

**Beyond the Lamppost:
Optimal Prevention and Control of the Brown Treesnake in Hawaii**

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I. Introduction

The threat of invasive species stems from their ability to change, rapidly and irreversibly, ecosystems and the direct and indirect economic services that ecosystems provide. Species spread both accidentally and intentionally, aided by human travel and exchange. Each of several stages of invasion dictates different human response. In general, policy makers must determine the proper balance between “prevention” expenditures that lower the probability of new introductions and “control” expenditures that limit the growth rate and/or the pest population. Optimal policy regarding invasive species will minimize the expected damages and costs of control within an ecosystem and will include full consideration of the cycle of prevention (or avoidance) and control (or removals) needed over time. Rarely, however, have policy makers or economists integrated prevention and control for optimal intertemporal allocation of resources.

The existing literature on the economics of invasive species has taken several complementary approaches to evaluating policy options, but to date these efforts remain rather fragmented across the timeline of an invasion. Due in part to the complexity of bioeconomic modeling and the specificity of biological factors involved in creating ecosystem changes, most case studies focus on preventing entry of new species as a function of trade (Horan et al. 2002; Costello and McCausland 2003; McCausland and Costello 2004; Horan and Lupi 2005a; Horan and Lupi 2005b; Margolis, Shogren and Fischer 2005), preventing or controlling a single invading species (Olson and Roy, 2002; Eiswerth and Johnson 2002; Knowler 2005; Knowler and Barbier 2000; Settle and Shogren 2002; Buhle, Margolis, and Ruesink 2005) or on broader ecosystem damages at a particular location and time (Kasulo 2000; Turpie and Heydenrych 2000).

With few exceptions (Kaiser and Roumasset 2002; Burnett et al. 2006), prevention and control have been handled separately so far in the empirical literature. Typically either prevention or control policies are investigated, but a full characterization of the threat has not yet been laid out. From these efforts, an economics of prevention and control (e.g. Kaiser and Roumasset 2002; Pitafi and Roumasset 2005; Olson and Roy 2005; Perrings 2005) is slowly evolving in which insights and tools of optimal control theory are combined with biological and economic parameters to solve for the optimal expenditures on avoidance and removal over time. Applications, when attempted, have been mainly illustrative to date. In this paper we will illuminate theoretically how expenditure paths change in response to various parameters, and solve for expenditures for every population level and each time period for the real-world case of the Brown treesnake (BTS). We find that the conventional wisdom that “an ounce of prevention is worth a pound of cure” does not reveal the whole story. Depending on the interaction of biology and economics, the message may be much richer than this.

The case of the snake is used to illustrate dynamic policy options for invasive species that may or may not be present, but has a high likelihood of arriving and continuing to arrive, in a new location (Hawaii) and that will cause extensive economic damages if established. For BTS, these concerns include damages to Hawaii’s fragile ecosystems and biodiversity, human health concerns, and infrastructure for power supply.

II. Case Overview: Brown Treesnake (*Boiga irregularis*)

Hawaii faces several threats from invasive species, all of which must be considered simultaneously for optimal avoidance and removal efforts to minimize expected damages to the state's ecological assets and economy. Perhaps the most dramatic candidate for Hawaii's top pest is the Brown treesnake (*Boiga irregularis*). This native of Australia and New Guinea, upon establishment in Hawaii, would introduce snakes² to the islands and create a list of damages that include direct economic impacts as well as widespread ecological disaster.

We infer potential damages from Guam, where the snake was introduced to the previously snake-free island in the 1950s. Since then, high-density populations of 12,000 snakes per square mile have arisen, sending thousands to the hospital with venomous bites over the last 10 years. The snakes have been blamed for the extirpation of 10 of 13 bird species, and currently generate power outages 1.5 hours every other day (up from one every 3-4 days in 1997). Finally, poultry productivity has been adversely affected (See USGS 2005 for recent overview of damages. Detailed power and medical data are courtesy of Stephanie Shwiff, USDA).

The snake is an imminent threat to Hawaii. Eight snakes have been intercepted and verified as BTS in the state since 1981 (Rodda et al. 1999 and Rodda 2005, personal communication). Many more sightings of snakes that were neither caught nor identified have occurred as well. Between 1969 and 1988, over 150 snakes were discovered in the state, with 21 in 1987 alone. Thus experts are unsure of the exact population of BTS in Hawaii, but estimate there may be between 0 and 100 individuals. Trade between Guam and Hawaii is extensive and Hawaii now pays to support Guam's efforts to prevent the Brown treesnake from escaping the island. We use the considerable information from Guam's infestation and expenditures on avoidance to model an integrated avoidance and removal strategy for minimizing expenditures on and damages from the snake.

III. Methodology

We employ optimal control theory to determine the paths of expenditures that minimize the present value of removal costs, avoidance expenses, and damages over time. For the sake of computational simplicity and clarity of exposition, we use a deterministic model. Each period, the snake population is known and new entrants arrive on a continuous basis. The solution involves a steady state population of snakes and corresponding time paths of expenditures on avoidance and removals.

