CONSERVATION ISSUES

Cost Savings from Properly Managing Endangered Species Habitats

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ABSTRACT: Needed active habitat management for many endangered species in the United States has often been deferred or neglected, specifically for species threatened by invasive exotic species and fire suppression. For endangered species to recover, the accrued debt of deferred management must be addressed, first by restoring critical habitat and then by continued habitat maintenance. I conducted a survey of management costs for federally listed species endangered by exotic species and fire suppression and compared the cost differences between initial "restoration" control and subsequent maintenance after the threat has been "controlled." Cost estimate analysis (45 cases obtained from contacting over 270 scientists and wildlife managers) indicated that initial control costs are approximately 1.8 to 350 times greater than maintenance costs. Without continued maintenance, these costs may triple in one or more years, depending on the specific threat. In many cases, after initial restoration, continued control is more cost-effective than neglect followed by renewed habitat restoration. In some cases, neglect followed by renewed restoration may be cost-effective, but during this period of neglect, the endangered species may be extirpated. Continued active management on both public and private lands will lead to minimized maintenance costs and the realization of further cost savings.

Index terms: deferred management costs, endangered species, habitat management, invasive exotic species, prescribed burns

INTRODUCTION

As the habitat of federally listed species in the United States continues to shrink, active management will be necessary to ensure their survival (Myers and Ewel 1990, Simberloff et al. 1997). Foin et al. (1998) determined that 63% of species with recovery plans require some form of management before the species can be downlisted or delisted. To protect certain endangered species, long-term active management of invasive exotic species and restoration of natural fire ecology must be addressed after the initial protection of the habitat. Of the 1,880 species listed under the Endangered Species Act since January 1996, Wilcove et al. (1998) estimated that exotic species threatened 49% of these species; disruption of fire ecology threatened 14% of the listed species. Some listed species face both threats. For instance, fire suppression in the southeastern United States, especially Florida, has allowed exotic species to proliferate (Simberloff et al. 1997).

Inadequate funding has hampered the recovery process for many federally listed species. The current rate of expenditure for endangered species has lagged compared to the number of endangered species listed (Dobson et al. 1997). Cost of managing currently occupied habitats of federally listed species threatened by exotic species and fire suppression is estimated at US (1997) $32–42 million annually (Wilcove and Chen 1998), approximately the amount of the U.S. Fish and Wildlife Service's budget for the recovery of endangered species. This cost includes management for these two threats in addition to expenses incurred in monitoring endangered species.

Preventing exotic species establishment or achieving their early control are widely believed to constitute the most cost-effective management option (Noss and Cooperrider 1994, Simberloff et al. 1997); delaying necessary management probably increases the cost of recovery and habitat management. Over time, invasive exotic species can become established and spread, making control efforts more expensive, especially when control requires manual, rather than chemical, removal. Fire-intolerant species, such as hardwood trees, will succeed fire-adapted species, such as longleaf pine (*Pinus palustris* [Miller]), when fire is excluded; the accumulated fuel must be removed or else intense fire will negatively impact both fire-intolerant and fire-adapted species.

Unfortunately, needed active habitat management has often been deferred or neglected, specifically for habitats of federally list-

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ed species threatened by invasive exotic species and fire suppression. Management of endangered species habitats often requires initial habitat restoration, such as intensive control of an exotic species to reduce it to more manageable levels, or removal of accumulated fuels. Afterward, habitats must be periodically maintained through continued control of exotic species or prescribed burning, otherwise the habitat could degrade back to its initial suboptimal condition.

Thus, adequately controlling alien species and reversing fire suppression can generate future cost savings for endangered species management. Here, I document differences between the costs of deferred management—the removal of exotic species and/or the reintroduction of fire to a neglected habitat—and the costs of minimal maintenance. In other words, I document the change over time in management costs, rather than an average overall management cost or minimal management cost (as documented by Stone and Keith [1987] or Taylor and Katahira [1988]). I also discuss several other factors that may affect management costs and the continued survival of endangered species.

