement*

INTRODUCTION

Worldwide, biodiversity loss is occurring at an unprecedented rate, negatively impacting the availability and quality of ecosystem services (Estes *et al.* 2011). The degradation of ecosystem services unequally impacts various regions of the world (Sutton 2011, Karampela *et al.* 2016). Therefore, it is imperative that biodiversity conservation funds be directed both into regions of high conservation value and into regions of high economic reliance on ecosystem services (Briguglio 1995).

Oceanic islands are hotspots for biodiversity. Using a metric known as endemism richness, Kier *et al.* (2009) assigned conservation values to 90 biogeographic regions spanning most of the terrestrial globe. The study included 14 island regions and 76 mainland regions. Oceanic and continental islands were not categorized separately. When compared with mainland regions, island regions were found to have significantly higher endemism richness values for vascular plants, vertebrates, reptiles, birds, and mammals, falling within the top sixth of all regions studied for all categories. Half of the 20 regions with the highest conservation value were island regions, despite accounting for significantly less land mass than mainland regions.

In addition to being more biodiverse than mainland regions, islands tend to be particularly vulnerable to invasive alien species (IASs). As stated by Russell *et al.* (2017): "The small size of islands leads to smaller populations, and their isolation creates evolutionary distinctiveness (Losos and Ricklefs 2009), species impoverishment (Simberloff 2000) and taxonomic disharmony (Williamson 1981) with the absence of some functional groups (Cushman 1995), which together create greater vulnerability to the impacts of IASs."

Island economies tend to rely disproportionately on ecosystem services (Briguglio 1995, Burnett *et al.* 2010, Russell *et al*. 2017). In French Polynesia, a territory of France, ecosystem services constituted 8 of the region's top 10 export commodities in 2013, with over half of all export value coming from a single commodity (pearls) (Poirine 2010). Notably, however, the economy of French Polynesia relies heavily on financial inputs from France. Small island developing states (SIDS) with independent economies are significantly more vulnerable to disruptions or losses to economic services than island territories receiving financial assistance from a governing nation, and the further development of SIDS relies on their ability to increase exports (Jaunky 2011).

The green cancer: Miconia calvescens

The melastome *Miconia calvescens* is among the most ecologically devastating invasive plants in the Pacific Islands. Initially introduced to the region as an ornamental plant species, *M. calvescens* has subsequently spread through numerous islands in the Pacific mid-latitudes (González-Muñoz *et al.* 2015). In French Polynesia, *M. calvescens* has invaded Tahiti, Moorea, Raiatea, Tahaa, Huahine, and Mehetia of the Society Islands, and at least two-thirds of Tahiti's forests have been overtaken by *M. calvescens* (Meyer *et al.* 2011). Footholds of *M. calvescens* have been established in Nuku Hiva and Fatu Iva of the Marquesas as well as the Hawaiian Islands of Maui, Hawaii, Kauai, and Oahu (Burnett *et al.* 2010).

A number of factors contribute to *M. calvescens*' success as an invader. In as few as four years, *M. calvescens* can grow from seed to reproductive maturity. Once mature, a single individual can produce millions of seeds annually, each of which is 0.5 mm in diameter and can survive in the soil for over a decade (Meyer 1998, Burnett and Wada 2016). Once *M. calvescens* establishes itself in an area, it is capable of forming dense, tall (up to 15 m), monotypic stands that prevent native plant species from returning to the area by significantly reducing light penetration through the forest canopy (Meyer and Florence 1996).

Case study: Hawaii

The State of Hawaii spends in excess of $1 million annually on *M. calvescens* control, with efforts split between application of herbicides (on the ground and aerially) and manual removal by ground teams. An economic study was prepared for the Hawaiian government to determine the net benefit of various hypothetical biocontrol programs. The study found that each of the hypothetical options— using a suite of biocontrol agents or a single biocontrol agent with a particular establishment rate (3, 5, or 7 years) and efficacy (50%, 77.5%, 92.5%, or 100%) released either in 2014 or 2019– would result in net benefits when the value of native habitat was considered. However, the magnitude of benefit from the alternatives considered varied by approximately an order of three— from a minimum of $12.8 million (single agent released in 2019 with a 7-year establishment period and efficacy of 50%) to a maximum of $36.1 million (single agent released in 2014 with a 3-year establishment period and efficacy of 100%) (Chock *et al.* 2010). Despite significant economic inputs, *M. calvescens* has not been eradicated in Hawaii (Burnett *et al.* 2010).

Manual removal

Sometimes used in combination with biological and/or chemical controls, manual controls have been widely applied in efforts to contain or eradicate *M. calvescens* in French Polynesia, Hawaii, and New Caledonia (Meyer *et al.* 2011). The relative simplicity, minimal risk, and low economic input required of manual control efforts have facilitated the use of volunteer groups (even schoolchildren) as ground teams (Meyer *et al.* 2011). The merit of incorporating manual removal methods into *M. calvescens* control strategies is as of yet unclear. Despite their numerous benefits, manual removal methods have not been systematically evaluated for efficacy. Manual removal has the potential to be considerably less expensive than chemical and biological controls because of its low up-front costs. Furthermore, manual control methods can be applied by individuals (and, in particular, volunteers) without special skills or training. There are, nonetheless, significant drawbacks to manual controls, including the need for a large labor pool and consistent applications. However, used in conjunction with other methods, manual controls may be suitable for long-term, low-cost containment strategies in SIDS or other economically limited regions.