The problem is to:

$$\text{Max} \int_0^{\infty} - \left(\int_{n-x}^n c(\gamma) d\gamma + D(n) + y \right) e^{-rt} dt \quad (1)$$

subject to

² With the exception of *Ramphotyphlops braminus*, a harmless blind snake present in Hawai'i since 1930.

$$\dot{n} = g(n) - x + f(y) \quad (2)$$

$$x \geq 0 \quad (3)$$

$$y \geq 0 \quad (4)$$

n_0 given,

where n is the population of snakes, c is the unit cost of removal, $D(n)$ is the damage function, y is avoidance expenditures, $g(n)$ is the growth function, x is the harvest level and $f(y)$ describes how many new snakes are added to the current population as a function of investment in avoidance.

The current value Hamiltonian for this problem is:

$$H = - \int_{n-x}^n c(\gamma) d\gamma - D(n) - y + \lambda [g(n) - x + f(y)]$$

Application of the Maximum Principle leads to the following conditions:

$$\frac{\partial H}{\partial x} = -c(n-x) - \lambda \leq 0 \quad (5)$$

$$\frac{\partial H}{\partial y} = -1 + \lambda f'(y) \leq 0 \quad (6)$$

$$\frac{\partial H}{\partial n} = -[c(n) - c(n-x)] - D'(n) + \lambda g'(n) = r\lambda - \dot{\lambda} \quad (7)$$

$$\frac{\partial H}{\partial \lambda} = g(n) - x + f(y) = \dot{n} \quad (8)$$

For all internal solutions, we get the following

$$\lambda = -c(n-x) = \frac{1}{f'(y)} \quad (9)$$

Equation (9) states that at every period where there is positive spending on prevention and control, we set the marginal costs of each equal to the shadow price of snakes.

Taking time derivatives of (9) yields

$$\dot{\lambda} = -c'(n-x)(\dot{n} - \dot{x}) = \frac{1}{f''(y)} \dot{y} \quad (10)$$

Equation (8) becomes

$$\dot{n} = g(n) - x + f\left(f^{-1}\left[\frac{-1}{c(n-x)}\right]\right) \quad (11)$$

Substituting (9) and (10) into (7) yields

$$\dot{x} = g(n) - x + f\left(f^{-1}\left[\frac{-1}{c(n-x)}\right]\right) + \frac{c(n) + D'(n) + (g'(n) - r - 1)c(n-x)}{c'(n-x)} \quad (12)$$

Equations (11) and (12) express the dynamics of the system on the n by x plane.

We note that the cost function used here for removals deviates from the standard $c(n)x$ as used in much of the literature. When using a function whose marginal cost of x was a constant for any given value of n , we arrive at a bang-bang solution whose switching function is

$$\sigma(t) = -[\lambda + c(n)] \quad (13)$$

This approach oversimplifies the role of population in the cost function. In standard resource problems, maintaining a high population today beneficially lowers the cost of harvest tomorrow, raising the value of that harvest. With an invasive species providing no benefits from a future population, this cost function is inadequate to respond to the large desired reductions in population in any given period. Because optimal adjustment to the steady state need not be instantaneous, and is unlikely to be feasible if the steady state is significantly lower than the initial population, we adapt the cost function to allow for the increasing costs of removal in continuous time through a non-instantaneous approach to the desired population.

IV. Empirical Investigation

The immediate obstacle to estimating economic impacts to Hawaii, as with any potential invasive species in a new habitat, is that we have no direct evidence on which to base cost, damage, and growth function parameters. Instead, we obtain rough estimates based on indirect evidence from Guam and the subjective assessments of invasive-species research scientists and managers.

The resulting parameters are discussed below, followed by results.

i. Growth function

We utilize the logistic function,

$$g(n) = bn\left(1 - \frac{n}{K}\right), \quad (14)$$

to represent the potential growth of the snakes. In this case, the intrinsic growth rate, b , is 0.6, based on based on estimated population densities at different time periods on Guam (Rodda et al. 1992 and personal communication 2005). The maximum elevation range of the snake may be as high as 1,400 m (Kraus and Cravalho 2001). There are approximately 777,000 hectares of potential snake habitat on Hawaii. Assuming a maximum population density of 50 snakes/hectare, carrying capacity K for Hawaii is 38,850,000.

ii. Damage function

Major damages from the Brown treesnake on Guam include lost productivity and repair costs due to power outages, medical costs from snakebites, and lost biodiversity from the extirpation of native bird species. Using data obtained from Guam, and positing a linear relationship between damages and number of snakes, we derive an equation for damages as a function of snakes.

$$D = 122.31 \cdot n_i . \tag{15}$$

For a more complete look at the derivation of this function, see Appendix 1.

iii. Removal cost function

We assume that marginal removal costs are decreasing in n and increasing in x . Data for current expenditures on snake removal in Hawaii is very limited. To date, sightings of BTS have been reported, but none has resulted in a successful capture. The State of Hawaii recently spent \$76,000 trying to catch a snake³ after a positive sighting was reported.

The primary expense of removing snakes is finding them. For illustrative purposes, we assume that it would cost \$100,000 to find and catch⁴ any one snake out of 100, but \$100,000,000 to find and catch the last snake in Hawaii.

The resulting marginal cost function is:

$$c(n) = \frac{7.16 * 10^6}{n^{0.9284}} \tag{16}$$

iv. Arrival function

³ Following a credible snake sighting (verified by a detailed interview), state and federal agencies employ a rapid response team to search for the snake in question. The search lasts approximately three weeks and often entails paying trained personnel overtime wages and flying specialized searchers out from Guam and other areas. State authorities estimate each program to cost around \$76,000 (although they never have caught a snake).

⁴ This is likely an underestimate, however. On Saipan, where an incipient population is known to exist, no snake has ever been caught after authorities responded to credible sightings.