METHODS

Over 270 wildlife managers, refuge managers, and scientists involved in federally listed species recovery in the United States were sent a questionnaire requesting information on the costs of managing exotic species and the effects of fire suppression. Most questionnaires were sent by electronic mail. Individuals contacted were those used in the study by Wilcove and Chen (1998) (identified by lead species' recovery offices and names mentioned in endangered/threatened species recovery plans) and those identified from the refuges Web site of the U.S. Fish and Wildlife Service. These individuals were from academic institutions, the U.S. Fish and Wildlife Service, Bureau of Land Management, the Forest Service, state personnel, and The Nature Conservancy. The questionnaire requested the following information:

- A cost estimate for habitat restoration and habitat maintenance at a particular site for managing exotic species and conducting prescribed burns (i.e., the cost to restore the habitat after it had been neglected, and the subsequent maintenance costs).
- The cost increase if management is deferred for some time (periods of 1, 3, 5, 10, 25, and more years were given as time examples). Likewise, after a period of neglect, what is the cost to restore the habitat to a condition that requires only minimal maintenance?
- The number of years of neglect that would be likely to cause the species' extirpation from the site.

The questionnaire also provided an example of a prescribed burn management plan in Dade County, Florida, and exotic tamarisk (salt cedar) (*Tamarix ramosissima* [Ledebour] and *T. parviflora* [De Candolle]) control in the Lake Mead National Recreation Area, Nevada. The Florida example discussed the large cost difference between the restoration of fire-adapted habitat and subsequent prescribed maintenance burns. The tamarisk control example described the large cost difference between the initial removal of tamarisk and later spot-herbiciding to prevent its reestablishment. A phone number and postal, and electronic mail addresses were included (contact the author for a copy of the questionnaire).

From the questionnaire responses, a ratio was first determined from dividing the costs of initial restoration by minimal maintenance costs. Second, the cost of continued management was compared to the cost of deferred management (i.e., not conducting habitat maintenance and then later re-restoring the habitat). The accumulated cost of continued management was then subtracted from the cost of deferred management for the same time period; the time period used was the time when minimal maintenance costs increased to the deferred maintenance costs. Cost figures were discretely discounted at 0% and 6% rates. A rate of 6% was used to incorporate inflation; 0% rate was used to take into account that these figures were only estimates and that the future costs may actually be greater.

For example, herbicide is used every 2 to 3 years for the management of salt cedar at the Lake Mead National Recreation Area, at a maintenance cost of $8.50/acre for areas that have been controlled (in year 0). However, if management is deferred for 10 to 15 years, the cost to return the habitat to the controlled state is $675/acre. To determine the low range figure of cost savings, the cost of biennial maintenance for 15 years per acre was summed using a 6% discount rate to attain a cumulative per acre figure of ~$38.4 (7 treatments in a 15-year period at a 6% discount rate: ~$38.40 = $7.60 + $6.70 + $6.00 + $5.30 + $4.70 + $4.20 + $3.80). This amount of ~$38.40was then subtracted from the deferred maintenance cost of $281.70 ($675/acre discounted at 6% per year for 15 years), resulting in a $243.30/acre cost savings for regular management. These figures were then converted to a per hectare cost.

RESULTS

Over 130 individuals (48.2%) responded to the questionnaire, but only 20 scientists and wildlife managers (7.4%) provided cost estimates for 45 scenarios (Table 1 and Table 2). Some respondents provided insufficient cost estimates (e.g., expenditures for only last year, but no historical expenditures, or estimated cumulative expenditures). However, most individuals replied that they were unable to provide cost estimates for various reasons (e.g., the difficulty of separating costs of treatment from the overall budget and/or an individual's general responsibilities of wildlife management, no adequate controls having been yet attempted). Also, management was sometimes conducted by volunteers, complicating cost estimates; in these cases, donated time was estimated at rates used for grants (e.g., $11.75/hour by O. Pollak, Regional Ecologist, The Nature Conservancy [TNC], California, pers. com.).

In the case of areas that had been restored, some managers were unable to estimate the number of years of neglect that would result in the habitat reverting to its condition before restoration and management. Managers understandably tried to prevent such scenarios from occurring.

