Duffy, D. C. and F. Kraus 2006. Science and the Art of the Solvable in Hawai`i's Extinction Crisis. Environment Hawaii 16 (11) May 2006 1, 3-6. Popular version without citations in paper version; The full paper on line at http://www.environment-hawaii.org/eh-xtralineup_more.php?id=163_0_11_0_M

**Science and the Art of the Solvable in Hawaii's Terrestrial Extinction Crisis**

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**Abstract:** Hawai`i has experienced massive species extinctions caused by habitat loss and invasive species, following the arrival of Polynesians and then Europeans. This loss will continue unless conservation and natural-resource management can be made more effective. Rigorous conservation biology is essential to increased efficiency, but currently suffers from a series of knowledge limitations. Primary among these are lack of basic distributional and natural history information, few population models for native or invasive species, few systematic assessments of different management methods, and poor knowledge of ecosystem processes and services. These knowledge gaps frequently follow from institutional limitations and poor practices that include a failure to publish study results; underappreciation of the proper role of natural history knowledge in conservation; lack of comparative studies of management methods; lack of long-term study sites; lack of a focused, problem-solving research agenda that goes beyond merely collecting scattered ecological information; and a failure to include scientific knowledge in many management decisions. We suggest several general strategies to change the existing research/management culture, including tightly focused, hypothesis-testing research agendas in response to management needs; evaluation of management efforts in relation to cost benefit, and incorporation of best scientific data; linking future funding to successful publication of previous work; improved dissemination of research results to managers; greater contact between graduate students and managers; creation of long-term ecological study sites; systematic, periodic peer-review of management efforts; and focused private funding to jump-start problem-solving research.

*Insanity is doing the same thing over and over and expecting a different result.* --Albert Einstein

**Introduction**

On 29 November 2004, a male po`ouli (Melamprosops phaeosoma) died of what was effectively old age while in captivity in Hawai`i. The only two other known birds of this species, both at least five years old, have not been seen since 2003 and the species is now presumed extinct (Anonymous 2004). With the passing of the po`ouli, it is appropriate to ask what Hawai`i's latest avian loss tells us about the state of terrestrial conservation and conservation science in the archipelago. Is the po'ouli's demise a representative reflection of conservation effectiveness in Hawai`i or is it merely an unlucky fluke?

Of the 107 endemic bird species present in Hawai`i before the arrival of humans around 400 A.D., only 10% are either not extinct or not threatened with extinction (James 1955). Almost 300 plant species, or approximately 30% (Eldredge & Evenhuis 2003), of the endemic native flora are officially listed as threatened or endangered and a roughly equal number are unlisted but in decline (M. Bruegmann, pers. comm.). For invertebrates, we have no idea how many species we have already lost, although numbers are large (Solem 1990; Asquith 1995). Finally, 20% of the total species of Hawai`i are now non-native (Eldredge & Evenhuis 2003).

The forces that have driven this ecological holocaust include massive, largely historical, habitat conversion by humans in the lowlands, ongoing habitat destruction by alien wild mammals and insects, wholesale replacement of native vegetation by alien plants, changes in fire frequency, and extensive mortality inflicted on native species by alien predators and diseases (e.g. Atkinson 1977; van Riper et al. 1986; Gambino et al. 1987; Cuddihy & Stone 1990; Reimer 1994).

The Hawaiian Conservation Alliance (Anon. 2003) stated that 737 staff and $63 million dollars are devoted to conservation in Hawai`i each year. Based on this impressive figure, it might be thought that biodiversity conservation in Hawai`i is a mature and effective operation. To the contrary, we argue here that the demise of the po`ouli accurately reflects that conservation practice and science suffer from a suite of problems that routinely compromise conservation effectiveness in Hawai`i. In this paper we will not discuss the failures of conservation practice (a topic of considerable scope) but instead focus on the contribution that suboptimal conservation science makes to limiting conservation effectiveness.

