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# Potential economic impact of introduction and spread of the red imported fire ant, *Solenopsis invicta*, in Hawaii

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ABSTRACT

Globally, many invasive alien species have caused extensive ecological and economic damage from either accidental or intentional introduction. The red imported fire ant, *Solenopsis invicta*, has created billions of dollars in costs annually, spreading as an invasive species across the southern United States. In 1998, the red imported fire ant spread into California creating a highly probable future introduction via shipped products to Hawaii. This paper presents the estimation of potential economic impacts of the red imported fire ant (RIFA) to the state of Hawaii. Evaluation of impacts focuses on the economic sectors of (1) households, (2) agriculture (cattle and crop production), (3) infrastructure (cemeteries, churches, cities, electrical, telephone, and cable services, highways, hospitals and schools), (4) recreation, tourism and business (hotels/resort areas, golf courses, commercial businesses and tourists), and (5) government expenditures (with minimal intervention). The full annual economic costs of the red imported fire ant to Hawaii are estimated (in US$ 2006) to be $211 million/year, comprised of $77 million in damages and expenditures and $134 million in foregone outdoor opportunities to households and tourists. The present value of the projected costs of RIFA over a 20-year period after introduction total $2.5 billion. RIFA invasions across the globe indicate that economic cost-effective action in Hawaii entails implementation of prevention, early detection and rapid response treatment programs for RIFA.



## 1. Introduction

The number of species being transported beyond their native range has increased with globalization resulting in increased non-native species invasions worldwide. Introduced alien species have led to extensive environmental change globally and cause over $120 billion in annual economic costs in the United States alone (Vitousek et al., 1997; Pimentel et al., 2000, 2005). Invasive alien species are considered the primary risk factor for 42% of species classified in the United States as threatened or endangered (Pimentel et al., 2005).

Oceanic islands are especially vulnerable to invasion by non-native species (Loope and Mueller-Dombois, 1989). The Hawaiian islands contain an extraordinary amount of endemic species serving as a showcase for biotic evolution in isolation and adaptive radiation, with genera of plants far exceeding diversity observed in the Galapagos Islands (Williamson, 1981). Not surprisingly, Hawaii is by far the most damaged U.S. region from alien species invasions (Loope, 1998). The loss of over 70% of Hawaii's endemic land bird and snail species is unequaled in any other region of the United States (Steadman, 1995; Loope, 1998). Habitat destruction played an important role in historic

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species loss, but the impacts of invasive species contributed greatly to past declines and are now the predominant cause of biodiversity loss in Hawaii (Loope, 1998). Beyond the risk of damage to native biota, Hawaii is a world-class tourist destination with a diverse agricultural industry and outdoor lifestyle that are also at risk from alien species invasions.

An imminent invasive alien species threat that could have broad economic and ecological effects in Hawaii is the red imported fire ant, *Solenopsis invicta*. The red imported fire ant (RIFA) is a notoriously destructive and aggressive stinging ant that is highly invasive and has so far proven impossible to eradicate once broadly established. It has invaded more than 125 million ha in the southern U.S. since the 1930s despite a US federal quarantine. RIFA invaded California in 1998, posing an enormous risk to Hawaii due to its high volume of trade with California (Krushelnycky et al., 2005). Since 2001, RIFA has been found in Australia (McCubbin and Weiner, 2002), New Zealand (New Zealand Ministry of Agriculture and Forestry, 2006), Malaysia (Na and Lee, 2001), Taiwan (Chen et al., 2006), China (China Daily, 2005), and Hong Kong (Xinhau News Agency, 2005), greatly exacerbating the risk to Hawaii.

In the continental U.S., RIFA seriously impact public health and safety, agriculture, many industries, biodiversity, and quality of life. Their aggressive nature and powerful sting have caused injury and death to people, wildlife, livestock, and pets (Vinson, 1997; Williams et al., 2001; Wojcik et al., 2001). They tunnel underneath and cause the collapse of roads (Banks et al., 1990), curtail outdoor recreation activities, and commonly infest and damage electric and other equipment such as power distribution systems, communication systems, traffic signals, airport runway lights, air conditioners, computers, well pumps, and irrigation systems (Vinson, 1997; Vinson and Mackay, 1990). RIFA can nest and forage indoors, causing problems in homes, businesses, and other buildings (Vinson, 1997; Rupp and deShazo, 2006). Consequently, regular pesticide use in infested areas is often necessary to protect people, resources, and industries (Vinson, 1997; Williams et al., 2001).

RIFA usually nest in the ground, and prefer nesting in sunny areas (Vinson, 1997). Colonies occur at high densities, grow rapidly and reach exceptional sizes. Colony density can exceed 500 colonies per hectare, with each mature colony containing up to 200,000 workers (Vinson, 1997). Large numbers of RIFA workers rapidly swarm when the colony is disturbed, and each individual ant can deliver multiple painful stings. Consequently, more than half of people living in RIFA infested areas are stung each year (DeShazo et al., 1999). RIFA prefer open, disturbed habitat such as pastures, lawns, and roadways, but are generally capable of colonizing any area with temperatures greater than −12 °C, about 25–50 cm of rainfall annually or other sources of water, and at least some exposure to sunlight (Wojcik, 1983; Vinson, 1997; Korzukhin et al., 2001). In Hawaii, they are likely to invade most areas, except dense rainforest and the highest-elevation areas on Hawaii's volcanoes (VanGelder and Korzukhin, 2001; Morrison et al., 2004). If RIFA invade Hawaii, they have the strong potential to negatively affect agricultural lands, parks, residential and other private properties, tourist destinations, and native biodiversity, especially Hawaii's invertebrates and ground nesting birds. Krushelnycky et al. (2005) indicate that RIFA could be ''the most destructive'' of introduced ant species in Hawaii.