We assume that avoidance expenditures buy a reduction in the number of snakes that arrive and become established. According to our sources, under current avoidance expenditures of \$2.6 million, Hawaii faces an approximate 90% probability that at least one snake will arrive over a ten-year time horizon. Assuming that each snake arrives independently, this gives us a 20.6% probability of at least one snake arriving in any given year.

If expenditures increased to \$4.7 million, the probability of at least one arrival would decrease two-fold, to about 45% over the ten-year horizon. Finally, if we increase preventative spending to \$9 million per year, the probability of an arrival decreases another two-fold, to about 20%. These percentages correspond to a yearly probability of arrival of 5.8% and 2.2% respectively. We convert these probabilities to expected values using the Poisson distribution.

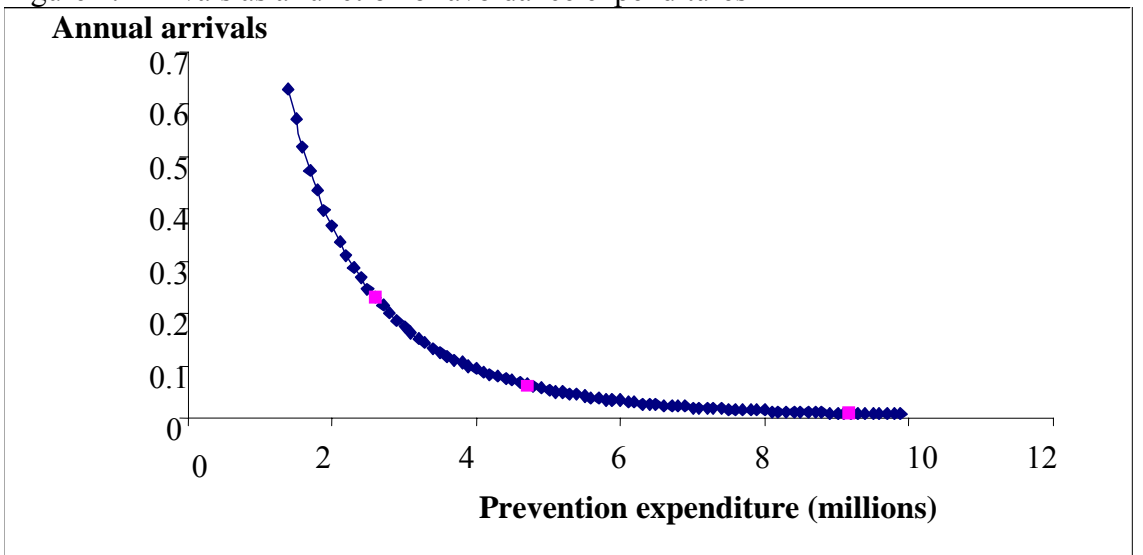
We then use the Weibull distribution to fit the arrival function because of its flexible shape and ability to model a wide range of failure rates (e.g., in engineering, such as capacitor, ball bearing, relay and material strength failures). Here, the Weibull describes failure of the avoidance barrier. The resulting function is

$$\lambda(y) = \exp(2.3 - 0.00224y^{0.5}) \tag{17}$$

Figure 1 illustrates this function.

For more explanation on the Poisson distribution and the Weibull function, see Appendix 2.

Figure 1. Arrivals as a function of avoidance expenditures



v. Optimal avoidance and removal results

As mentioned previously, there is great uncertainty surrounding the present population of snakes in Hawaii, although the number is estimated to be between zero and 100. For this reason, we look at two cases, first, optimal policy if there are no snakes in Hawaii and second, optimal policy given an initial population of 50 snakes.

Given our functional forms, if the current population is zero, then today it is optimal to spend \$6.0 million only on avoidance. Once $n=1.33$, removal expenditures should begin. The optimal path requires a rising removal cost over time as the number of snakes increases. It takes about 10 years to reach $n=46$, and 10 more years to reach $n=145$. The system approaches the steady state population of approximately 543 snakes asymptotically. In the steady state, we spend \$10 million to remove 331 snakes every year and \$84,000 on avoiding 4.78 snakes. The marginal costs of these activities are equal at \$49,600 per snake.