Comparison of Deferred Management Restoration Costs to Maintenance Costs

Initial control/restoration costs ranged from approximately 1.8 to 350 times greater than the maintenance costs, which indicates a substantial investment in restoring a habitat in which management has been deferred (Table 1). These ratio figures are influenced by several factors: severity of deferred management (duration of habitat neglect), costs of maintenance, and proactive restoration. Although cost accounting methods may have influenced cost figures, I assumed that cost accounting influenced both the initial control/restoration

Table 1. Ratio of restoration or control cost to maintenance costs (ranked in order of ratio). NWR=National Wildlife Refuge.

Site/Species/Habitat	Threat	Years of Neglect	Ratio of Restoration or Control Cost to Maintenance Cost	Contact
Dune restoration for beach layia, Humboldt Bay wallflower	European beach grass, iceplants	not given	350	(1)
Kudzu eradication[a]	kudzu	not given	80 to 140 (32-37)	(2)
Ash Meadows naucorid and listed fish (Amargosa pupfish, warm springs pupfish, speckled dace)	salt cedar	not given	100	(3)
Big Bear Valley–Baldwin Lake Preserve[b]	exotic grasses and lupines	not given	80	(4)
Desert tortoise, Nelson bighorn sheep (rare), southwestern willow flycatcher	salt cedar	10 to 15	79.4	(5)
Scrub habitat	fire suppression	20 to 25	40 to 60	(6)
Smith's blue butterfly (*Euphilates enoptes smithi)*	exotic plants	5 to 20	50	(7)
Scrub habitat	fire suppression	10 to 20	30	(8)
Bosque del Apache NWR	salt cedar	10 to 15	35.7 to 61.9	(9)
Coastal scrub habitat	fire suppression	10 to 25	20 to 30	(10)
Yellow bush lupine control for Humboldt Bay wallflower, beach layia	yellow lupine	not given	26	(1)
Coastal scrub habitat	fire suppression	10 to 15	10	(10)
Prairie	fire suppression (& weeding)	not given	2 to 10	(11)
Hakalau Forest	ungulates	not given	5.8	(12)
Nonforested marsh unit (Dismal Swamp shrew)	fire suppression	25 to 30	5.7	(13)
Prairie	*Rhamus* spp.	not given	3.8	(14)
Prairie and oak barrens	musk thistle	5	3	(15)
Okefenokee scrub habitat (indigo snake, gopher tortoise)	fire suppression	not given	3	(16)
Ash Meadows naucorid and listed fish (Amargosa pupfish, warm springs pupfish, speckled dace)	cattails	not given	2.7	(3)
Eastern Neck NWR	Johnson grass & Canadian thistle	5	3[c]	(17)
Jester Park woods and grassland	*Lonicera* spp.	not given	2.2	(12)
Oak barrens for Karner blue butterfly (NH)	fire suppression	4	2	(18)
Nonforested marsh unit (Dismal Swamp Shrew)	fire suppression	10 to 15	1.8	(14)
Santa Cruz Island Preserve	feral sheep	not given	$1.2 M total spent, $5 k/year	(19)
Santa Cruz Island Preserve	feral pigs	not given	$2.5 M total spent, $~30 k/year	(19)
Santa Cruz Island Preserve	fennel	not given	$1.25 M total spent, $1 k/year	(19)

Table 1, *continued.*

[a] Figure given for initial restoration; at current "transition" restoration cost, ratio at 32-37

[b] Bear valley sandwort (*Arenaria ursina* [Robinson]), ash-grey Indian paintbrush (*Castilleja cinera* [Gray]), southern mountain wild buckwheat (*Eriogonum kennedyi var. austomontanum* [Munz and Johnston]), San Bernardino bluegrass (*Poa atropurpurea* [Lamson-Scribner]), California dandelion (*Taraxacum californicum* [Munz and Johnston])

[c] $62/ha treatment cost constant, more land need to be treated with neglect

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costs and the maintenance costs similarly, thereby minimizing its influence on the ratio.

