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Controlling Fire Tree (*Myrica faya*) in Hawaii

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Introduction

Myrica faya, or firetree, is an invasive exotic plant species in the Hawaiian Islands. Firetree is native to the Azores, Madiera, and the Canary Islands off the northwest coast of Africa in the Atlantic Ocean. Firetree alters ecosystem processes in ways that allow it to out compete the native vegetation of affected ecosystems in Hawaii. By primarily changing the nutrient balance of affected ecosystems, invasion of firetree leads to the alteration of vegetation succession. Ultimately, firetree increases the invasibility and disrupts native community dynamics of Hawaiian natural areas, and as a result, jeopardizes the survival of Hawaii's native plant communities. The system most affected by firetree is the seasonal sub-montane rainforest which is an early successional and open-canopied ecosystem; however, firetree will colonize a wide range of habitat.

Vitousek and Walker (1989) state that colonists from Europe and Asia, beginning in the 18th century, introduced many plant species into Hawaii for agricultural, medicinal, and ornamental purposes. Firetree was among these many introductions and was probably used for ornamental or medicinal purposes. In the 1920s and 1930s, the Territorial Department of Forestry planted firetree for watershed reclamation until its invasive qualities were recognized; unfortunately, firetree had already colonized five of the six main islands of Hawaii (Vitousek and Walker 1989). The invasion of firetreee into Hawaii Volcanoes National Park (HAVO) began in 1961 and became extensive enough for intensive control to be initiated. By 1977, firetree infestation had spread across 12,200 hectares in HAVO and 34,365 hectares in the Hawaiian Islands (Vitousek 1990).

In 1955, the search for biological control agents began with the entomologist, F.A. Bianchi, under sponsorship from the Hawaii Territorial Board of Agriculture, who traveled to firetree's native habitat. However, research was abandoned because the most promising agent was found to attack valued trees in Hawaii, such as mango and avocado (Gardner 1992). Later, research involved herbicidal programs, however, these programs involved too much labor and had other inherent disadvantages. Biological control is a current focus of research. This paper will discuss the biology that allows *Myrica faya* to be a successful invader and the resulting ecological impacts in the invaded Hawaiian ecosystems. The approaches to control this invasive in Hawaiian natural areas, primarily, the effectiveness and feasibility of chemical and biological methods will be characterized.

Geography and Climate of Hawaii

The Hawaiian archipelago is a small chain of volcanic formed islands located in the Pacific Ocean. Hawaii consists of 6 main islands. The climate of Hawaii is highly influenced by its proximity to the ocean (about 95 percent of Hawaii is within 20 miles of the coast) and its mountainous terrain (Blumenstock and Price 1994). Marine affects (mainly precipitation) are lessened on the leeward side of mountains, resulting in drier ecosystems. Fifty percent of Hawaii's elevation reaches 600 meters and 10 percent reaches 2100 meters, therefore, the landscape is characterized as mountainous. Hawaii is within the tropical zone, however, its climate occupies a wide range of world climatic zones. Lastly rainfall and temperature characterize the most variable climatic features (Blumenstock and Price 1994).

Hawaii's geographical pattern of climates inherently affects the diversity and composition of its ecosystems. These ecosystems can be ordered into the following vegetation zones: strand, coastal, dryland forest and shrub, mixed mesic forest, rain forest, bogs, subalpine woodland, shrubland, and desert, and cliffs. The result is a unique assemblage of vegetation on the Hawaiian landscape. According to the Hawaii Tropical Forest Recovery Task Force (1994) rainforest ecosystems dominated the main islands of Hawaii in pre-settlement time, approximately 1500 years ago. However, by the late 1700s, most of these forests had become severely altered or stressed through nearly 1000 years of agricultural disturbance and species introductions by Polynesians. These disturbances were then followed by European settlement, which brought degradation to an explosive scale through further introductions and more direct exploitation of the land.