Figure 2. Optimal avoidance and removal expenditure paths

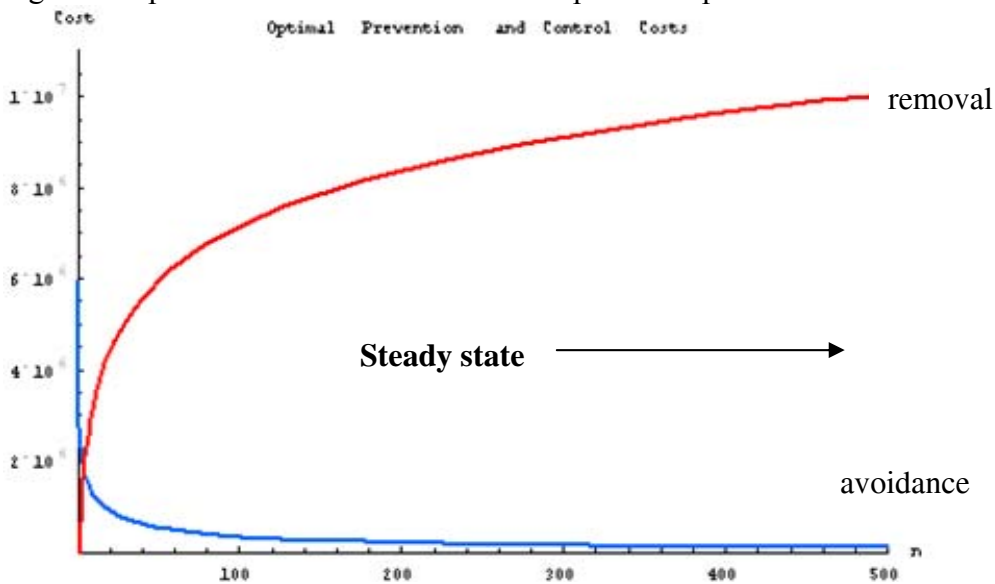


Figure 2 above illustrates the optimal expenditure paths for removing and avoiding snakes in Hawaii. The optimal paths require removal expenditures that increase with population and avoidance expenditures that decrease with snake population. The steady state level of snakes is 543.

Figure 3 below illustrates the time path of avoidance and removal expenditures in the case of zero initial population. Because the steady state population is to the right of both of our assigned initial populations, the time paths in Figures 3 and 4 closely resemble the graph of optimal avoidance and removals as a function of population in Figure 2⁵.

⁵ Figure 4 is simply a truncated version of Figure 3 (the difference is that it takes 14.42 years to reach a population of 50 snakes along the optimal path).

Figure 3. Time path of spending on avoidance and removal when $n_0=0$

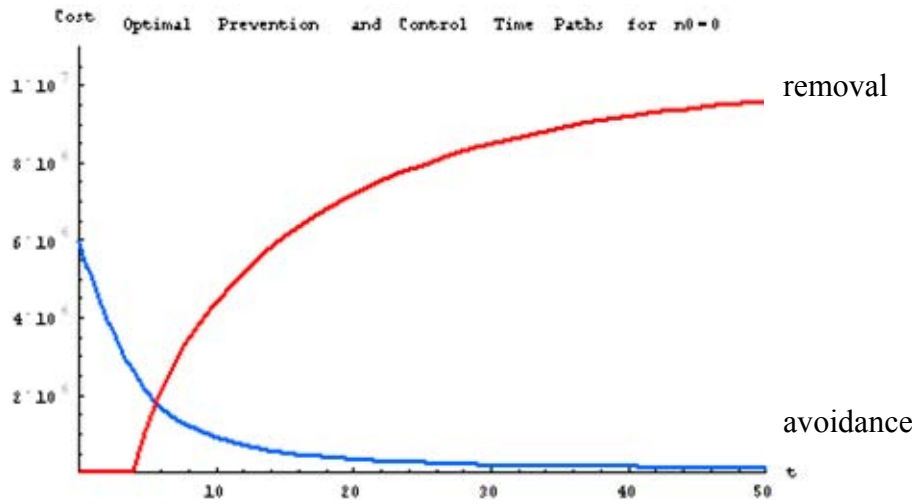


Figure 4. Time path of spending on avoidance and removal when $n_0=50$

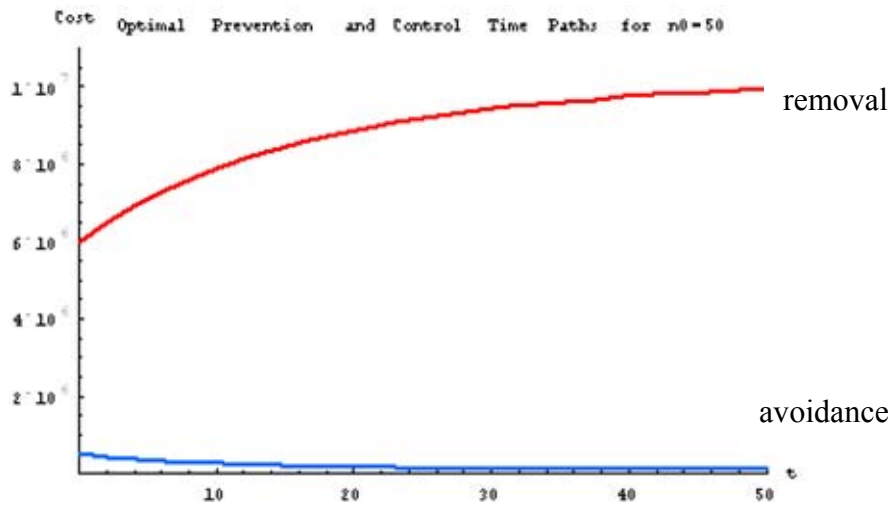


Table 1 reports the optimal policy of avoidance and removal under both of these assumptions.