We describe knowledge gaps that exist for conservation science and its application in Hawai`i, discuss some of the institutional problems and poor practices that contribute to those gaps, and propose changes in practice in the hopes that far more of Hawai`i's biological wealth can be preserved in the future than would be the case if the present trajectory of practices continues. Failing that, Hawai`i may inevitably become an ecological Potemkin village of lush alien vegetation, with a few remnant native birds and plant communities clinging to life in the hills, as much of the island of O`ahu arguably already is.

**Current Knowledge Gaps**

Providing effective conservation in Hawai`i requires that conservation science attend to three broad topics: invasive species, endangered species, and habitat restoration. The first is the overwhelming cause of biotic impoverishment in these islands, the second is its most imperative set of symptoms, and the last is one of the primary means by which the problem may be rectified.

*Invasive Species*
There are three stages in the alien invasion process – transport, establishment, and spread. Each stage poses a different set of research questions appropriate to informing meaningful management decisions (Hobbs & Humphries 1995).

For known or probable invasives not yet arrived but likely to be introduced, we need to know how they are apt to arrive and how best to intercept/exclude them. There is a growing body of work on how to identify potential invasives (Bomford & Hart 1998; Pheloung et al. 1999; Walton et al. 1999; Daehler & Carino 2000; Bomford 2003; Bomford & Glover 2004; Bomford et al. 2005) but little of it has been Hawai`i-focused (see Daehler et al. 2004 for an exception). Information about modes of invasion in Hawai`i are available for vertebrates (Long 1981; Tomich 1986; Kraus & Cravalho 2001; Kraus 2002, 2003), plants (Wester 1992), some disease vectors and a few parasites (Joyce 1961; Goldberg & Bursey 2000; Kilpatrick et al. 2004), but not for most taxa. We have few scientific studies for Hawai`i on the best ways of preventing introductions, but we can borrow profitably from New Zealand and Australia for certain taxa (e.g., Daehler et al. 2004; Pheloung et al. 1999; Walton et al. 1999; Williams 2000).

There are over 5,000 established alien species (Eldredge & Evenhuis 2003), but there is limited information on how many are invasive. An early estimate for vascular plants (Smith 1985) is now quite dated. An estimate of invasive potential among the 8,000 already-cultivated plants is available (Staples et al. 2000), but no similar compendium has been attempted for animals. Potentially most could become invasive, even after a non-invasive lag period that can span centuries (Crooks & Soulé 1999; Hulme 2003). Documented ecological impacts have largely been restricted to a few vertebrates, plants, and some insects. Taxa of major ecological importance in structuring continental ecosystems (e.g., earthworms, mycorrhizae) have largely gone uninvestigated, and even studies on hymenopterans, a group of widely acknowledged ecological significance, have been restricted to a handful of taxa (Gambino et al. 1987, 1990; Cole et al. 1992; Gillespie & Reimer 1993; Reimer 1994; Krushelnycky et al. 2004).

At present, managers rely on sporadic observations and personal impressions to identify new species that appear invasive, but such impressions are difficult to convey to others in a compelling manner or to use in ranking response activities. Decision-support systems to prioritize action among the large number of incipient invasives are lacking. We are aware of only a single study that attempts a systematic survey (of plants on Maui) to identify potentially invasive species before they are too widespread to stop (Loope et al. 2004). This study, laudably, has resulted in immediate eradication of 12 high-risk species. It is being replicated on other islands, but it needs to be extended to other taxa and repeated on a regular basis.

Simple, tactical population models for invasive species have rarely been used in Hawai`i but could assist in setting eradication priorities. We need, but rarely have, at least crude estimates of age of first breeding/fruiting, intrinsic rates of increase, seed persistence in the soil (for plants), geographical extent, and propagule dispersal distance. Such models need not be exact to help estimate the feasibility and cost of containing or eradicating an invasive species (cf. Kaiser in press for a model for *Miconia calvescens*). Data-based planning and budgeting allow for effective attack on recently established species before they become firmly entrenched and allow realistic allocation of effort to contain entrenched species; otherwise, control actions are apt to merely chase after such species as they expand their ranges. For example, current legislative attempts to divert $2-3 million from rapid-response programs against incipient invasive species to coqui (*Eleutherodactylus coqui*) control on Hawai`i Island seem senseless when conservative estimates are that more than $25 milliona year would be needed to treat the 5,000-plus infested acres in the Hilo and Puna districts alone. Similarly, if *Miconia calvescens* first fruits at age three, then a successful eradication program must revisit each infested area every three years or less. Knowing the area infested and the cost to treat an acre, one can calculate the dollar cost and personnel to achieve eradication. Committing any less money would simply not be effective, as the coqui example will demonstrate, if funded.