RIFA is a major pest to various economic sectors (Miller et al., 2000; Thompson and Semenov, 2001), costing an estimated $6 billion annually in the U.S. (Drees and Lard, 2006). In California, damages were forecasted by University of California researchers to range from $3 to $9 billion over the next 10 years if RIFA were left unchecked (Jetter et al., 2002). This damage has inspired heroic eradication efforts in newly invaded locations. Australia has spent $137 million (AUD 175 million) since 2001 trying to eradicate RIFA (Queensland Dept. of Primary Industries and Fisheries, 2007), and New Zealand has spent over $6.1 million (over NZD 9 million) since 2001 responding to three RIFA incursions (Sarty, pers. comm., 2007).

Given the high risk of a RIFA invasion of Hawaii, the purpose of this study is to estimate the potential economic costs to Hawaii from RIFA in the case of introduction and establishment. Benefits of stopping a RIFA invasion include the avoidance of these RIFA costs. Analyses are conducted to: (1) highlight the potential economic damages and economic sectors at risk from a RIFA invasion in Hawaii, and (2) address policy options for decision-makers attempting to minimize the economic costs from a RIFA invasion.

## 2. Methodology

Impacts of RIFA in Hawaii are estimated from expenditures and damages experienced currently throughout the southern United States, and applied to Hawaiian economic sectors in consideration of the level of local production and consumption, and sector size. Economic impacts are estimated under minimal governmental intervention concerning the spread of RIFA with expenditures limited to facilitating individuals and groups to perform ant treatments. Minimizing economic costs of a RIFA introduction at the state level involves addressing the tradeoff between abatement costs (i.e. costs of aversion, eradication, or control) and damages to economic sectors caused by RIFA represented as

$$\mathrm{MIN}\,\mathrm{TC}_{\mathrm{invasion}} = \int_0^t (A + D)\,e^{-rt}\,dt \tag{1}$$

where TC is the total cost of a RIFA invasion, $A$ abatement costs per year (costs of governmental efforts to avert, eradicate or control RIFA), $D$ economic damages (costs) per year incurred from the spread of RIFA, $r$ discount rate, and $t$ is the time since introduction of RIFA.

Fig. 1a presents potential scenarios for annual costs of an alien species invasion over time (the area under the curve representing total costs of the invasion). Scenario 1 represents a worst-case scenario in which delayed governmental intervention attempts to halt an alien species invasion that is virtually uncontrollable due to population size and rapid spread resulting in high total economic costs (maximum economic damages + failed abatement efforts). No effort by the state or federal government to stop an alien species results in little to no abatement costs and results in annual costs that include extensive economic damages from the alien species (scenario 2). Scenario 3 includes state intervention that occurs shortly after introduction and results in lower total costs by eventually controlling the alien species and driving down annual costs.

Hobbs and Humphries (1995) highlighted that in general a diminishing ability to control an invasive species occurs with an increase in the invasive species population and time since initial introduction (see Fig. 1b). In Hawaii, examples of diminishing ability to control a spreading alien species abound including intensive heroic efforts to control the plant species *Miconia calvescens* on Maui (a species that decimated native biodiversity in Tahiti, Meyer and Florence, 1996; Medeiros et al., 1997) and failed efforts to control spread of the coqui frog, a species native to Puerto Rico (Raloff, 2003; Beard and Pitt, 2005).

Once established, species are often difficult or impossible to eradicate due to a lack of economic resources, political will, knowledge, or eradication techniques (Myers et al., 1998). Many examples of failed eradication attempts exist, such as the infamous attempt to eradicate the red imported fire ant from the southeastern United States in the 1970s (Davidson and Stone, 1989). Without eradication, management options are limited to ongoing control, or doing nothing, both of which can

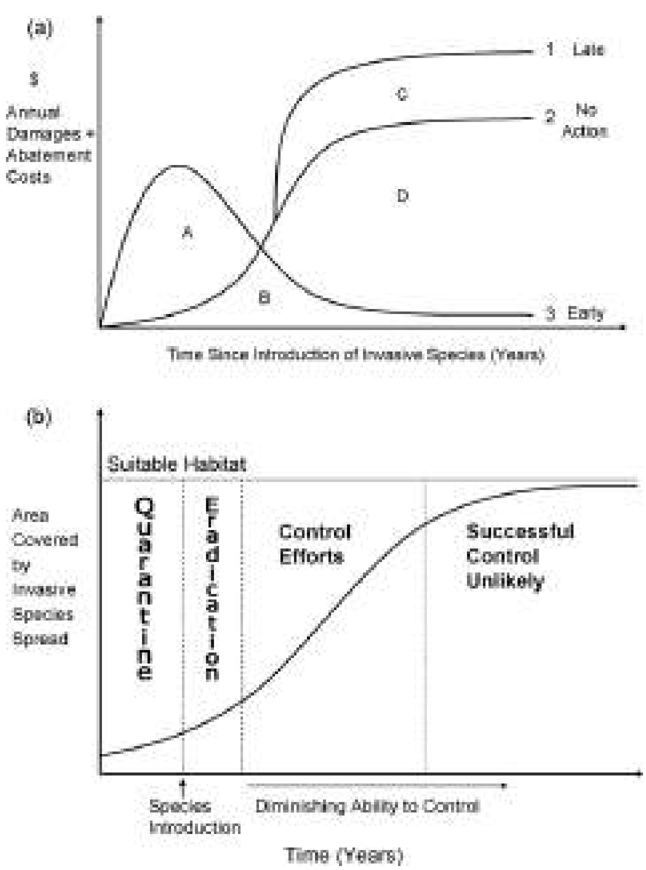


**Fig. 1 – (a) Annual costs of an invasion under three scenarios of alien species management (late response = 1, no action = 2, and early response = 3). Total costs (area under each curve) = damages from invasive species + abatement costs (efforts to avert, eradicate and/ or control the exotic species). Total costs for each scenario include: (1) late response = B + C + D, (2) no action = B + D, and (3) early response = A + B. (b) Sequential management options available for addressing the invasion of an alien species. Ability to control the alien species diminishes with spread of the invasion (after Chippendale, 1991 and Hobbs and Humphries, 1995).**