Invasion of Moorea

The island of Moorea lies northwest of Tahiti in the Society Islands, French Polynesia. Following its introduction to Tahiti in 1937, *M.*

calvescens was unintentionally spread to the island of Moorea, roughly 20 km away (Meyer and Florence 1996). Consecutive distribution studies have been conducted to determine the extent of *M. calvescens* on Moorea (Schwartz 1993, Bock 1997). Over the 4-year period between these distribution studies, the range of *M. calvescens* increased markedly, especially in the valley regions. In 2000, the biological control agent *Colletotrichum gloeosporioides* f. sp. *miconiae* (*Cgm*) was released in Tahiti, later spreading to Moorea. One study of the impact of *Cgm* on *M. calvescens* in Moorea found *Cgm* to be more effective at higher elevations, where moisture is more readily available and where *M. calvescens* tends to grow more readily (Chen 2009). However, the same study suggested that the biocontrol *Cgm* was unlikely to effectively control *M. calvescens* in Moorea.

Present study

The present study aimed to quantify the efficacy of a manual control technique for *M. calvescens* seedlings which was observed to be in practice by the author of this study. The technique involved the uprooting and subsequent hanging of a seedling from a tree, where it was left for a period of time. While investigating the efficacy of this "uproot and hang" technique, several questions were considered: (1) whether relative water content (RWC) of leaves can be used as a proxy for *M. calvescens* seedling health, (2) whether *M. calvescens* hung from trees tended to remain in place, and (3) whether the fate of *M. calvescens* seedlings that fell from their respective hanging locations varied from that of those that remained in place.

METHODS

Study site

This study took place on the island of Moorea, part of the Society Islands, French Polynesia. Experiments were conducted within the Opunohu Watershed along and nearby to a hiking trail known as Three Pines, which is accessible from Belvedere Point. All field trials were executed in trees located near a marae within a 10-meter vicinity of one another to minimize differences in canopy cover, temperature, humidity and wind exposure.

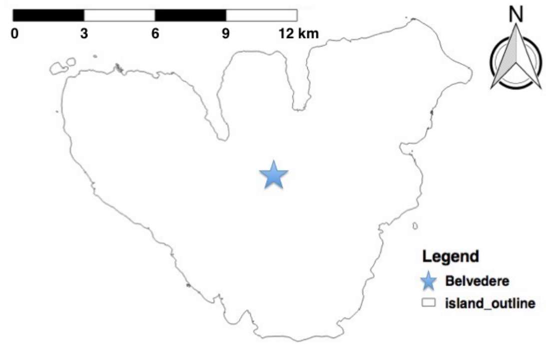

FIG. 1. All field trials were conducted along Three Pines Trail, accessible from Belvedere Point (S 17.53550° W 149.82561°).

Specimen choice

M. calvescens specimens used for laboratory and field experiments were size-restricted to individuals whose height (measured vertically from the location where the stem emerges from soil) was approximately 3 - 8 cm.

Laboratory experiment

To determine the range of relative water contents (RWCs) for a typical *M. calvescens* seedling, specimens were collected in the field and immediately sealed in individual bags. Specimens were promptly returned to the UC Gump Research Station, where their leaves were weighed ("wet weight") before being placed into a drying oven at 300° F. Usable leaves were restricted to healthy leaves—minimal, if any, herbivory; no chunks missing; etc.— and the oldest and youngest leaves were excluded. Plants with fewer than 3 usable leaves were excluded from statistical analyses. Dry weight values were accepted once the leaf set for a plant maintained a consistent weight over two measurements on a milligram-precision scale (to within +/- 5 mg). Typically, leaves were completely dried (i.e., no further change in weight) within 12-16 hours. Once the wet and dry weights of each leaf set were determined, the RWC (ratio of wet minus dry weight to dry weight) of that set was calculated.

The laboratory experiment was conducted on groups of specimens collected on 3 different days (3 trials). Each trial was considered individually in addition to combining data from all 3 trials. To determine whether the RWCs of *M. calvescens* seedlings were normally distributed, the excess kurtosis and skewness were calculated for each trial individually and for all of the trials combined.

Field experiment

A field experiment was conducted on paired groups of *M. calvescens*. Within each pair, one specimen was randomly chosen to be in the control group while the other was in the treatment group. In all cases, the control group was hung with a twist tie to prevent specimens from falling, while the treatment group was hung without a twist tie. Specimens were paired (one treatment, one control) and hung in close proximity to one another to prevent changes in RWC caused by minute differences in hanging location (e.g. distance from ground, placement beneath tree leaves, radial distance from tree trunk, etc.) Treatment groups were placed so that they would not fall under the environmental conditions at play during hanging. However, no additional consideration was taken to account for possible changes in precipitation, wind patterns, or animal interference. When hanging treatment specimens, every attempt was made to mimic the real-life application of this technique by community members or volunteers.

