The Invasive Alien Tree *Falcataria moluccana*: Its Impacts and Management

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Abstract

Falcataria moluccana (Miq.) Barneby and Grimes is a large tree that has become invasive in forests and developed landscapes across many Pacific islands. A fast-growing nitrogen-fixing species, it transforms invaded ecosystems by dramatically increasing nutrient inputs, suppressing native species and facilitating invasion by other weeds. Individuals rapidly reach heights of 35 m, and their massive limbs break easily in storms or with age, creating significant hazards in residential areas and across infrastructure corridors such as roads and power lines. Their management is extremely costly for landowners, utilities, and local governments, since removal of hazardous trees can cost several thousand dollars apiece. Although efficient mechanical and chemical controls are being used with some success against incipient invasions of *F. moluccana*, biological control is needed to manage spread of populations and the massive seedling recruitment that occurs once mature individuals have been killed. The benefits of a biological control program for *F. moluccana* would likely extend to tropical islands throughout the Pacific, helping prevent further loss of native forest biodiversity and saving many millions of dollars in damage and maintenance associated with these trees growing near utilities, roads, homes and workplaces.

Introduction

Alien species have caused untold damage to the ecology and economies of areas they have invaded (Elton, 1958). Where such species introduce new biological processes or disturbance regimes into ecosystems, they have the potential to profoundly alter both community characteristics and ecosystem functions, often to the extreme detriment of the native flora and fauna being invaded (Vitousek et al., 1987; D'Antonio and Vitousek, 1992). The invasive alien *Falcataria moluccana* (Miq.) Barneby and Grimes (synonyms: *Paraserianthes falcataria* (L.) I.C. Nielsen, *Albizia falcataria* (L.) Fosberg, *Albizia falcata* auct) is a very large, fast-growing, nitrogen-fixing tree in the legume family (Fabaceae) (Wagner et al., 1999). Recognized as the world's fastest growing tree species, it is capable of averaging 2.5 cm gain in height per day (Walters, 1971; Footman, 2001). Individuals reach reproductive maturity within four years and subsequently produce copious amounts of viable seed (Parrotta, 1990) contained within seed pods that can be wind-dispersed over substantial distances (i.e., > 200 m up- and down-slope during windy conditions). Mature trees can reach heights over 35 m, with the canopy of a single tree extending over a one-half hectare area. The broad umbrella-shaped canopies of multiple trees commonly coalesce to cover multiple hectares and even up to square kilometers (Hughes and Denslow, 2005). An important constraint to *F. moluccana* seedling recruitment is light availability; seedlings are very sensitive to shade and germinate in abundance only where the overstory canopy is open enough to allow sufficient light penetration (Soerianegara et al., 1994).

Although valued by some, *F. moluccana* has become invasive in forests and developed landscapes across many Pacific islands. Native to the Moluccas, New Guinea, New Britain, and Solomon Islands (Wagner et al., 1999), *F. moluccana* was exported widely across the Pacific, typically for the purpose of providing shade and nutrients (via litterfall) to crop species. It is currently considered invasive in the Republic of Palau, Pohnpei, Yap, New Caledonia, Fiji, Independent Samoa, American Samoa, the Cook Islands, the Society Islands, and the Hawaiian Islands, and it is present though not yet considered invasive on Guam, Wallis and Futuma, and Tonga (USDA Forest Service, 2012). Given the widespread presence of *F. moluccana* across the Pacific Islands, it poses a serious threat to the highly diverse biological hotspot that these islands collectively constitute (Myers et al., 2000). An archetypical early successional (i.e., pioneer) species, *F. moluccana* is generally found in mesic to wet forest and favors open, high-light environments such as disturbed areas; its capacity to readily acquire nitrogen via its symbiotic association with *Rhizobium* bacteria allows it to colonize even very young, nutrient-limited lava flows such as those found on Hawaii Island (Hughes and Denslow, 2005).