be costly to the environment, human health, and local economies. Fortunately, with planning, effective techniques, adequate resources, and sustained effort, it is possible to eradicate certain invasive species, especially in the early stages of an invasion, or when the invasion is confined by geography or habitat (Clout and Veitch, 2002). Simberloff (2002) cites numerous examples of successful eradications including those from islands (e.g. Pacific rats from Tiritiri Matangi, oriental fruit fly from Rota and Guam), continental areas (e.g. Taurian thistle from Victoria, African mosquito from 31,000 $km^2$ of northeastern Brazil), and the entire planet (e.g. smallpox).

Abatement costs are greatly influenced by the timing of efforts to avert, eradicate or control an invasive alien species. Diminishing ability to control creates a substantial economic "penalty" (i.e. economic inefficiency) to society when policymakers and government agencies fail to screen for potential invasive species or fail to respond quickly after an introduction. Policy actions are cost-effective when total costs are minimized and abatement costs are less than economic damages the abatement efforts help prevent.

Here, an estimate is derived of the annual economic damages (costs) of a RIFA invasion if the government chooses not to abate the alien species invasion. Estimates provided serve as a baseline for which decision-makers can compare the situation of minimal government intervention to other control options such as preventative measures, early detection programs, eradication or control efforts.

Economic impacts modeled consist of damage, treatment costs (under current technology) and foregone opportunities to economic sectors. Individual and group treatment costs represent individuals attempting to reduce the level of damage from RIFA for which they are at risk given no or little state efforts to stop the RIFA spread. Treatments by individuals are reactionary to the problem and are captured as damages (new costs to households from the RIFA invasion) and not as control costs that would be captured in a coordinated state effort to hinder the RIFA invasion.

All economic impacts of RIFA are reported in US$ 2006. Unit costs from other studies were adjusted for inflation utilizing the Consumer Price Index (in 2006) and adjusted for the higher cost of living in Hawaii using regional Consumer Price Indices for the year-end totals of 2004 (U.S. Dept. of Labor, 2006).[1] All

[1] The difference between the CPI of the original study area to that of Honolulu (the only CPI for Hawaii) was calculated as a percentage for regional CPIs (year ending in 2004). Original unit prices were adjusted by this percentage to obtain estimated unit cost in Hawaii. For unit costs from studies conducted in Texas, we compared the Honolulu CPI to the average of the CPIs for Texas (Houston–Galveston–Brazoria and Dallas/Ft.Worth CPI) to obtain a cost of living adjustment factor of +8.6%. For unit costs from Florida, we compared the Honolulu CPI to the average of the CPIs for Florida (Miami-Ft. Lauderdale and Tampa-St. Petersburg-Clearwater) to obtain a cost of living adjustment factor of +8.8%. For the unit cost for nursery/flower production, we compared the Honolulu CPI to the CPI for the southern region (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Texas, Virginia, and West Virginia) since the unit cost was based on a range of costs from more than one State in that region. The southern urban cost of living adjustment was +4.6% (U.S. Dept. of Labor, 2006).

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economic sectors discussed, except roads, occur exclusively in areas of suitable temperatures for RIFA establishment and each sector is assumed to be located in areas of adequate moisture for establishment of RIFA. RIFA impacts are assumed to occur to the entire sector for all economic sectors except highways.

A deterministic ecological-economic computer simulation model was constructed in STELLA™ to estimate total costs of the invasion and run incorporating the biological spread of the fire ants over a 20-year period utilizing a 3% discount rate. RIFA spread was modeled as density-dependent logistic growth as

$$\frac{dR}{dt} = rs \times R \times \left(1 - \frac{R}{S}\right) - E \quad (2)$$

with $R$ = area covered by RIFA (miles$^2$ or km$^2$); rs = rate of spread per area covered; $S$ = maximum suitable habitat for RIFA spread; $E$ = area eradicated by abatement efforts; $E = f(c, a)$. Rate of spread was limited by the density of RIFA established and the remaining suitable habitat. Maximum suitable habitat was estimated as 95% of land area of the Hawaiian islands. RIFA will most likely establish in open, disturbed areas first incurring high economic costs in areas of high human population density. Economic costs of the invasion were modeled as

$$\frac{dA}{dt} = R \times c \quad (3)$$

$$\frac{dD}{dt} = R \times d \quad (4)$$

$$\frac{dTC}{dt} = (A + D) \times e^{-rt} \quad (5)$$

where TC is the total cost of a RIFA invasion, $A$ abatement costs per year (costs of all types of government efforts to avert, eradicate or control RIFA), $c$ expenditures to eradicate/control per area treated/year; $a$ percent area eradicated per expenditures to eradicate; $D$ economic damages (costs) per year incurred from the spread of RIFA, $d$ damages per area covered/year, $r$ discount rate, and $t$ is the time since introduction of RIFA.