First, areas in which management has been deferred for longer periods of time (as seen in Table 1 when management was neglected for over 10 years compared to management neglected in < 10 years) will require more costly restoration measures because habitat has been more severely degraded. For exotic plants, inexpensive herbicide application is often used for immature plants; however, mature, established exotic plants may require a combination of expensive, labor-intensive manual and/or mechanical control and herbicides. Because burning-neglected, fire-adapted habitats can produce fires of greater intensity than would naturally occur, accumulated herbaceous and woody fuel material must be removed manually, or with rotary drums, hog-chokers, or similar machinery, increasing restoration management costs.

Second, when restoration costs for exotic species and fire suppression are roughly equivalent, higher maintenance costs will decrease the ratio of deferred management restoration costs relative to maintenance costs (since maintenance cost is the ratio's denominator). In general, herbicide application is less expensive than prescribed burns on a per-unit-area basis, which could explain the tendency for fire suppression cases to have higher ratios than the control of invasive exotic species cases in Table 1.

Third, conducting proactive restoration—management that reduces future maintenance—can often decrease the amount of subsequent maintenance required. Spending more on initial restoration can decrease cost of subsequent maintenance. For example, restoration activities that include soil replacement and revegetation can prevent reestablishment of exotic plants. High initial restoration costs ($35,000 for soil replacement and revegetation with native plants) and low maintenance costs (about $100 per year for spot weeding), are responsible for the high ratios seen in the dune restoration project (European beachgrass, *Ammophila arenaria* [L.], and yellow lupine bush, *Lupinus arboreus* [Sims], removal for the Humboldt Bay [Menzies'] wallflower, *Erysimum menziesii* [Price], and beach layia, *Layia carnosa* [Nuttall]), in Table 1.

Cost Savings of Continued Habitat Management

Without continued maintenance, management "re-restoration" costs may triple in one to tens of years relative to maintenance costs (Table 2). Rate of cost increase for some of these threats may cause management costs to double, relative to maintenance costs, before the next management cycle.

In 7 out of 20 cases (counting the first set and second set of two scenarios each as a total of two cases), neglecting management and later restoring the habitat is more expensive than conducting regular maintenance (Table 2). The economic benefits of continued maintenance for these projects (prescribed burns in scrub habitats, salt cedar control, feral pig [*Sus scrofa*] eradication, cattail [*Typha* spp.] control, and kudzu [*Pueraria montana* var. *lobata* (Willd.)] eradication) are greater than the costs of neglecting management of these threats and controlling them later.

In 11 of 20 cases, it was more cost-effective to defer habitat management for certain projects than to manage the habitat regularly. However, in some cases when it is cost-effective to defer management and re-restore habitat, the species in question may become extirpated. (Species extirpation is obviously an unsatisfactory outcome. Again, this study only evaluates the cost-effectiveness of deferring management of an imperiled species' habitat, but does not consider the additional costs that could be associated with recovery of a species, such as cost stemming from establishing an artificial breeding program.) This was seen for three cases: prescribed burns for the Karner blue butterfly (*Lycae-*

Table 2. Estimated cost savings of continued active management versus deferred management (at 6% discrete discount). NWR= National Wildlife Refuge.