Affected Ecosystems

In Hawaii, the problem of exotic invasive plants and animals is highly detrimental to native populations. Approximately 86 exotic species pose a considerable threat to native biota (Vitousek and Walker 1989). The ecosystem of most concern to firetree invasion is primarily the dry seasonal sub-montane rainforest, although, a wide range of ecosystems and production landscapes are also negatively affected by firetree's invasion (Vitousek and Walker 1989). The rainforests that are most invaded are early successional sites, disturbed primarily by volcanic lava flows and cinder ash deposits (Vitousek and Walker 1989). These sites often have an open-canopied or interspersed pattern due to the uneven occurrence of disturbance. According to Mueller-Dombois (1981) evergreen species (*Metrosideros polymorpha*), along with the legume tree (*Acacia koa*) are the dominant vegetation types in the rainforests; also present are the native tree ferns (*Cibotium spp.*). *Metrosideros'* distribution pattern has a wide habitat range which includes the warmer tropical-dry climate, where it is the dominant native species (Mueller-Dombois 1981). *Metrosideros* is also a primary successional pioneer species and would likely colonize volcanic cinderfalls and lava flows first, which, like most early primary successional sites, are nitrogen-limited (Vitousek 1989). However, firetree is also a primary successional pioneer and would also colonize these disturbed sites. The effect of *Metrosideros'* early establishment has been found to create a safe habitat for firetree. Firetree is then able to occupy these open-canopied sites of *Metrosideros.*

Invasive Biology of Firetree

The successful invasion of firetree is primarily due to its biology and Hawaii's high invasibility. Vitousek and Walker (1989) state that every successful invader interacts with its site, often exploiting or altering its environment for the benefit of its survival. This affected site may be conducive to invasion through its available open niches or safe places for which the invader can easily colonize. According to Loope (1992), the Hawaiian Islands provide a powerful example of islands' high invasibility, with the idea (held common among natural scientists, including Darwin) that island biota are lacking in adaptive capacity. Loope (1992) outlines these following four theoretical reasons as to why islands are highly invasible: (1) archipelagos are isolated from powerful selective forces of continents; (2) the Hawaiian Islands have been highly altered by humans; (3) Hawaii has low species numbers relative to continental systems, and also, important taxonomic [or functional groups] are entirely absent, such as large mammals, ants [and nitrogen-fixing plants]; and (4) species in Hawaii have low aggressiveness and are highly vulnerable to extinction. The early successional sites invaded by firetree are lacking the nitrogen-fixing functional group (Vitousek and Walker 1989). Nitrogen is the limiting resource in these ecosystems, and therefore, any species that has the ability to fix nitrogen could potentially out compete other pioneer species.

Firetree's capacity to fix nitrogen is aided by its actinorrhizal symbiosis with *Frankia*, and provides the biological advantage that allows it to out compete and dominate other early successional native species. Nitrogen fixation is the conversion of di-nitrogen gas to ammonium, which is the inorganic form of nitrogen. Ammonium is the most usable form by plants and micro-organisms. Once ammonium is released into the soil it undergoes many transformations through processes such as nitrification and denitrification. Most importantly, nitrogen fixation transforms unavailable nitrogen into a form that can be exploited for energy, which eventually will be released into the soil environment to become available among many organisms as an energy source.

Vitousek (1990) has suggested the importance of individual species as controlling factors on whole ecosystems. He relates firetree's ability to alter the sites it invades through the alteration of the nutrient balance by increasing nitrogen inputs 4-fold. This added nitrogen to the system increases firetree's rate of growth and the total pool size of available nitrogen in the site, which ultimately allows further invasion by other opportunistic and invasive species. Increased rates of nitrogen mineralization and nitrification indicate that the total pool of nitrogen available in the soil increases under firetree (Matson 1990). Matson (1990) found that colonization of other invasives was not correlated with firetree's invasion. Apparently, the dense canopy cover of firetree shades out the entire understory. It seems likely, however, that with any amount of firetree dieback, other invasive species would rapidly exploit the increased nitrogen and available light energy.

In addition to firetree's ability to fix nitrogen, the several other characteristics make firetree a successful invader. Wind-pollination allows firetree's independence from pollen-vectors; production of male and female flowers on one plant allows one species to found a whole community; and, prolific seed production (ranging from 40,000 to 400,00 fruits/year) and rapid growth allows the rapid spread of firetree.