For long-term control of established alien species that are damaging native ecosystems, only two options exist: biocontrol across landscapes or mechanical/chemical control in limited sensitive areas, such as implemented by the National Park Service in its Special Ecological Areas (Tunison & Stone 1992; Tunison 2002). In Hawai`i, agricultural interests have been able to set priorities for biocontrol (e.g. Nakahara 1999), but these have eluded natural resource managers and researchers (Denslow et al. 2002). In Hawai`i, biocontrol, exclosures or direct control are being pursued against several widespread invasive species– such as strawberry guava (*Psidium cattleianum*), wild pigs (*Sus scrofa*) and apple snails (*Pomacea canaliculata*) – but it is unclear what criteria managers are using to target such species or to judge success. Formal triage models to prioritize taxa for control within reserves have been developed and widely used in New Zealand (Williams 1997; Owen 1998) but are not yet applied in Hawai`i. Much could probably be gained by their general application in land management within Hawai`i but this would, again, be predicated on having basic natural-history information for the proposed target species.

In Hawai`i, efforts to identify novel mechanical and chemical control methods are virtually nonexistent, although fencing against ungulates and management after fire have met with success (e.g., Loope & Scowcroft 1985; Loh 2004). As a result, rapid response to eradicate incipient pest species is routinely hindered by lack of knowledge on how to efficiently kill them. The need for simple herbicide trials on scores of incipient plant species has been recognized for years but has gone unaddressed, in part due to lack of funding. Absence of reliable control mechanisms has also been partially responsible for allowing feral parrot and frog populations to explode on Maui and Hawai`i islands. Useful detection methods are often lacking (making it difficult, for example, to evaluate or respond effectively to reports of mongoose, *Herpestes auropunctatus*, on Kaua`i) and need to be developed for many invasive taxa, animals and plants alike.

Studies establishing the costs that terrestrial invasive species impose on Hawai`i's economy and quality of life would help establish political support for making the difficult decisions necessary for effectively addressing this problem, but are only now being pursued in earnest (E. Campbell, pers. comm.; K. Burnett, pers. comm.). Studies elsewhere have documented tremendous economic impacts of these species (Pimentel et al. 2000, 2005).

*Endangered Species*

For those Hawaiian species officially listed as endangered – a few invertebrates, many plant species, and most land and wetland birds – there is a series of science and management problems that hinder or preclude their recovery. We will focus below on birds as they have received most of the attention and funding and, thus, presumably represent the "state of the art" for endangered-species conservation in Hawai`i. For plants and invertebrates the situation is much worse. For most of the hundreds of endangered plants, pollination biology, seed dispersal, and genetic structure of populations are unknown, but all three are essential to directing successful recovery efforts. Reasons for seedling recruitment failure are also unknown for most endangered plants, but recovery can hardly be implemented without controlling those factors. For large numbers of invertebrate taxa, such as land snails and many insect orders, we do not even know which species still exist, their numbers, trends, or geographic ranges (Solem 1990; Asquith 1995). Hence, it is currently impossible even to decide which taxa require intervention efforts, much less how to intervene, even though this is the group that has likely already experienced the greatest number of extinctions and currently has the largest number of biologically endangered species.