Threat Managed for Species and/or Habitat	Years of Neglect Causing Increased Maintenance Costs	Cost Difference (per acre, unless otherwise noted) between Minimal Maintenance Costs and Re-restoration Costs	Approximate Cost Savings per Hectare (unless otherwise noted) When Managed	Contact
Prescribed burns for scrub habitat	10 to 20	increase to $15,000 from $500/acre	$4,332 to $19,076	(1)
Prescribed burns for scrub habitat	20 to 25[a]	increase to $20,000–$30,000 from $500/acre	$3,389 to $19,308	(1)
Prescribed burns for coastal scrub habitat	10 to 15	increase to $1000 from $100/acre	$758 to $1,215	(2)
Prescribed burns for coastal scrub habitat	10 to 25[a]	increases $2,000–$3,000 from $100/acre	$803 to $3,974	(2)
Salt cedar control for desert tortoise, bighorn sheep, and southwestern willow flycatcher	10 to 15	return to initial restoration costs of $675/acre, from maintenance $8.5/acre	$600 to $887	(3)
Salt cedar control at Bosque del Apache NWR	10 to 15	return to initial restoration costs of $304 to $526/acre, from maintenance $8.50/acre[b]	$217 to $682	(4)
Pig control at Hakalau Forest NWR	1	maintenance costs of $215/acre, tripled	$445	(5)
Cattail control at Ash Meadows NWR[c]	3 to 25	per stream-mile: $110 eradication; $310 after 3 years, $350 after 5 years, $500 after 10 years, $1,000 after 25 years	$76 to $105 per stream-kilometer	(6)
Kudzu eradication	5	return to restoration $100/acre from $25/acre for maintenance	$32	(7)
Largemouth bass control at Ash Meadows NWR for Ash Meadows speckled dace[c]	3 to 25	per stream system: $1,000 eradication, $1,800 after 3 years, $1,200 after 5 years, $2,000 after 10 years, $5,000 after 25 years	($-254) to $408 per stream system	(6)
Prescribed burns for pondberry	10 to 25	increase to $100 after 10 years, $200 after 25 years, from maintenance $24/acre	$62 to ($-133)	(8)
Salt cedar control at Ash Meadows NWR[c]	3 to 25	per acre: $100 eradication; $101 after 3 years, $105 after 5 years, $120 after 10 years, $150 after 25 years	($-38) to ($-161)	(6)
Tree removal for pondberry	10 to 25	increase $100 after 10 years, $150 after 25 years, from maintenance $50/acre	($-22) to ($-193)	(8)
Other non-native fish control at Ash Meadows NWR for Ash Meadows speckled dace[c]	3 to 25	per stream system: $1,000 eradication; $1,020 after 3 years, $1,040 after 5 years, $1,100 after 10 years, $1,500 after 25 years	($-356) to ($-1,608) per stream system	(6)
Noxious weed control at Ash Meadows NWR[c]	3 to 25	per acre: $200 eradication; $202 after 3 years, $206 after 5 years, $220 after 10 years, $250 after 25 years	($-74) to ($-351)	(6)
Prescribed burns for Dismal Swamp shrew	10 to 30	increase $100/acre after 10 to 15, and $320/acre after 25 to 30 years, from maintenance $56/acre	($-52) to (-$556)	(9)
Musk thistle eradication	5	maintenance costs, $20/acre, tripled	($-96)	(10)
Canadia thistle and Johnson grass eradication[d]	5	acres treated tripled, from 200 to 600 acres	(-394%/acre)	(11)
Prescribed burns for Karner blue butterfly	4 year; 8 years[e]	maintenance costs doubled; maintenance costs quadrupled	(-398%/acre) to (-1021%/acre)	(12)
Fennel control at Santa Cruz Island Preserve	5 to 10	maintenance costs of $100/acre double or triple	($-487) to ($-1,405)	(13)
European beachgrass removal for Humboldt Bay wallflower and beach layia	5 to 10[f]	costs increase $5 to $10/acre on top of $100/acre maintenance cost	($-837) to ($-1,667)	(14)
Yellow lupine bush removal for Humboldt Bay wallflower and beach layia	5 to 10[g]	costs increase $5 to $10/acre on top of $500/acre maintenance cost	($-4,260) to ($-8,393)	(14)

Table 2, *continued.*

[a] Florida scrub jay extirpated after 25 to 40 years of deferred management
[b] using assumption of tamarix reestablishment from C. Deuser
[c] threat eradicated
[d] cost per acre figure does not change, but the number of acres needing treatment increases
[e] Karner blue butterfly extirpated after 3 to 4 years of deferred management
[f] European beachgrass overtakes and extirpates Humboldt Bay wallflower and beach layia after 10 years of deferred management
[g] yellow bush lupine overtakes and extirpates Humboldt Bay wallflower and beach layia after 5 years of deferred management

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ides melissa samuelis [Nabokov]), and European beachgrass and yellow lupine bush removal for the Humboldt Bay wallflower and beach layia. In these three cases, contacted individuals were able to estimate the years of neglect that would lead to local extirpation of species. Deferring prescribed burns for 25 to 40 years was estimated to result in the Florida scrub jay's (*Aphelocoma coerulescens coerulescens* [Bosc]) extirpation (Steve Morrison, TNC, Florida, pers. com.).