According to Vitousek and Walker (1989), several factors make the open-canopied sites invasible to firetree. *Metrosideros sp.* are good perch trees for birds, which are firetree's primary seed dispersers. The primary dispersing agent of firetree fruit is the exotic Japanese white-eye (*Zosterops japonica*). Seed drop also leads to population growth by nucleation. Further, there is partial shade at ground level allowing for firetree's successful germination. At the same time, there is enough light at ground level for firetree to grow fast and fix nitrogen (Vitousek and Walker 1989). The population growth of firetree has been evaluated and it is estimated that in 1 year >150 mature firetree would establish from seeds of 21 adults (Vitousek and Walker 1989). This estimation expresses how rapidly firetree spreads. Ultimately, firetree creates dense monospecific stands and sparse understory; this homogenization of the landscape is a significant alteration in ecosystem dynamics (Whiteaker and Gardner 1992).

Control measures/management techniques

Currently there are no proven long-term control methods for firetree in Hawaiian natural areas (Whiteaker and Gardner 1992). The need for a long-term control method assumes a very high cost when considering any method that is labor-intensive. Physical and chemical control methods have been successful in certain situations, however, because these methods are too labor-intensive they are not currently considered for control in the natural areas most affected by firetree (the sub-montane rainforests). Firetree's most successful invasions occur in upper-elevation rainforests that are highly inaccessible in terms of transporting equipment and machinery. Physical removal is most common in agricultural landscapes where machinery can access firetree.

Biological control offers certain potential advantages over herbicidal and mechanical methods including longevity and self-dispersal of the agent into the environment. Biological control, although initially research intensive, could potentially offer long-term control which over time, would diminish in the amount of overall management and labor input (Gardner 1998). There are disadvantages of biological control however, mortality is often slower and less perceptible, and there is less complete control of the agent (Gardner 1998). The latter concern is the cause for so much required initial research and laboratory testing.

Chemical Control

Research by Donald E. Gardner from Hawaii Volcanoes National Park in the early 1980s focused on finding the least labor-intensive method of chemical treatment on firetree. Herbicidal control agents that have been tested include: 1) 4% Kuron in diesel oil; 2) Tordon 22K; and 3) Roundup (glyphosate). Chemical control of firetree is often not feasible because the sites most highly invaded are within Hawaiian Volcanoes National Park where herbicide is avoided at all costs. However, Gardner and Kageler (1982) investigated the efficiency and environmental soundness of herbicidal treatments in the early 1980s, acknowledging that the intensity of firetree invasion allows permission of chemicals as appropriate control agents. This research found that injection of undiluted Roundup was a more successful treatment to previous herbicidal control programs. The previous control program composed a treatment of 4% Kuron in diesel oil, which involved spraying the solution on the lower tree stems so that a 0.5 meter wide area around the stem would be treated. Although this program was effective, Gardner (1982) acknowledged that transporting the required large amount of solution became difficult and costly, the use of oil as opposed to a water-based solution was an inconvenience, and further, treatment was limited to windless and dry days to avoid exposure to non-target, native species. However, the practice of spraying inevitably exposes native plants, because firetree often grows right next to or is interspersed with native vegetation.

Roundup was found by Gardner (1982) to be the most efficient herbicidal treatment because of its effectiveness in undiluted form and through its rapid absorption rate (30-40 minutes). In its undiluted form, Roundup can be used in small quantities (5-10 ml per tree). Tordon 22K was also effective in small quantities of undiluted form, however, absorption rate was intermediate (24-48 hours). Kuron absorption rate was slow (more than 1 week). Treatment of undiluted Roundup or Tordon 22K allowed for the reduction in treatment quantity. The smaller quantities of treatments necessary due to the elimination of a solution reduced the amount of total treatment needed out in the field, therefore reducing labor and transportation costs. The absorption rate of Roundup allowed for the rapid reuse of tube sections, which affected the amount of equipment needed in the field. Also, the absorption rate (30-40 minutes) allowed the field workers to leave the site shortly after application allowing for quicker site-to-site application (Gardner 1982).

Gardner's research results concluded that injection of undiluted Roundup provided the least exposure to nearby non-target species. Environmental soundness is related to the chemical's rapid inactivation in the soil by micro-organisms, which is well proven in the appropriate soil conditions of the target ecosystem (Gardner 1982). The appropriate soil conditions for rapid inactivation often are is the result of temperature and pool size of nutrients already present, thus providing an inviting and optimum habitat for micro-organisms. It seems an appropriate assumption that firetree the soil these conditions. Therefore, trace amounts of chemical treatment locked within dead plant material will most likely be degraded by soil fauna. It is highly improbable then, that Roundup will enter the soil environment (Gardner 1982).