Table 1. Optimal policy under two initial populations

	1 st period		Steady state	Present value	
	$n_0=0$	$n_0=50$		$n_0=0$	$n_0=50$
Removal, x	0	23.7	331		
C(x)	0	6.0 million	10. million	373 million	456 million
10-f(y)	9.96	8.08	4.78		
y	6.0 million	545,000	84,000	32 million	8.4 million
Damage	0	6,100	66,000	1.6 million	2.1 million
Total	6.0 million	6.6 million	10. million	408 million	466 million

Whether or not we are currently spending “enough” on avoidance or removals depends on the actual number of snakes currently present in Hawaii. If indeed there are no snakes in the state, avoidance expenditures need to be increased more than two-fold. However, if there is a small population of close to 50 snakes, optimal policy calls for increased control (from \$100,000 to \$6 million) and decreased avoidance measures. This result emphasizes the need for better information regarding the current population of snakes in Hawaii.

vi. Sensitivity to changing the cost

Because the true cost of catching and removing snakes in Hawaii is unknown, we wish to investigate the sensitivity of policy to changes in this cost. If the cost of removal is lower than above, the steady state population will be larger since optimal policy will call for fewer removals and less avoidance. However if the cost of removal is greater a more interesting result is obtained. Assume the last snake will still cost \$100 million to catch and remove, but now the cost of removing 1 of 100 increases to \$500,000. The following equation describes this function:

$$c(n) = \frac{19.91 \cdot 10^6}{n^{0.8009}} \tag{18}$$

Facing this cost function it will now be optimal to “eradicate”⁶ given any population of snakes. If the current population is zero, it is optimal today to spend only on avoidance at a level of \$18 million. This is still insufficient to guarantee prevention; removal expenditures begin after 1.86 years to remove incoming arrivals. The steady state population assuming this high cost of removal is 0.386 snakes. In the steady state, we spend \$16 million to remove 0.256 snakes every year and \$7.3 million to avoid 9.98 snakes every year. Under the assumption that there are 50 snakes in Hawaii, it will be optimal to spend \$7.2 million on avoidance and \$150 million on removals today.

⁶ $n^* < 1$

Figure 5. Optimal avoidance and high cost removal paths

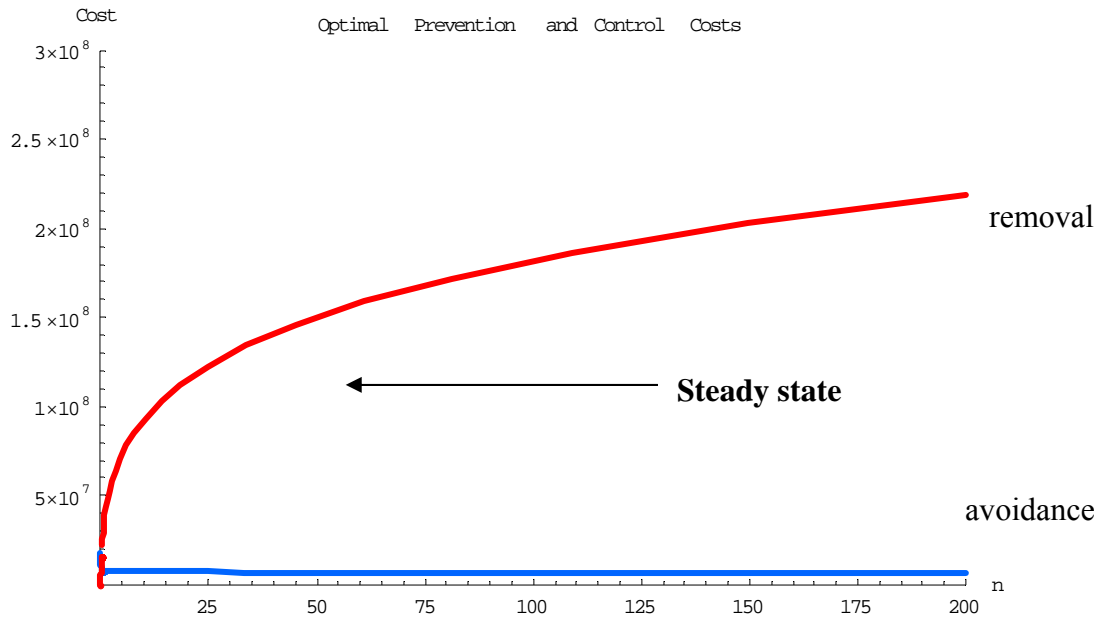


Figure 5 above shows the optimal avoidance and removal expenditure paths under this higher cost of removal assumption. The steady state is less than one snake, essentially an eradication result. Figures 6 and 7 illustrate the time path of avoidance and removal expenditures in the case of initial populations zero and 50, respectively. If the population is initially zero, the time path requires increasing removal and decreasing avoidance over time. However if the population begins at 50, the opposite is true. Removal costs are initially very high and fall over time until the steady state of practically zero snakes. Avoidance expenditures should be increasing over time.