In two cases, there was a threshold number of years in which it was either cost-effective or not to defer management. For largemouth bass (*Micropterus salmoides* [Lacepede]) eradication at Ash Meadows National Wildlife Refuge (NWR) in Nevada, deferred management did not exceed the cost of regular maintenance under 5 years (Table 2). However, if management was deferred >10 years, the situation changes. Thus, it would be more cost-effective to control bass after 10 years.

However, for conducting prescribed burns for pondberry (*Lindera melissifolia* [Walt.]), the opposite situation was true. Under 5 years, deferred management costs exceeded costs of conducting regular maintenance. However, after 10 years it was more cost-effective to defer management and re-restore habitat than to conduct periodic prescribed burns. Thus, it would be more cost-effective to conduct periodic maintenance burns within 5 years, but not after 10 years. This result is due to use of the discount rate, which is discussed later.

In all these cases, except for the three mentioned above (prescribed burns for the Karner blue butterfly, and European beachgrass and yellow lupine bush removal for the Humboldt Bay wallflower and beach layia), and the case of cattail eradication at Ash Meadows NWR (where the managers do not believe that cattail will cause extirpation of the Ash Meadows speckled dace, *Rhinichthys osculus nevadensis* [Gilbert]), the consequences of deferred management on the federally listed species' status was not considered. The costs outside of managing for exotic species and fire suppression were not considered. In situations in which regular maintenance has negative cost savings relative to deferred management, prolonged neglect may lead to greater economic costs beyond the parameters considered in this assessment (i.e., additional costs related to endangered species recovery such as a captive breeding program).

As expected, the discount rate will have a substantial effect on cost savings obtained from proper habitat management. In general, cost savings increase when a zero discount rate is used. Using a zero discount rate, an additional four projects would show positive cost savings from proper management: salt cedar control, other non-native fish and noxious weed control at Ash Meadows NWR, and prescribed burns for pondberry. A 0% discount rate does not make tree removal for pondberry more cost-effective. At a 0% discount rate, prescribed burns for the Dismal Swamp shrew (*Sorex longirostris fisheri* [C. H. Merriam]) (now delisted) become cost-effective when management is deferred after 25 years, similar to the situations previously described for fire management of pondberry and eradication of largemouth bass.

As seen earlier, use of the 6% discount rate accounts for the negative cost savings after 25 years of deferred management of prescribed burns for pondberry (but the positive cost savings after only 10 years). With a 6% discount rate, the sum of the accumulated discounted regular maintenance costs, \$133.40 ha^{-1}, is greater than the discounted deferred management cost at 25 years, \$116.10 ha^{-1}. At a 0% discount rate, there are positive cost savings for regular management after both 10 and 25 years of deferred management. The sum of the cumulative periodic maintenance costs, \$296.40 ha^{-1} (\$59.30 ha^{-1} every 5 years), is less than the deferred management costs of \$494 ha^{-1}.

DISCUSSION AND CONCLUSIONS

Numerous factors influence costs for controlling exotic species and conducting prescribed burns for endangered species. First, costs can be reduced by managing as much land as possible (economy-of-scale savings: the per-unit-area costs decrease as area managed increases, because base costs are divided over a larger area while additional land managed requires only incremental expenses). This includes managing both public and private lands in tandem. Also, without comprehensive area-wide control, exotic species may reestablish themselves from other sources, such as nonmanaged private lands.