Steiner (2002) estimated that $37.8 million was spent between 1987 and 1997 on research on Hawaiian birds. He conceded that only one species (nene, *Branta sandwicensis*) emerged as a success story and he provided a long list of basic natural-history information that remains ungathered. He also estimated that at least an additional $57.7 million has been spent on management and habitat acquisition. A recent draft plan calls for another $3.6 billion to be spent on forest bird research and conservation in the next 50 years (U. S. Fish and Wildlife Service 2003). Despite large research expenditures, some of the most basic science necessary for understanding the target species has never been done. For example, Population Viability Analysis or similar analyses (determining minimum population size of the species that has some acceptably low chance of going extinct over some defined time period), have been done for only seven birds: Laysan teal (*Anas laysanensis*) (Reynolds 2002), `Alala (*Corvus Hawaiiensis*) (Hughes et al. 1992), Akohekohe (*Palmeria dolei*) (Seal et al. 1992), Palila (*Loxoides bailleui*) (Lacy et al. 1992), `Elepiao (*Chasiempis sandwichensis*) (VanderWerf 2004), Hawaiian Stilt *Himantopus mexicanus knudseni*) (Reed et al. 1998) and Laysan finch (*Telespiza cantans*) (McClung 2005). This despite the fact that the Hawaiian Forest Birds Conservation Assessment and Management Plan (Ellis et al. 1992) called for an additional 21 such analyses for species or for island populations, the draft recovery plan for Hawaiian forest birds eleven years later ranked population viability analysis as "Priority 2," and population viability is one of the criteria for downlisting of Hawaiian forest birds (U. S. Fish and Wildlife Service 2003).

We know that numerous factors threaten Hawaiian birds, including habitat loss, disease, mammalian predators, food loss, and competition from introduced birds, but we do not know if all are equally powerful, if their importance varies among bird taxa, or even if all are currently at work. Managers would benefit from knowing against which threats they should focus their efforts. We also don't know the carrying capacity of the habitats in which most endangered species occur (the Palila, *Loxioides bailleui*, being an exception [Banko et al. 2002]) or even whether currently occupied habitats are optimal (but see Freed 2001 and Hart 2001, for the `Akepa, *Loxops coccineus*). Conservation efforts directed at suboptimal habitats may ultimately be futile (as the case of the po`ouli arguably demonstrates), but we cannot currently assess the degree to which this is a problem. If we did know the most serious threats and the optimal habitats, we could then test methods for managers to use for converting suboptimal habitats to optimal ones.

*Habitat Protection and Restoration*

The first step in restoration is to ask to what target condition the habitat or ecosystem should be restored? We have some general knowledge of pre-contact conditions (e.g. Cuddihy & Stone 1990; James 1995; Allen 1997; Athens 1997; Burney et al. 2001), but, as with the recovery of native species, we are hindered by a lack of details. It would be useful to have clear data on the location, amount, and quality of native Hawaiian habitats, for use in prioritizing habitat stabilization and recovery efforts. We know a little of the present and past distribution of ecosystems (e.g. Jacobi 1990), but this knowledge is not as well-developed as for other states, despite our small geographic size. Hawai`i has long been involved in the national GAP program (Scott et al. 1993), which may eventually make such data available.
We know little of past ecosystem processes. Hawaiian ecosystems originally lacked earthworms and ants, two dominant forces in continental terrestrial ecosystems (Darwin 1881; Holdobler & Wilson 1990) and now ubiquitous across Hawai`i. Their introduction may have forced massive shifts in ecosystem structure or functioning, but the ramifications have not been investigated. Many pollinating and seed-dispersing species are believed to have gone extinct (e.g. Cox & Elmqvist 2000) and have likely affected plant populations. Following the introduction of parasitoids, lepidopterans ceased to be mass-defoliating agents in ecosystems (Gagne & Howarth 1985), probably altering the cycle of forest disturbance and nutrient cycling. Land snails used to occur at great densities, potentially providing significant grazing pressure on fungi and providing food for birds, but are now ecologically extinct. Aboriginal hunting, land clearing, and introduction of mammalian predators may have led to massive decreases in seabirds nesting in vegetation, decreasing importation of marine nutrients to forests (Duffy 1992; Loope 1998). Finally, many plant species disappeared or became very rare, following the introduction of ungulate herbivores (Cuddihy & Stone 1990). Indeed, many forests in Hawai`i exhibit wholesale recruitment failure of native vegetation and it is not clear which of the many possible alien agents is largely responsible. Each of these changes is of potentially profound importance for understanding current Hawaiian ecosystems and how to more closely approximate original ones, but these have eluded rigorous study.