A key determinant in the magnitude of economic impact incurred from a RIFA invasion is the rate at which the fire ants spread across Hawaii. In our analysis, the rate of RIFA spread was conservatively estimated at 5 miles$^2$/year/mile$^2$ inhabited (8 km$^2$/year/km$^2$ inhabited), falling within the range observed for the natural spread of RIFA. Estimates of rates of spread of RIFA range from: 5 to 6 miles/year (8–9.7 km) from natural mating flights (Vandermeer and Lofgren, 1988), 10 miles/year (16 km) under ''normal conditions'' (Markin et al., 1971), to 125 miles/year (198 km) based on their movement westward after introduction in the US in the mid-1930s (Vinson, 1997). From a reproductive standpoint, a RIFA colony can produce alates (i.e. winged reproductives) within 6–12 months after colony founding (Vinson, 1997). Most queens fly less than 0.4 miles (0.6 km), but they can travel up to 10 miles (16 km) or more aided by wind (Markin et al., 1971), potentially advancing a colony over 20 miles (32 km) a year in windy conditions.

RIFA impacts are assessed for the following economic sectors: households; agriculture; infrastructure; and recreation, tourism and business (with major economic sector analysis similar to MAF, 2001). RIFA impacts are also assessed for forgone outdoor opportunities for households and tourists, and for government expenditures under a minimal intervention scenario.

## 3. Results

### 3.1. Household impacts

A wide range of estimates have been derived for the annual household costs from a RIFA invasion (Lard et al., 1999; Miller et al., 2000; University of Arkansas, 2000; MAF, 2001; Thompson and Semenov, 2001). Here, cost estimates for household impacts from the Texas A&M Fire Ant Research Project are utilized to estimate Hawaii household costs. The Texas A&M project conducted extensive surveys of households in both urban and rural areas (Lard et al., 1999, 2001a,b), and their estimates represent mid-range values of household impacts observed in U.S. states infested with RIFA.

In Texas, estimated household costs included: annual pesticide treatment costs; expenditures towards restoring and replacing property and equipment directly affected by RIFA damage; and costs for medical and veterinary treatment of RIFA stings to family members and pets. Cost to single-family households (defined as households living in single-family detached units) was estimated to be $187.26 ($2006) per Texas household (Lard et al., 1999). Costs for households living in multi-family structures were calculated on a per acre basis (i.e. costs to single-family households was translated into cost/acre which was then multiplied by the number of acres occupied by multi-family structures).

In estimating RIFA costs to Hawaii households, we used a cost of $202.98 per household (i.e. Texas cost-per-household (in $2006) plus an 8.6% cost of living adjustment). We defined the number of single-family households as the number of single-detached units in Hawaii according to the US Census (2000). We assumed that unoccupied property would also incur RIFA property damage, and require pesticide treatment to avoid property damage and potential liability issues and therefore did not adjust for vacancy rate (property damage and pesticide treatments represent 91% of household costs in the Texas studies; Lard et al., 1999). We did not include costs to households living in multi-family structures in our assessment as we were not able to obtain acreage occupied by these structures in Hawaii.

We estimate that RIFA would cost 239,626 single-family households $48,639,285/year with the largest proportion of costs going toward pesticide treatments associated with fire ant control (see Table 1). This estimate represents the minimum cost to households in the state, since almost 50% of Hawaii households (those living in single-attached units, multi-unit structures, etc.; US Census, 2000) were not included in our calculation.

### 3.2. Agricultural impacts

Potential impacts of the fire ant on Hawaiian agriculture include those to cattle production, crop production, and flower/nursery production.

**Table 1 – Projected annual economic impact of the red imported fire ant on the economy of Hawaii (US $2006)**

| | Annual cost | (US $2006) |
|---|---|---|
| Households | | |
| Fire ant treatment | $21,398,602 | |
| Medical | $3,057,628 | |
| Repair | $6,206,313 | |
| Replacement | $17,976,742 | |
| Total household damages and expenditures | | $48,639,285 |
| Agriculture | | |
| Cattle production | $1,075,000 | |
| Crop production | $741,844 | |
| Flowers/nursery quarantine costs | $1,519,927 | |
| Total agricultural production costs | | $3,336,771 |
| Infrastructure impacts | | |
| Cities (access to public urban areas) | $2,112,425 | |
| Electrical, telephone and cable | $11,802,233 | |
| Highways | $1,378,899 | |
| Schools | $2,594,630 | |
| Total infrastructure costs | | $17,888,187 |
| Recreation, tourism and business impacts | | |
| Golf courses | $6,486,805 | |
| Hotel/resort areas | $158,364 | |
| Commercial businesses | $306,301 | |
| Total recreation, tourism and business damages and expenditures | | $6,951,470 |
| Government expenditure (w/minimal intervention) | | $77,033 |
| Foregone outdoor activities | | |
| Households | $22,329,012 | |
| Tourists | $112,042,710 | |
| Foregone outdoor activities for households and tourists | | $134,371,722 |
| Total annual RIFA costs to the economy of Hawaii | | $211,264,468 |

#### 3.2.1. *Cattle production*

Costs to cattle production include a wide range of expenditures including repair and replacement costs for equipment and materials, cattle injury and death, losses in hay production, and insecticide expenditures. In Texas, impacts of RIFA on cattle production incur an average annual cost of $5.77/head of cattle (Barr and Drees, 1994, 1996). Adjusted for the cost of living, impacts of RIFA on cattle production in Hawaii were modeled as incurring an average annual cost of $6.25/head. Beef and dairy cattle numbering 172,000 in Hawaii (DBEDT, 2001) will result in an annual statewide cost of $1,075,000. Hawaii county will incur the highest cost to cattle production at $715,000/year.