Biological Control

The goal of biological control is often not to eliminate the invasive, but to lessen its impact, by suppressing its aggressiveness and allowing the native flora to compete. Invasive species control in

Hawaii Volcanoes National Park has focused on “Special Ecological Areas,” or areas that are ecologically important and/or intact, in a report by Tunison and Stone (1992). Firetree was included as being one of three most costly target species in this paper. The prioritizing of sites into “Special Ecological Areas” seems to be a feasible goal towards firetree control because this process acknowledges the limitations of current control of firetree. In addition, these priority sites may provide the suitable scale for field experiments and research.

Classical biological control involves importing the target-species’ native enemy (disease or insect) into the nonnative target ecosystem. This method involves intensive research on the foreign control agent in quarantine and has proven to be very expensive and time-consuming. Insects as control agents are a common practice, although the use of plant pathogens is relatively new in the field. Diseases or insects that already exist in Hawaii and that cause target species’ decline are manipulated to intensify their effect. As a result, the insect or pathogen does not have to be imported or quarantined (Gardner 1998). This “alternative” approach to control holds most promise in future control research (Duffy and Gardner 1994).

Botrytis cinerea is the first locally established pathogen that has been found to diminish the survival of firetree communities. Duffy and Gardner (1994) report *B. cinerea* as one of the more promising control agents because it poses little or no threat to native species in firetree’s range. This fungus causes fruit rot, which ultimately affects the reproductive capacity and spread of firetree populations. Infection of *B. cinerea* was found by Duffy and Gardner (1994) to significantly reduce firetree seed viability from 66 to 16.8% in 1992 in a site in Hiawaii Volcanoes National Park. The infected fruit were also found to be less attractive to birds, therefore lessening the spread of firetree. Interestingly, firetree’s spread would be much more widespread without *B. cinerea* having a control factor on it already; apparently, the effect of this fungus, until now, was not easily perceptible among firetree populations.

Firetree is infected by *Botrytis cinerea* through fruit-feeding adult insects and larvae, which, as vectors, carry the infection from plant to plant. Two compatible vectors, *Amorbia emigratella* and *Cryptoblabes gnidiella.* These vectors can be artificially-reared through the inoculation of *Botrytis* in the laboratory (Duffy and Gardner 1994). Duffy and Gardner (1994) have suggested that the level of control on firetree could be enhanced through the introduction of a high number of *Botrytis* infected vectors into stands of firetree during the early fruiting season. In fact, they urge that locally established agents be considered before foreign insects or pathogens because these agents have already established themselves in a niche, which expresses their compatibility to the community and environmental dynamics of the target system. Furthermore, introduced foreign agents could weaken the effects of locally established agents on the target species, therefore diminishing the naturally occurring control of firetree (Duffy and Gardner 1994).

Conclusion

The invasion of exotic species in Hawaiian natural areas is a topic of great concern among preservationists and conservation scientists. The invasion of the introduced exotic species, *Myrica faya*, or firetree, typifies the right situation for which research and methodology can be tested because its cause-effect relationships are so well understood; furthermore, firetree exemplifies a powerful force of change on ecosystem and community dynamics. Through its ability to fix nitrogen, firetree alters the natural nitrogen dynamics of the early successional submontane rainforest ecosystem in Hawaii, characterized by frequent volcanic disturbances. These sites are naturally nitrogen-limited because they lack a native nitrogen-fixer, and therefore provide an open niche for which firetree can invade. Through increasing nitrogen input 4-fold, firetree increases the total available nitrogen pool, which ultimately will allow other invasive species to exploit the affected ecosystems and out compete the native species on these sites. Funding for the control of firetree and other invasives is necessary if the future of Hawaii’s unique assemblage of ecosystems is to be preserved. Funding should encourage research that aims towards long-term control and preservation of ecologically important systems in Hawaii. This analysis of control on *Myrica faya* expresses promise that biological control will suppress firetree's continued and pervasive spread upon the sub-montane rainforest landscape. Through understanding the controlling factors of individual species on whole ecosystems, the importance and devastation of invasive species will become more apparent, although currently, their impacts in the future are largely unpredictable.

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