Abiotic perturbations such as rain, floods, storms, El Niño events, hurricanes, fire, erosion, and volcanism may have caused ecosystems to oscillate between different stages of secondary succession (Vogl 1980), creating a natural mosaic of habitats in pre-human Hawai`i. We know little to nothing about such 'rhythms of the land,' nor have we much knowledge of current patterns of perturbation, but van Riper and Scott (2001) suggested that such forces, combined with habitat loss following the arrival of humans, play a critical role in the fate of many rare species (cf. Conant et al. 1998). If conserved areas, networks of areas, or secondary succession and recovery of habitat are smaller/slower than the scale of major perturbations, suitable habitats will not persist over time, resulting in loss of constituent species (Pickett & Thompson 1978; Armstrong 2005). The smaller, fewer, or more widely dispersed the conservation areas, the more active must management be to maintain islands of suitable habitat within their borders, but we have no idea of the minimum areas needed for any of our natural habitats, ecosystems, or even species. Of our existing natural areas, perhaps only upland East Maui and upland Mauna Loa are big enough to survive intact over five hundred to one thousand years without intensive human intervention. Even the Alaka`i Swamp area on Kaua`i, last refuge of several endemic bird species, proved too small or ecologically simple to shelter them from two hurricanes (Conant et al. 1998). No analysis exists of how long Hawai`i's Natural Area Reserve System is likely to preserve its stunning ark of Hawai`i's biodiversity, nor what would be necessary to slow or stop loss in individual units. Finally, climate change needs to be incorporated into such considerations (Benning et al. 2002) as it is likely to significantly alter native and alien species distributions and to seal the fate of a number of endangered species.

Most restoration, as well as management of established natural areas, has been tactical, rather than strategic, in the sense of lacking an overarching recovery goal. With a few nascent exceptions, such as watershed partnerships, we have no consensus 'best practices' beyond fencing, removing ungulates and outplanting native plants, with some efforts to change fire regime (e.g. Parman & Wampler 1976; Tunison et al. 2001; Beavers & Burgan 2002). Because of the data gaps enumerated above, few if any plans have been based on any a priori considerations about long-term goals or how the immediate efforts will achieve them, despite an emerging body of knowledge elsewhere on how to do this (e.g. Pickett & Thompson 1978).

## Institutional Challenges to Hawaiian Conservation Biology

Hawaiian conservation biology faces the formidable research agenda above if it is to provide land and natural resource managers the information needed to guide their efforts, but several major institutional challenges loom.

Academic ecological science has two components, basic natural history and hypothesis testing of models or theories. Unfortunately, the two are often used in inappropriate contexts in Hawai`i. Collection of natural history data is rather common in Hawai`i, but largely restricted to a handful of attractive and larger taxa that mostly don't need that work (cf. Gaston & May 1992) . Its application to invertebrates, where it is needed, is far rarer, partly because describing distribution, abundance and attributes of species, communities and ecosystems is widely viewed as "unsexy" (and sometimes as "unscientific") in the broader scientific community, making funding and interest among talented researchers difficult to obtain. Nonetheless, such work is absolutely imperative for providing baseline ecological knowledge for conservation, and its absence is a critical bottleneck for long-term conservation of the mass of Hawai`i's endemic diversity, such as invertebrates. Alternatively, for well-studied taxa in Hawai`i (most birds and mammals), science too often never advances beyond the merely descriptive, failing to test alternative hypotheses or to explore models that might explain species rarity, invasion, or how ecosystems work or collapse. For example, despite years of research, we don't know the relative current contributions of different factors to the endangerment of Hawai`i's native forest birds or to wholesale replacement of native forests by alien vegetation and thus we can't suggest priorities to managers. More generally, conservation effectiveness of much conservation science is compromised because broader research agendas are lacking and projects are rarely coordinated to build logically toward on-the-ground solutions.