Falcataria moluccana was first introduced to the Hawaiian Islands from Borneo and Java in 1917 by the explorer botanist – and champion of native Hawaiian species – Joseph F. Rock (Rock, 1920). He noted the rapid growth rate of *F. moluccana*, stating that it is capable of reaching a height of over 35 m in 25 years time and that, "trees nine years old had reached a height of over a hundred feet, a rapidity of growth almost unbelievable." Ironically, Rock also commented on the life cycle of *F. moluccana* that "the only objection to the tree is its short-lived period, but as it is an abundant seeder, there should always be a good stand of this tree present" (Rock, 1920), yet individuals planted by Rock in 1917 remain living today, nearly 100 years later, on the grounds of the Lyon Arboretum on Oahu, Hawaii. Following its introduction, *F. moluccana* was one of the most commonly planted tree species in concerted, long-term, and wide-ranging non-native tree establishment efforts conducted by Hawaii Territorial and State foresters during the early to mid-1900s; approximately 140,000 individuals were planted throughout the Forest Reserve systems across the Hawaiian Islands, and populations have spread extensively from those intentional plantations (Skolmen and Nelson, 1980; Woodcock, 2003).

Ecological Impacts

Previous research on the impacts of *F. moluccana* on native forests in Hawaii has demonstrated that this species profoundly transforms invaded forests by dramatically increasing inputs of nitrogen, facilitating invasion by other weeds while simultaneously suppressing native species. Hughes and Denslow (2005) described the impacts of *F. moluccana* invasion on some of the last intact remnants of native wet lowland forest ecosystems in Hawaii. They found that primary productivity in the form of litterfall was more than eight times greater in *F. moluccana*-dominated forest stands compared to stands dominated by native tree species. More importantly, nitrogen (N) and phosphorus (P) inputs via litterfall were up to 55 and 28 times greater in *F. moluccana* stands compared to native-dominated forests (Hughes and Denslow, 2005), and rates of litter decomposition – as well as rates of N and P release during decomposition – were substantially greater in *F. moluccana* invaded forests relative to native-dominated forests (Hughes and Uowolo, 2006). These inputs of up to 240 kg N ha^{-1} y^{-1} in *F. moluccana* stands exceed typical application rates of N fertilizer documented for industrial, high output corn cropping systems of the US Midwest (Jaynes et al., 2001). As a consequence, soil N availability was 120 times greater in *F. moluccana* forests relative to native-dominated forests on comparably-aged lava flow substrates. Simultaneously, *F. moluccana* invasion increased soil enzyme – particularly acid phosphatase – activities and converted the fungal-dominated soil communities of native stands to bacteria-dominated soil communities (Allison et al., 2006). These profound functional changes coincided with dramatic compositional and structural changes; *F. moluccana* facilitated an explosive increase in densities of understory alien plant species – particularly strawberry guava (*Psidium cattleianum* L.). Native species – particularly the overstory tree, ʻohiʻa lehua (*Metrosideros polymorpha* Gaud.) – suffered widespread mortality to the point of effective elimination from areas that they had formerly dominated. Based on these findings,

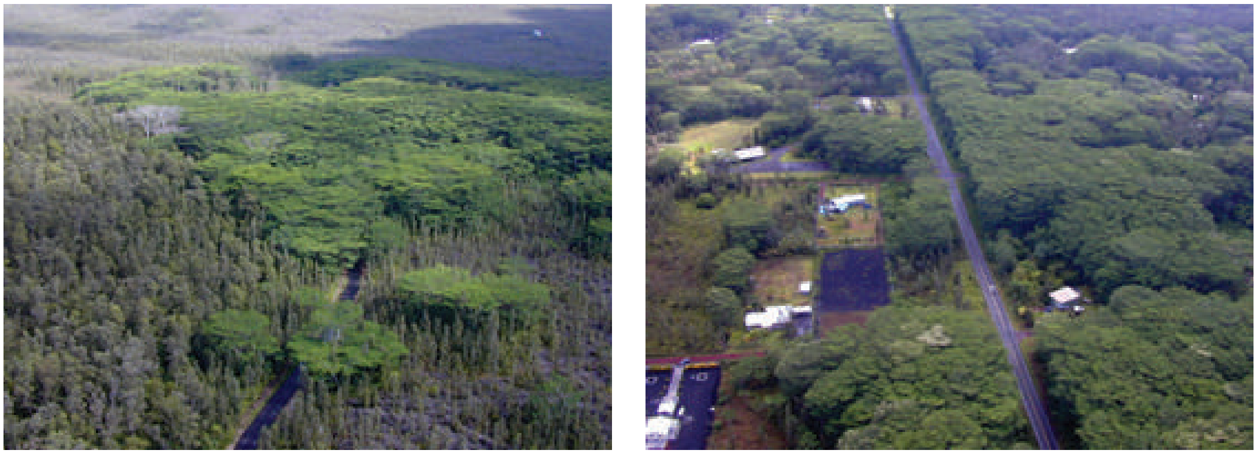

Figure 1. Invasion by *Falcataria moluccana* on Hawaii Island within Keauohana Forest Reserve (left) and in a residential area (right).