After a period of 5 days, specimens were collected from the field and brought to the UC Gump Research Station, where their RWCs were determined according to the protocols outlined above (see *Laboratory experiment*). Specimens that fell during the sampling period and could not be found were considered lost, while specimens that fell and were identified and retrieved were considered recovered.

To determine whether there was a significant difference in the number of plants that fell between the control and treatment groups, a Pearson's Chi-squared test with Yates' continuity correction was used. To determine whether there was a significant difference in the RWCs of the control and treatment groups (lost and recovered plants excluded), a two-tailed paired t-test was used. Finally, sample pairs with a recovered plant were isolated and a two-tailed paired t-test was used to determine whether the recovered plants had significantly higher RWCs than their control counterparts.

RESULTS

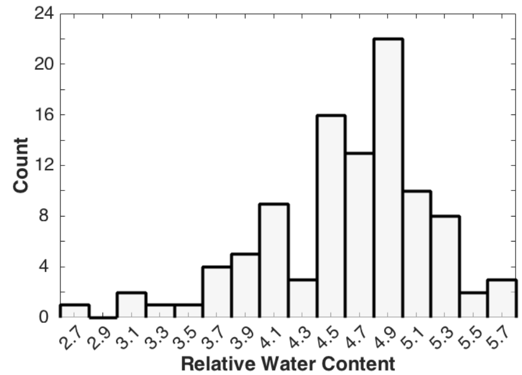

FIG. 2. Relative water contents (RWCs) of *M. calvescens* specimens used in the laboratory experiment (Trials 1-3) reveal a non-normal distribution.

The RWCs of *M. calvescens* seedlings were found not to fall within a normal distribution when considered together (excess kurtosis = 0.93, skewness = 0.00080). When individual trials (that is, individual collection days) were considered, the results more closely resembled tailed normal distributions, with Trial 1 being the most normal and most skewed (n=16, excess kurtosis = 0.24, skewness = 0.42), Trial 2 being the least normal and least skewed (n= 18, excess kurtosis = 0.52, skewness = 0.067), and Trial 3 having similar results to Trial 1 (n = 66, excess kurtosis = 0.31, skewness = 0.41).

A Pearson's Chi-squared test with Yates' continuity correction was applied to determine whether the incidence of falling was significantly greater in the treatment group than in the control group. This study found that the treatment group (which was unfastened) fell at a significantly higher rate than the control group ($p < 0.05$).

In order verify that the fastening method (a twist tie) did not unintentionally sway the RWC of control plants, a two-tailed paired t-test was used to compare the RWCs of control and treatment groups. The results of this test, which excluded pairs with lost or recovered treatment specimens, indicated that there was no significant difference in the RWCs of control and treatment specimens ($p > 0.05$). The two-tailed paired t-test was similarly applied to determine whether the RWCs of recovered plants (which spent time on the forest floor during the start of rainy season) varied from the RWCs of their corresponding controls, and found that recovered plants had significantly higher RWCs ($p < 0.05$) despite a small sample size (n = 7 pairs).

DISCUSSION

The present study found that the RWCs of *M. calvescens* seedlings could be modelled using a moderately normal distribution within trials, but not across trials. This suggests that the RWCs of *M. calvescens* seedlings may be normally distributed under a constant set of environmental conditions (temperature, relative humidity, sunlight, etc.), e.g. within a given area on a particular day, but that fluctuations in environmental conditions may strongly influence the distribution of RWCs.

The RWCs of the treatment and control groups were found not to differ significantly, alleviating concerns that the use of a twist tie might interfere with the drying process if this technique were applied in the future at wider scale. The author would like to propose the possibility of a field campaign targeting *M. calvescens* seedlings along major trails in Moorea. The budget for such a campaign would be relatively low, requiring signage (including background and instructions) at major trailheads, biodegradable twist ties, and a staff-member or volunteer to refill the twist ties. While such a program would not encompass all of the invaded areas, it may help to reduce the spread of *M. calvescens* seeds by human vectors by reducing the spread of *M. calvescens* in well-treaded areas.

The significantly higher RWCs of recovered plants in comparison with their control counterparts suggests that *M. calvescens* specimens that fall to the ground may die more slowly or, if capable and under appropriate environmental conditions, resprout. These results pose interesting questions for continued research. Firstly, do *M. calvescens* seedlings that fall to the forest floor actually die? Secondly, are *M. calvescens* seedlings capable of resprouting under ideal conditions? And finally, if *M. calvescens* are capable of resprouting, are the environmental conditions in Moorea sufficient for resprouting to take place? A future study might observe the growth patterns of fallen seedlings over a period of several months to determine this.

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