Second, partial control efforts that do not reduce an ecological threat to a threshold level, where removal rate is less than replacement rate, may lead to higher control costs coupled with continued ineffective management. For example, insufficient control efforts for feral ungulates (wild goats, pigs, and deer) at Volcanoes National Park in Hawaii, from 1917 to 1971, had no impact because the ungulates reproduced at rates faster than they were removed. A later comprehensive effort adequately controlled ungulates in 10–20 years (Stone and Keith 1987). Thus, immediate restoration may be imperative in areas imminently reaching threshold levels of non-indigenous invasive or late-successional species, rather than native species. Without this restoration, the result would be a habitat with an alternative steady-state community consisting of exotic and fire-intolerant species, rather than native species. The proliferation of exotic and fire-intolerant species may cause a positive feedback loop, encouraging further establishment of exotic and fire-intolerant species, and a negative feedback loop to native species reintroductions. Feedback loops may be caused by alterations in disturbance regimes, changes in the ecosystem (such as hydrology), and/or exotic species invasions. One may expect to see slow and expensive rehabilitation for areas in which thresholds have been passed (Noss and Cooperrider 1994).

Third, political and ethical constraints on management practices may require managers to use more expensive and less effective controls. For example, because of public pressure, pigs were removed from Hakalau Forest NWR using hunting methods that were more expensive and time-consuming than snares, whose use arouses humane control concerns (Jack Jeffrey, Hakalau Forest NWR, Hawaii, pers. com.). Similarly, because human hunters may be secondarily exposed to rat poison from eating feral pigs, the poison must be placed in tamper-proof bait stations (Hilton and Pank 1981, Engeman and Pank 1984), which increases the cost of rat (*Rattus rattus*) control in these habitats.

Immediate action may provide for substantial savings in recovery of endangered species threatened by exotic species and fire suppression. Achieving minimal maintenance both protects endangered species and saves money in recovery cost (and damage costs from nonindigenous species [Pimentel et al. 2000, Vitousek et al. 1996]). Neglecting management for even a few years may cause the cost of control to increase to the same high as restoration costs. Equally, if not more important, neglecting management for even a few years may also cause local extirpation of a species. Ultimately, timely management may eventually provide the greatest cost savings—the recovery of a species.

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LITERATURE CITED

Dobson, A.P., J.P. Rodriguez, W.M. Roberts, and D.S. Wilcove. 1997. Distribution and causation of species endangerment in the United States. Science 277:1116-1117.

Engeman, D.P. and C.F. Pank. 1984. Potential secondary toxicity from anticoagulant pesticides contaminating human food sources. New England Journal of Medicine 311:257-258.

Foin, T.C., S.P.D. Riley, A.L. Pawley, D.R. Ayres, T.M. Carlsen, P. J. Hodum, and P.V. Switzer. 1998. Improving recovery planning for threatened and endangered species. BioScience 48:177-184.

Hilton, H.W. and L.F. Pank. 1981. Recommendations on anticoagulants and zinc phosphide as rodenticide. Insect and Rat Control Report 32, Experimental Station of the Hawaiian Sugar Planters' Association, Aiea. 2 pp.

Myers, R.L. and J.J. Ewel. 1990. Problems, prospects and strategies for conservation. Pp. 619-632 *in* R.L. Myers and J.J. Ewel, eds., Ecosystems of Florida. University of Central Florida Press, Orlando.

Noss, R.F. and A.Y. Cooperrider (eds.). 1994. Saving Nature's Legacy: Protecting and Restoring Biodiversity. Island Press, Washington, D.C. 380 pp.

Pimentel, D., L. Lach, and R. Zuniga. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53-65.

Simberloff, D., D.C. Schmitz, and T.C. Brown. 1997. Why we should care. Pp. 359-367 *in* D. Simberloff, D.C. Schmitz, and T.C. Brown (eds.). Strangers in Paradise. Island Press, Washington, D.C.

Stone, C.P. and J.O. Keith. 1987. Control of feral ungulates and small mammals in Hawaii's national parks: research and management. Tropical Pest Management 32 (Suppl. 1):277-287.

Taylor, D. and L. Katahira. 1988. Radio telemetry as an aid in eradicating remnant feral goats. Wildlife Society Bulletin 16:297-299.

Vitousek, P.M., C.M. D'Antonio, L.L. Loope, and R. Westbrooks. 1996. Biological invasions as global environmental change. American Scientist 84:468-478.

Wilcove, D.S. and L.Y. Chen. 1998. Management cost for endangered species. Conservation Biology 12:1405-1407.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Philips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607-615.