Figure 6. Time path of spending on avoidance and high cost removal when $n_0=0$

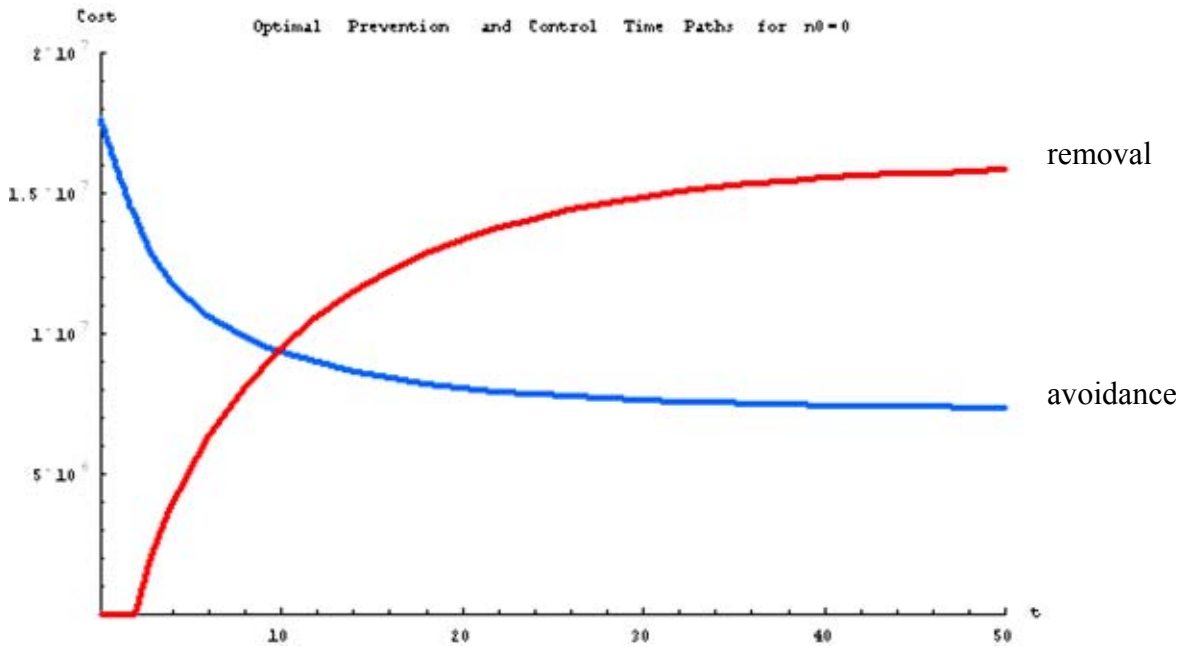
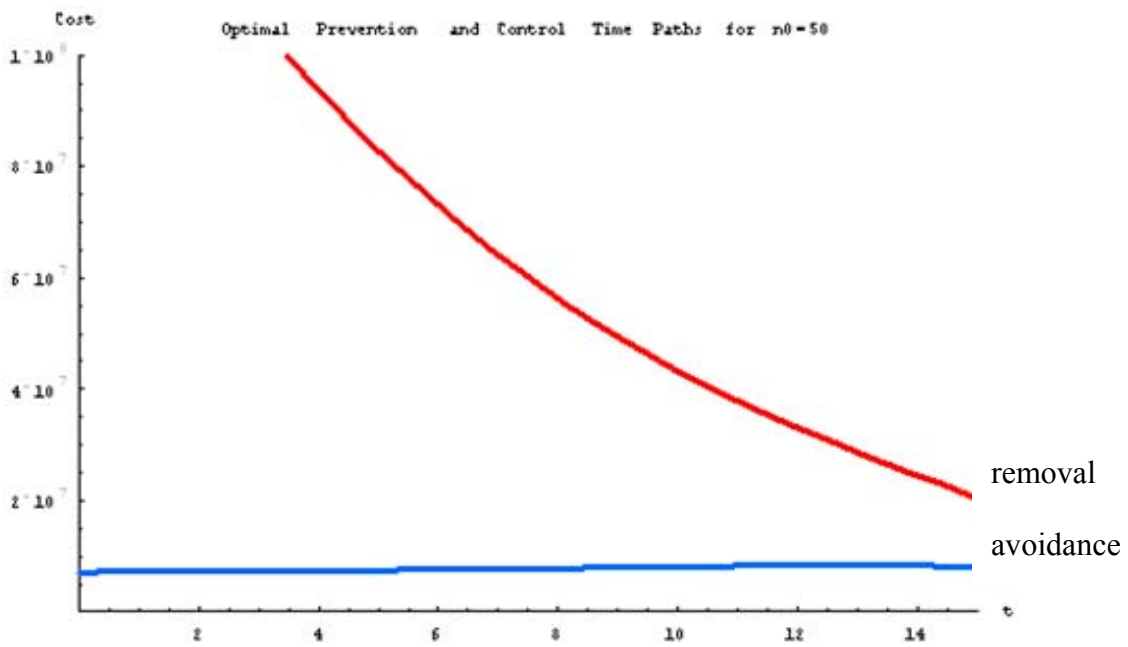


Figure 7. Time path of spending on avoidance and high cost removal when $n_0=50$



Results are summarized in Table 2 below.

Table 2. Optimal policy assuming the higher cost of removal

	1 st period		Steady state n=0.386	Present value	
	$n_0=0$	$n_0=50$		$n_0=0$	$n_0=50$
Removal, x	0	49.86	0.256		
C(x)	0	150 m	16 m	648 m	1.5 b
10-f(y)	9.9992	9.98	9.98		
y	18 m	7.2 m	7.3 m	422 m	370 m
Damage	0	6,100	46.87	1,600	17,000
Total	18 m	157 m	23 m	1.1 b	1.9 b

vii. Status quo vs. optimal policy

It is difficult to compare our results to Hawaii's actual strategy, as we cannot be sure of the government's response in combating BTS at different population levels. We thus derive several alternative scenarios that the government might choose.

Table 3. Losses from following alternative status quo policies

Alternative status quo steady states	Loss compared to optimal program	
	$n_0 = 0$	$n_0 = 50$
100	\$24 m	\$17 m
543	\$29 m	\$23 m
10,000	\$113 m	\$122 m
N_{MAX}	\$127 b	\$149 b

In all the scenarios listed in Table 3, authorities continue to spend what they are currently spending each year until they abruptly decide to keep the snake population constant. In the first scenario, the invasive is discovered early (when the population is only 100 snakes), and population is maintained at that level. In the second scenario, the policy is not switched until there are 543 snakes, the same number as we have for the optimum steady state. The third scenario lets the snakes multiply until it keeps the snakes stable at a population of 10,000 snakes. Our final scenario observes what happens if the current policy is continued without change.