Hughes and Denslow (2005) concluded that the continued existence of native-dominated lowland wet forests in Hawaii largely will be determined by the future distribution of *F. moluccana* (Figure 1).

In American Samoa, where *F. moluccana* (locally known as tamaligi) was introduced in the very early 1900s and was present across 35% of the main island of Tutuila by 2000, an aggressive campaign has been undertaken by federal, state, and local groups to control and ideally eradicate this invasive species from the island (Hughes et al., 2012). Research addressing the role of *F. moluccana* in Samoan native forest communities supports the need for control as well the feasibility of eradication in these ecosystems. Results indicate that *F. moluccana* displaces native trees: although aboveground biomass of intact native forests did not differ from those invaded by *F. moluccana*, greater than 60% of the biomass of invaded forest plots was accounted for by *F. moluccana*, and biomass of native species was significantly greater in intact native forests. Following removal of *F. moluccana* (i.e., killing of mature individuals), the native Samoan tree species grew rapidly, particularly those which exhibit early successional, or pioneer species traits. The presence of such pioneer-type tree species appeared to be most important reason why *F. moluccana* removal is likely a successful management strategy; once *F. moluccana* is removed, native tree species grow rapidly, exploiting available sunlight and the legacy of increased available soil N from *F. moluccana* litter. Recruitment by shade intolerant *F. moluccana* seedlings was severely constrained to the point of being non-existent, likely a result of the shade cast by reestablishing native trees in management areas (Hughes et al., 2012). Thus, although *F. moluccana* is a daunting invasive species, its ecological characteristics and those of many of Samoa's native trees actually create conditions and opportunities for successful, long-term control of *F. moluccana* in lowland forests of American Samoa.

Socio-Economic Impacts

Falcataria moluccana is also a roadside, urban forest and residential pest of major significance. Because individuals rapidly and routinely reach heights near 35 m and their weak wood breaks easily in storms or with age, catastrophic failure of massive limbs creates major hazards in residential areas and across infrastructure corridors such as roads and power lines. For example, on April 16, 2010, a 25-30 m tall *F. moluccana* tree fell across a residential street in the Puna District of Hawaii Island, destroying power lines and fences and landing in a backyard area where children often play (Hawaii Tribune Herald, May 6, 2010). Management of these large hazardous trees is extremely challenging for landowners, utilities, and local governments (Figure 1).

The potential economic burden posed by *F. moluccana* is staggering. In 2009 on the island of Kauai, the Hawaii Department of Transportation (HDOT) was compelled to act on two unconfirmed near fatalities involving large branches of *F. moluccana* dropping onto cars and a house located close to the road right-of-way. In response, the HDOT spent one million dollars to remove approximately 1,500 *F. moluccana* individuals growing along a single mile of roadway. Because *F. moluccana* has such soft wood and unstable branches, arborists were forced in this case to employ expensive cranes and lifts to remove these trees. As a consequence the larger trees cost in excess of $10,000 per individual to remove safely. Across the state of Hawaii, it has been estimated that over 40% of HDOT damage claims involving falling trees and branches are due to *F. moluccana* and between 50 and 100 miles of state roads have maturing *F. moluccana* populations (personal communication, Christopher A. Dacus, Landscape Architect and Certified Arborist, Hawaii State Department of Transportation). Even where *F. moluccana* grow at some distance from roads, they are considered problematic and hazardous because limbs can fall into waterways and accumulate against bridges, potentially causing flooding and physical damage to critical infrastructure. In addition, natural events such hurricanes or storms often cause extreme damage to *F. moluccana* stands which in turn contribute to road closures, electrical outages, and property damage, thus exacerbating post-storm and cyclone cleanup and repair work. With no natural predators to constrain them, *F. moluccana* populations are increasing in both stature and area, with concomitant maintenance costs increasing annually.