#### 3.2.2. *Crop production*

RIFA can impact a wide range of crops including grain and arable crops, fruits, vegetables and nuts depending on availability of food sources and climate (MAF, 2001). Exceptions include cotton and sugarcane crops where evidence suggests RIFA may be beneficial by feeding on insects that feed on these crops (Lofgren, 1986; Bessin et al., 1990; Bessin and Reagan, 1993).

Increased annual Hawaii crop production costs resulting from RIFA establishment are estimated at $9.71/acre (acre = 0.4 ha). This figure represents the cost of living adjusted unit cost of $8.95/acre observed for six major Texas crops (Segarra et al., 1999), which falls within a range of crop production RIFA costs reported in other studies ($5.10/acre—Lard et al., 2001b; $9.30/acre—MAF, 2001). Given the large sugarcane industry in Hawaii, and the fact that sugarcane is one of the few crops where RIFA benefits may balance RIFA costs (due to RIFA predation on sugarcane borers), we estimated increased costs to Hawaiian crop production without impacts to sugarcane. Hawaiian crop production totals 76,400 acres without sugarcane, resulting in RIFA related increased crop production costs of $741,844/year.

#### 3.2.3. *Nursery/flower production*

Nursery/flower production will incur greater costs than other crops if RIFA invades Hawaii, due to costs associated with the federal imported fire ant quarantine. All nurseries in quarantined areas must meet federal imported fire ant quarantine regulations in order to ship outside the area. In Hawaii, annual treatment costs required to comply with the federal quarantine are conservatively estimated at $496/acre (per 0.4 ha). This figure represents the inflation-adjusted midpoint between cost estimates from other U.S studies ($125/acre in Georgia—Sparks et al., 1997; $650/acre in South Carolina—

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EDCU, 1998), adjusted for Hawaii cost of living. In Hawaii, nursery and flower products were grown on 3049 acres (NASS, 2002). At $496/acre, increased annual costs for nursery and flower production in Hawaii due to RIFA quarantine compliance alone will total $1,512,304.

### 3.3. Infrastructure Impacts

Potential impacts of RIFA on the infrastructure of Hawaii include impacts to: electrical, telephone and cable services, schools, highways, and public urban areas (cities and counties).

#### 3.3.1. *Electrical, telephone and cable services*

Average annual RIFA cost to Hawaii electrical, telephone and cable companies of repairing and replacing equipment damaged is estimated to be $9.64 per capita. This figure is derived from expenditures of Texas companies at $8.90 per capita (Segarra et al., 1999; Teal et al., 1999) and adjusted for Hawaii cost of living. Adjustments were not made for specific per capita electricity use and communications use across Texas and Hawaii. In Hawaii, with a population exceeding 1.2 million, annual expenditures for the electric, telephone and cable companies will increase $11,802,233/year due to invasion by the red imported fire ant.

#### 3.3.2. *Schools*

Average annual costs of fire ant treatment, and repair and replacement of RIFA damaged equipment at Hawaii schools is estimated at $6,668/school/year. We derived this figured by adjusting expenditures in Texas schools ($6,151/school/year—Lard et al., 1999) to Hawaii cost of living. A majority of the RIFA costs to schools is related to RIFA pesticide treatment, and includes hiring professionals and utilizing school staff to perform these treatments. In Hawaii, RIFA costs are estimated for 255 public schools and 134 private schools statewide (Hawaii Department of Education, 2002; HAIS, 2002). Projected RIFA costs for Hawaii schools in the public and private sectors will total $2,594,630/year.

#### 3.3.3. *Highways*

Roadways offer ideal (i.e. open, disturbed) habitat for RIFA. RIFA tunneling under road surfaces leads to road damage with the formation of potholes as documented in North Carolina and Florida. Expenditures to repair potholes in Florida highways in RIFA infested areas averaged $322/mile ($322 per 1.61 km; Morrison-Silva, 1991). Adjusting for cost of living, RIFA would cost Hawaii $351/mile in road repairs. There are 4127 paved miles (6642 km) of road (DBEDT, 2001) in Hawaii. The vast majority of these are within areas of suitable temperature for RIFA colonization (VanGelder and Korzukhin) and most have sufficient annual rainfall (20 in./year (50.80 cm/year); see Korzukhin et al., 2001) to provide adequate moisture. We used a GIS (Arcview) presentation of Hawaii's major roads together with rainfall isohyets, elevation contours, and the results of a RIFA range prediction study (VanGelder and Korzukhin, 2001) to determine the number of miles of major roads in unsuitable RIFA habitat, and assumed major roads represented paved roads in these areas. Approximate major road miles in areas without sufficient temperatures or precipitation totaled 176 miles (283 km; 4.3% of paved road miles). Projected road damage per year from a RIFA invasion in Hawaii, considering approximately 3951 miles (6359 km) of road are within suitable habitat, will total $1,386,801/year.

#### 3.3.4. *Public urban areas (cities, counties, state)*

Local government will have increased expenditures for treatment, repair and replacement in RIFA areas accessed by the public. Areas include airports, parks, athletic fields, recreational areas, public cemeteries, swimming complexes, public office and building areas (Lard et al., 1999). In assessments of RIFA costs for the metro-complexes of San Antonio, Austin, Dallas, Fort Worth and Houston, metropolitan RIFA expenditures averaged $36.73/acre ($36.73 per 0.4 ha; Lard et al., 1999). Adjusted for cost of living, metropolitan RIFA expenditures would be $39.80/acre in Hawaii. For this study, we defined local government areas that would incur RIFA costs as: (1) all county owned land (since it is mostly in town/urban areas), and (2) all state land that lies within "urban" designated land-use districts. Acreage was calculated using GIS data from the State Department of Business, Economic Development and Tourism (see DBEDT, 2004a). All state lands were not included in our calculation because the majority of state land is undeveloped (state forest, Natural Area Reserve System land, etc.) and is therefore unlikely to have infrastructure that will be damaged or be treated by the state with pesticides (except perhaps, spot-treatment of small high priority sites within these parcels). Thus, 53,076 acres (21,230 ha) of city, county and state land will be affected, costing local governments $2,112,425/year.