As we can see, improper management of BTS can easily cost Hawaii tens of millions of dollars. Even if the problem is ignored only until we reach the optimal population, \$20 million in value is still lost. The situation is much worse if ignored even longer. If the status quo is maintained until the snake population reaches 10,000 snakes, over \$100 million is forgone, which itself is still less than a thousandth the cost of letting the snakes roam freely. If the snakes multiply until they reach carrying capacity, we suffer a loss of over \$100 billion.

Even though we should not expect that the state would knowingly let BTS reach its carrying capacity in Hawaii, the potential invader is a real threat to our own well-being.

V. Limitations and Directions for Further Research

Using optimal control theory, we generate appropriate comparisons for policy options concerning a potential invasive species. In the cases above, we show that optimal policy will likely require expenditures that differ from current avoidance and removal activities. However, how current expenditures should change is radically different depending on what the starting population is. Because of the massive uncertainty surrounding issues such as initial populations and the probability of arrival and establishment, our analysis suggests early detection of small populations is crucial. Therefore, we recognize that our biggest limitation in assigning an optimal policy is the lack of concrete information, particularly in regards to current population size.

In computing the optimal outcome, we also encountered some quantitative challenges regarding the specification of functional forms for all four essential components: growth, damages, costs of removal, and arrivals. In particular, choosing functional forms that both accurately reflected our understanding of the biological and economic processes and resulted in computationally feasible equations required several simplifications upon which further research might improve.

The deterministic arrival of a fraction of snakes per year was used as an approximation for the probabilistic event of a snake's arrival. Ideally, the model would replace this arrival function with an explicit function describing the probability that a snake arrives in any given period. We made this simplification for two reasons. First, because of the uncertainty surrounding the initial population, building a straightforward probability distribution is highly complex. Furthermore, there is imperfect scientific information concerning the probability distribution of a snake's arrival to Hawaii for obvious reasons.

However, additional scientific information might improve the ability to estimate the probabilities associated with successful establishment. In particular, a better understanding of the probability of a snake mating and reproducing would enhance our ability to estimate accurately the probability of establishment separate from the probability of arrival. The scientific evidence from Guam does suggest that male-female ratios are not one-to-one, with perhaps many fewer females than males moving into transport zones (Rodda 2005, personal communication). An extended model of the snakes would also consider the extent to which future introductions matter, which should be rapidly decreasing with population size.

Despite all of these limitations, we still feel that we have made significant progress towards the determination of optimal BTS policy. Our results suggest that it is more advantageous to spend money finding the small population of snakes as they occur than attempting to prevent all future introductions. No prevention system can be perfect. We need to be sure to detect the pest early and start finding and controlling the population before significant potential losses are realized.

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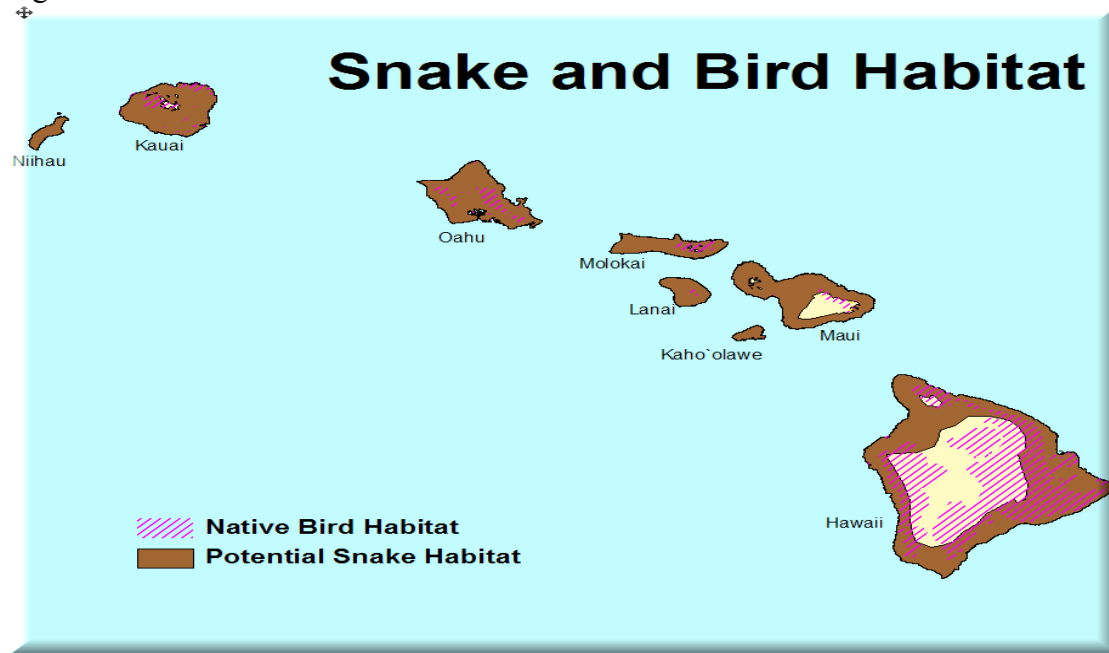
Appendix 1. Derivation of the damage function

Guam has a land area of approximately 53,900 hectares, with a maximum elevation of about 400 meters. With a population density of 50 snakes per hectare, the carrying capacity for Guam is 2,695,000 snakes. With approximately 272 hours of power outages per year attributable to snakes, we estimate that there are $1.01 * 10^{-4}$ power outages per snake per year. Annual electricity generation capacity per capita in Guam is virtually the same as on Hawaii, at 2kW/capita. Fritts and Chiszar estimate that an hour-long power outage on Oahu causes \$1.2 million in lost productivity and damages (Fritts and Chiszar 1997). Positing a linear relationship between snake population and power outages, the expected damage per snake in Hawaii, in terms of power outage costs, is \$121.11.