Control Measures

Successful efforts to control *F. moluccana* populations within the National Park of American Samoa (NPAS) and adjacent lands employed a girdling method. Field crews of 2–6 people incised the bark of each mature individual at its base using bark spuds and manually peeled up the bark in large strips around the entirety of the trunk, resulting in a 1–3 m wide girdled section. Individual trees died gradually but inevitably, six months to a year following treatment. NPAS field crews have killed over 6,000 mature trees, thus restoring approximately 1,500 ha of native Samoan forest. This approach has been successful for three main reasons. First, significant funding was available to implement *F. moluccana* control across the targeted areas. Second, overwhelming public support for the *F. moluccana* control effort has been cultivated through outreach and informational meetings with local village leadership, employment of villagers from areas adjacent to infestations, and use of media outlets on a consistent basis. Third, *F. moluccana* exhibits characteristics that make it vulnerable to successful control: it is easily killed by girdling or herbicides, and its seeds and seedlings are exceedingly shade intolerant, while many of the common native Samoan tree species recover quickly from disturbance, and the shade they cast preempts subsequent *F. moluccana* seedling recruitment (Hughes et al., 2012).

Herbicides also have proven to be effective in controlling saplings and larger, mature *F. moluccana*. On the Hawaiian Island of Molokai, the Molokai-Maui Invasive Species Committee spearheaded a multi-agency effort in 2008 to eliminate a large stand of *F. moluccana* with extensive root systems threatening sensitive cultural sites (Wianecki, 2011). Field crews girdled the trees with chainsaws and applied Garlon 3A mixed with crop oil. Significant canopy defoliation was noted within weeks of treatment. Mortality of treated trees was 98% one year following application, and 100% with no subsequent seedling recruitment in the 3 years since treatment. As of this writing, all known populations of *F. moluccana* on Molokai have been killed, providing a compelling example of island-wide eradication of this highly invasive tree. As in American Samoa, the *F. moluccana* control project was successful in bringing together a diversity of community members, agency staff, and cultural practitioners. Participants are determined to use this project as a model for community involvement and creating a proper emphasis on Hawaiian cultural practices.

Encouraging recent advances in the development and use of another herbicide, Milestone® (EPA reg. no. 62719-519; active ingredient aminopyralid), have provided a highly effective means to quickly and efficiently kill mature *F. moluccana*. Milestone is administered by injection of very low volume, metered doses of the undiluted formulation. Trials indicate that very low dosage treatments resulted in near 100% mortality in less than one month. This new method – demonstrated to be safer and more effective than current conventional methods – appears to be a "game changer," allowing efficient control of *F. moluccana* populations across broad landscapes of Hawaii (personal communication, James Leary, Invasive Weed Management Specialist, University of Hawaii; http://www.ctahr.hawaii.edu/LearyJ/videos/albizia.html).

Biological Control

While girdling and herbicide can provide effective means to kill *F. moluccana* saplings and mature trees, more challenging is control of the massive seedling recruitment that occurs once mature individuals have been killed. This is particularly true in Hawaii, where fast-growing pioneer-type tree species are not common in the native flora (Wagner et al., 1999). Identifying appropriate biological control agents is a logical and compelling solution to this challenge. Already at least one natural enemy of *F. moluccana* appears worth investigation: the gall rust *Uromycladium tepperianum* (Sacc.) McAlpine has been identified as a damaging pest of *F. moluccana* grown in plantations of Southeast Asia (Rahayu et al., 2010).

Recent biological control programs targeting alien *Acacia* species in South Africa have met with considerable success by focusing on agents that attack reproduction and reduce spread of trees from existing stands (Hoffmann et al., 2002; Post et al., 2010). In another successful effort in South Africa, seed feeders have been employed to control a close relative of *F. moluccana*, the Australian tree *Paraserianthes lophantha* (Willd.) I.C. Nielsen (Donnelly, 1992; Dennill et al., 1999). Seed predators make sense as a potential biological control agent for *F. moluccana* given that ongoing herbicide trials demonstrate the ease of killing mature trees: if post-control seedling recruitment could be minimized through seed predation, effective control of *F. moluccana* populations in Hawaii might be feasible. The benefits of a combined chemical and biological control program for *F. moluccana* would likely extend to tropical islands throughout the Pacific. Further loss of native forests and biodiversity, as well as extremely high costs in damage to private property and public infrastructure, can be expected from *F. moluccana* invasion if chemical and biological control work is not initiated.

Conclusions

Previous research and recent experience demonstrate that unchecked invasion by *F. moluccana* poses significant threats to native ecosystems and human health and welfare across the Pacific Islands. Successful containment of *F. moluccana* by self-perpetuating biological control agents, along with improved chemical control measures, are needed to sustainably manage native ecosystems and to save many millions of dollars in damage and maintenance costs associated with these trees growing near utilities, roads, homes and workplaces.

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