### 3.4. Recreation, tourism and business impacts

Potential impacts to recreation, tourism and businesses are assessed for golf courses, hotel/resorts, and commercial businesses.

#### 3.4.1. *Golf courses*

Golf courses have been particularly impacted by the spread of RIFA as the fire ants cause physical damage to the course often colonizing grassy, sunny areas and inhabiting irrigation systems (Lard et al., 1999; MAF, 2001). RIFA costs to golf courses include treatment of grounds, repair and replacement of equipment and medical costs. A significant portion of golf course costs for the five metro areas of Texas was replacement cost of irrigation systems due to fire ant inhabitation (Lard et al., 1999). Average annual RIFA costs at these golf courses totaled $4,003 per hole per year. Adjusted for cost of living, we estimate RIFA will cost Hawaii golf courses $4,339 per hole. In Hawaii, there are 1495 holes on golf courses across the state (DBEDT, 2001). Annual costs to golf courses from full RIFA spread will total $6,486,805.

#### 3.4.2. *Hotel/resort areas*

Hotel and resort areas would incur at least costs similar to public areas of cities and counties ($39.80/acre; $39.80/0.4 ha), for costs of treatment to control ant numbers, and costs to repair or replace RIFA damaged property/equipment. Hotel/resort acreage in Hawaii was obtained from the City and County of Honolulu Real Property Assessment Division, the County of Maui Department of Planning, and the Hawaii

County Office of Research and Development (2001). We used the average of hotel/resort acreage in these counties (612, 1096, and 1276 acres, respectively) for an estimate of the hotel/resort acreage in Kauai County (995 acres). RIFA costs of $39.80/acre were applied to an estimated 3979 acres (1592 ha) of hotel/resort areas statewide, resulting in costs to hotels and resorts totaling $158,364/year. This estimate does not include potential losses due to foregone opportunities of tourists in the event of RIFA establishment (see Section 3.5).

#### 3.4.3. Commercial business

Commercial businesses would also incur costs similar to public areas of cities and counties ($39.80/acre; $39.80/0.4 ha), including costs of treatment to control ant numbers, and costs to repair or replace RIFA damaged property/equipment. Commercial acreage in Hawaii was obtained from the same sources as hotel and resort areas. We used the average of commercial acreage in these counties (2774, 1076 and 1922 acres, respectively) for an estimate of the commercial acreage in Kauai County (1924 acres). Statewide, commercial acreage totals an estimated 7696 acres (3078 ha). Projected increased costs to commercial business due to a full RIFA invasion total $306,301 per year.

### 3.5. Foregone outdoor opportunities

Loss of benefits from the inability to access areas and enjoy outdoor activities due to RIFA are estimated for households, and for tourists.

#### 3.5.1. Foregone outdoor opportunities for households

Surveys in Texas of persons affected by RIFA have indicated that approximately 30% of the people (27% of households; 34% for residents of cities) have limited their outdoor activities due to fire ants (Lard et al., 1999). Utilizing the value put on these activities by persons interviewed, one can derive general estimates for the value of potential foregone activities by persons in Hawaii for similar activities.

Foregone household activities as seen in previous studies include picnicking, gardening, sunbathing, swimming, landscaping, and children playing at $170/year (Lard et al., 1999). Adjusted for Hawaii cost of living, foregone benefits for 27% of all Hawaiian households (i.e. 120,972 HH) at $184.58/year (Lard et al., 1999; DBEDT, 2001) results in $22,329,012/year of RIFA costs to households.

#### 3.5.2. Foregone outdoor opportunities for tourists

In the year 2000, nearly 7 million visitors to Hawaii spent over $10 billion dollars fueling the state economy which has an overall annual state gross product of $40 billion (DBEDT, 2001). Although the events of 11 September lowered aggregate numbers of visitors in 2001, visitors were spending more money at $169/day and staying longer on vacation, over 9 days (DBEDT, 2001). By 2004, tourism rebounded and 6.99 million visitors spent $10.9 billion dollars and stayed on average 9.06 days (DBEDT, 2004b).

In this analysis, 3 out of 10 tourists are estimated to forego outdoor activities as displayed by persons on the U.S. mainland, which include picnicking, sunbathing, swimming and children playing at a cost of $49/affected tourist/year (Lard et al., 1999). Adjusted for Hawaii cost of living, 2.097 million affected tourists/year (out of 6.99 million visitors/year) will incur RIFA costs for foregone outdoor opportunities at $53.43/affected tourist, totaling $112,042,710/year.

### 3.6. Government pest-regulation expenditures (with minimal intervention)

RIFA annual costs are estimated under the assumption of minimal government intervention and include reactive expenditures to a substantial spread of RIFA across Hawaii. An intensive spread of RIFA in Hawaii would eventually require certain government expenditures as seen in Texas such as facilitating effective community management, quarantine (for shipments of high risk materials such as nursery plants), and regulatory and educational activities in infested areas (MAF, 2001; Texas A&M, 2001). These government expenditures are not considered part of a coordinated effort to halt a RIFA invasion, but very small reactionary government expenditures after RIFA has spread in Hawaii (and included as economic damages (costs) under a no-action scenario; Fig. 1a, scenario 2). Minimal government expenditures are estimated at $0.061 per capita/year (based on $0.056 per capita/year in Texas—Texas A&M, 2001) and thus for the state population estimated at 1,262,840 (DBEDT, 2005) would total $77,033/year for the state of Hawaii.