Guam has experienced a snake-bite frequency average of 170 bites per year, at an average cost of \$264.35 per hospital visit. Thus the expected number of bites per snake per year is at least $6.31 * 10^{-5}$, implying an expected cost of \$0.02 per snake. Hawaii's population density below 1,400 m is approximately $\frac{1}{2}$ that of Guam's. Snake/human interactions should occur less frequently per square mile. However, Hawaii's population is 8 times greater than Guam's, so we adjust the expected costs for Hawaii to \$0.07 per snake.

The Brown treesnake has extirpated 77% (10 of 13) of Guam's native bird population since its arrival (USGS 2005). Contingent valuation studies have estimated the average value of the continued existence of an endangered bird species at \$31 per household per year for Hawaii (Loomis and White 1996). There are 15 endangered bird species in Hawaii whose main habitat is below 1,400 m. (www.hear.org). Figure A1 illustrates the overlap between snake habitat and bird habitat. Of these, 3 are native to small, unpopulated islands that are unlikely to experience the arrival of the snake and 4 are water birds, also users of unlikely habitat for the arboreal snake.

Figure A1: Brown Treesnake and Native Bird Habitat in Hawaii



To obtain a conservative interval estimate, we assume that the birds are valuable to households in Hawaii alone. We estimate that there is between a 100% chance of losing a single species and a 75% chance of losing each of eight bird species. Using an expected value to 403,240 Hawaii households of losing one species of \$12.5 million, the expected per snake damage level ranges from \$0.32-\$1.93 per year, assuming that each snake is equally likely to contribute to the extirpation.

Thus, expected damages from human health factors, power outages, and expected endangered species losses can be expressed as:

$$D_H = 123.11 \cdot n_i, \text{ and}$$

$$D_L = 121.50 \cdot n_i.$$

The maximum annual damages that Hawaii faces without control efforts are therefore $N_{\max} * 123.11$, which equals \$4.8 billion.

Our final equation takes the expectation of the high and low damages, yielding:

$$D = 122.31 \cdot n_i.$$

Appendix 2. The Arrival Function

The Poisson Distribution

The Poisson distribution is the limiting distribution of a series of Bernoulli trials as the time over which those trials take place approach zero. In our particular case this allows us the ability to predict the expected number of snake arrivals over any given period of time so long as a few conditions are met:

- a) At least one probability of arrival for some number of snakes over a given amount of time is known
- b) Snake arrivals can take place on a continuous time basis with no one time more probable than any others
- c) Each snake arrival is independent of any others (note: this does rule out a group of snakes arriving together)

Once we know that the probability of x snakes arriving over the course of y days (or years or seconds), then we can use this simple formula to determine the Poisson distribution's primary parameter, λ , by means of the following formula:

$P(x) = \frac{e^{-\lambda} \lambda^x}{x!}$ over the given period of time. One interesting result of this is that λ is both the expected value of the trial as well as the standard deviation.

In our particular case, we know from conversations with snake managers and scientists that the probability that there are exactly no snake arrivals (under certain conditions) over the course of 10 years is roughly 0.1. From our formula above, we can determine that for any given 10 year period, $P(0) = e^{-\lambda}$ because $x=0$. Thus, λ would equal $-\ln(.1) = 2.30259$. Thus we would expect to have 2.3 snakes arrive over a 10 year period with a standard deviation also of 2.3. If we wanted to calculate the probabilities of specific numbers of snakes arriving in the 10 year period we could then plug the appropriate numbers into x in the formula above.

Table A1. Calculating snake arrivals using the Poisson distribution

Avoidance expenditures (y)	Probability that at least 1 snake will arrive in 10 years	Probability that no snake will arrive in 10 years	Probability that no snake will arrive in a given year ($f(0)$)	Implied Poisson λ ($\lambda = -\ln[f(0)]$)
2.6 million	0.9	0.1	$0.1^{1/10} = 0.794328$	0.230259
4.7 million	0.45	0.55	$0.55^{1/10} = 0.941968$	0.059784
9 million	0.2	0.8	$0.8^{1/10} = 0.977933$	0.022314

The Weibull Distribution

The Weibull distribution takes the form $f(x) = e^{(a-bx^c)}$. The Weibull distribution was chosen primarily because it had several nice properties. First of all, we assume that the first dollar spent on prevention would be much more effective than the billionth dollar spent on control, but that every increase in spending would decrease the probability of arrival (and thus the expected value). A strictly decreasing convex function was thus desired. We also assume that as spending increased a perfectly impenetrable barrier with no BTS arrivals was approached. The Weibull also has the nice feature that the limit as prevention expenditures goes to 0, of marginal snakes prevented approaching infinity. This guarantees that we will spend on prevention in every period.