### 3.7. Rate of RIFA spread and total costs

Total RIFA cost to the economy of Hawaii from a full RIFA invasion under minimal governmental intervention is estimated at $211 million/year. Damages and expenditures are projected at $77 million/year and the value of foregone opportunities to households and tourists at $134 million/year.[2]

[2] Pertinent caveats of analysis:

(a) Due to Hawaii's milder climate, it is likely that RIFA will be a year-round problem, as opposed to seasonal (as in Texas), thus incurring higher year round costs than estimated.
(b) Our cost estimates for HH are derived from costs in Texas, where average lot size can be expected to be larger than that found in Hawaii. Larger lot size would increase pesticide treatment costs, however it would have much less influence on costs of property damage/repair, medical costs, etc. Although smaller average lot size in Hawaii might decrease the amount of pesticides used per household, this apparent cost-saving is likely offset by higher costs of pesticides, PCO services, and property repair/replacement in Hawaii correlated to ant density.
(c) Overall RIFA cost estimates are inherently low bound because the analysis has excluded hospitals, cemeteries, and churches due to limited acreage information of these entities.
(d) It is logical to conclude that hospitals, nursing homes, and childcare facilities will have costs above/beyond those of general city per acreage costs because they are dealing with the high-risk population, i.e. individuals that are bed-ridden or cannot get away from ants have incurred fatalities from RIFA in nursing homes.
(e) Agricultural impacts did not include potential adverse impacts to the sugarcane industry.

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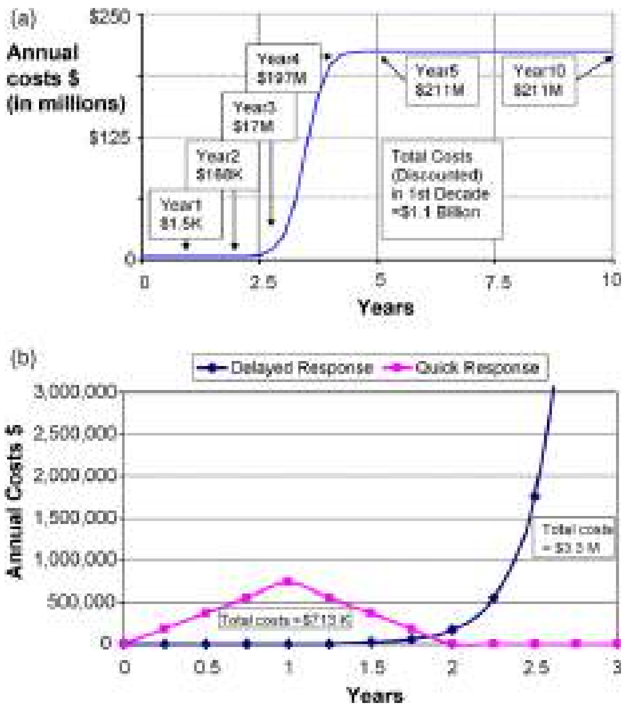


**Fig. 2 – (a) Projected Hawaii annual RIFA costs with minimal government intervention. Total costs of $1.1 billion over the first decade are discounted at 3%. (b) Comparison of delayed RIFA response in Hawaii versus a "New Zealand" quick response approach. Discounted total costs in the first 3 years: quick response = $713 thousand; delayed response = $3.3 million.**

Results of the deterministic ecological economic simulation model indicate that under no government intervention RIFA would cover nearly all suitable habitat in Hawaii within 5 years[3] (see Fig. 2a). Lags between ant colonizers and full effects from ant mound density are estimated to be insignificant due to further RIFA dispersal aided by humans. Present value of the economic costs over a 20-year period (discounted at 3%) from introduction and complete spread of the RIFA in Hawaii total $2.5 billion.

Fig. 2b illustrates the economic penalty of a delayed response to RIFA in Hawaii and highlights the benefits when comparing the New Zealand quick response approach to minimal governmental action. In 2001, a RIFA nest was detected at Auckland International Airport in New Zealand (MAF, 2001; BNZ, 2006a,b). Rapid response and treatment has eradicated RIFA at the site and surveillance has been established to determine if RIFA has spread to other areas of the country at a cost of approximately US$651,000 (Pascoe, pers. comm., 2002). In 2004 and 2006, RIFA was introduced again and eradication efforts were implemented with a quick response (BNZ, 2006a,b). Total eradication and control costs since 2001 in New Zealand for all RIFA invasions total $6.1 million (NZD 9 million; Sarty, pers. comm., 2007).

In Fig. 2b, model runs indicate that in the first few years economic outlays of $713,000 (similar to NZ expenditures) to locate and eradicate a one time RIFA invasion seem comparatively high to damages. However, the benefits of the RIFA abatement efforts (even considering only the first 3 years) are obvious by producing millions in net benefits of eradicating RIFA quickly. Such a high economic return of quick response to a RIFA invasion has already been observed across countries. Australia with a delayed response to RIFA has spent $137 million (AUD 175 million) since 2001 trying to eradicate RIFA which has now spread to over 167,688 acres (67,890 ha; Queensland Dept. of Primary Industries and Fisheries, 2004, 2007). Comparatively, New Zealand has spent just $6.1 million (over NZD 9 million) since 2001 responding to three RIFA incursions with successful quick response eradication and control (Sarty, pers. comm., 2007).

## 4. Discussion and conclusion

RIFA will have a wide range of effects across households, infrastructure, agriculture, tourism, and commercial business in Hawaii (see Table 1). Households will incur a majority of the annual damages and expenditures from RIFA at $48.6 million (63%), followed by electrical, telephone and cable services ($11.8 million; 15%), golf courses ($6.5 million; 8%), agriculture ($3.3 million; 4%), schools ($2.6 million; 3%), cities (public urban areas; $2.1 million; 3%), highways ($1.4 million; 2%) and various other sectors as listed (~1%; see Table 2). The percentage of foregone opportunities to households (11%) and tourists (53%) represents a significant portion of the total costs of a RIFA invasion in Hawaii. Total annual cost of foregone activities to households and tourists is $134 million (64% of the total RIFA costs per year) while total annual damages and expenditures is estimated at $77 million.

Potential damage to Hawaiian endemic plants and fauna from a RIFA invasion would also be substantial. Ant species are predatory and RIFA have been observed decreasing invertebrate population abundance, invertebrate community diversity, and insect biomass and abundance (Porter and Savignano, 1990; Allen et al., 1995; Wilson, 2002; Krushelnycky et al., 2005). The red imported fire ant has also been shown to negatively affect bird populations (Allen et al., 1995; Loope et al., 2001). Here, our economic cost estimates of a RIFA invasion can be considered low bound as we do not attempt to estimate the non-market effects to native biodiversity. Further economic studies may assess these non-market costs estimating the willingness to pay for biodiversity through contingent valuation (i.e. surveys at state and/or national parks in Hawaii) and/or travel cost methods (En Chee, 2004).

One can logically consider a situation in which a full RIFA invasion dampens future tourism growth rates as tourists find substitute travel destinations attempting to avoid parks and beaches filled with stinging red ants (or extensive amounts of

[3] Callcott and Collins (1996) indicated two rates of spread of RIFA in acreage across the Southern U.S. at 365 thousand acres/year (1918–1953) and 5.9 million acres/year (1958–1995). The first rate falls within our model estimates, but a human assisted RIFA spread of 5.9 million acres/year for Hawaii would provide higher cost estimates and indicate that 5 years for complete spread across the islands may be optimistic considering such suitable habitat and temperature occur year round. Yet, annual rates of spread are a function of the base population established and RIFA may display a lag phase as modeled.

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**Table 2 – Projected impact by percentage of the red imported fire ant on economic sectors of Hawaii**

| Economic sector | Annual cost (US $2006) | % of damages and expenditures | % of total RIFA cost |
|---|---|---|---|
| Households | $48,639,285 | 63.3 | 23.0 |
| Electrical, telephone and cable | $11,802,233 | 15.4 | 5.6 |
| Golf courses | $6,486,805 | 8.4 | 3.1 |
| Agriculture | $3,336,771 | 4.3 | 1.6 |
| Schools | $2,594,630 | 3.4 | 1.2 |
| Cities (public urban areas) | $2,112,425 | 2.7 | 1.0 |
| Highways | $1,378,899 | 1.8 | 0.7 |
| Commercial businesses | $306,301 | 0.4 | 0.1 |
| Hotel/resort areas | $158,364 | 0.2 | 0.07 |
| Government expenditure | $77,033 | 0.1 | 0.04 |
| Total damages and expenditures | $76,892,746 | 100% | 36.4% |
| Foregone outdoor activities | | | |
| Households | $22,329,012 | | 10.6 |
| Tourists | $112,042,710 | | 53.0 |
| Value of foregone outdoor activities | $134,371,722 | | 63.6% |
| Total cost per year | $211,264,468 | | 100% |

pesticides to keep RIFA in check). Indirect effects across economic sectors from a RIFA invasion may be substantial with potential negative feedbacks to sectors such as tourism captured in more detailed economic models.

Our economic cost estimates are low bound comprised mostly of direct costs derived from market goods and services with consideration of a few non-market effects of certain tourist activities (picnicking, sunbathing, the opportunity for children to play, and swimming). Even without considering damages to non-market native Hawaiian biota, a relative comparison to the estimated value of Hawaiian coral reefs reveals the magnitude of an invasion of RIFA in Hawaii. Cesar et al. estimated the annual economic benefits of coral reefs in Hawaii ($2002) at $363 million/year with a net present value of $9.7 billion (over 50 years at 3%; Cesar et al., 2002). In economic terms, a full RIFA invasion under minimal governmental response of $211 million/year would incur annual economic costs to the state of Hawaii equivalent to losing nearly 52% of its coral reefs ($211/$409 million in annual coral reef benefits in $2006).

RIFA invasions in other states and countries provide evidence for a diminishing ability to control RIFA over time as New Zealand has apparently controlled RIFA with a quick response (treating only limited nests for $6.1 million, Sarty, pers. comm., 2007) and Australia now hopes for control from a delayed response (167,000 acres or 67,000 ha for $137 million; Davis et al., 2004; Loope, 2004; QDPIF, 2004; BNZ, 2006a,b; Queensland Dept. of Primary Industries and Fisheries, 2007). Our economic costs are derived under one scenario of minimal government action with RIFA economic damages to Hawaii at $211 million/year (see Fig. 2a).

RIFA invasions in other countries and results of ecological economic modeling indicate that cost-effective economic action in Hawaii entails implementation of preventative, early detection and rapid response treatment programs for RIFA. A logical next step will be to quantify a more precise economic marginal cost of control efforts (i.e. amount of RIFA controlled/eradicated per additional dollar allocated towards control effort) for comparison to the damages avoided (i.e. benefits) of control efforts. This study highlights however that minimal governmental efforts to prevent the spread of RIFA in Hawaii will result in substantial economic costs estimated at $2.5 billion over the next 20 years.

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