Conservation science in Hawai`i generally doesn't use on-going management operations as opportunities for research; hence, it frequently fails to provide answers in a timeframe useful to managers. Managers are too often left to assess their own effectiveness without a scientific or even quantitative basis. There is truth to the aphorism "You can't manage what you can't measure". Science should be able to measure success of management and provide feedback that can be used to fine-tune management. Such 'adaptive management' of natural resources (Walters & Holling 1990) has been used successfully for species restoration in New Zealand (e.g. Innes et al. 1999) and is routinely used in forestry and fighting of wildfire on the mainland (e.g. Taylor et al. 1997; Shindler & Cheek 1999; Klooster 2002; Busenberg 2004). For adaptive management to be successful, though, one logically requires quantitative assessment of results and use of controls in one's experimental approach. Few management plans in Hawai`i seem to have either, so they lack the raw materials for adaptive management. Two rare exceptions are fire-restoration and weed-control management approaches developed at Hawai'i Volcanoes National Park (Tunison et al. 2001; Loh 2004).

Hawai`i has been singularly unsuccessful at organizing any focused multi-institutional research sites since the days of the International Biological Program (1970-1975). It has no terrestrial field stations generally open to researchers, and it has few field sites with long runs of environmental or biological data, although the Forest Service is in the process of establishing an experimental forest on the island of Hawai`i (B. Kauffman, pers. comm.). It has no site in the National Science Foundation's Long-Term Ecological Research (LTER) system and, unless the research community can coalesce around a shared research vision, appears destined to play only a satellite role in the new NSF National Ecological Observatory Network (NEON). We believe that establishment of such a dedicated resource in Hawai`i could facilitate many of the ecological studies needed for better understanding how Hawai`i's ecosystems are structured and the actions likely needed to rehabilitate them. Barro Colorado Island in Panama and The Charles Darwin Station in the Galapagos are both examples of ecological-research facilities that have had major positive effects on research and management in their respective ecosystems by achieving a critical mass that allowed detailed understanding of ecosystems impossible to achieve with solitary or short-term projects. Both have generated substantial bodies of sustained basic and applied research that have informed and supported management. Finally both have helped support their local economies, generating support for conservation, science, and the environments they deal with.

Failure to publish is a persistent limitation of Hawai`ian conservation biology. The Hawai`i Ecosystems at Risk website (www.hear.org) and the Technical Reports of the Pacific Cooperative Studies Unit (http://www.botany.Hawai`i.edu/faculty/duffy/techrep.htm) have helped make some agency "gray" literature available, but too many studies never make it to the refereed literature. This casts doubt on the competence of

Hawaiian science and management (Denslow et al. 2002) and leads managers and scientists to needlessly repeat suboptimal methodologies. For example, while there have been numerous attempts to control rats in Hawai`i, few studies have been published that provide the details, such as reported by Nelson et al. (2002), that are needed to allow rigorous evaluation of optimal methodology. Similarly, we lack published details of stock, planting techniques, subsequent care, and eventual survival for almost every outplanting effort in the state. Word of mouth is not the most effective means of transmitting best management practices; moreover, it is singularly ineffective at convincing funding sources that further efforts deserve funding.

Even when relevant scientific knowledge is produced, it may well be ignored by agency officials in reaching management decisions (Stone & Scott 1985; Stone and Stone 1989; van Riper & Scott 2001). Reasons for this include political and funding limitations, the cultural divide that too often separates managers and academics (Farnsworth 2004), and a tradition of consensus-based decisions that inhibit adoption of novel approaches or heeding of variant opinions (Janis 1982; Peterson et al. 2004). As a result, decisions as to which species or issues receive funding are frequently based on inchoate emotional or political criteria, instead of a scientifically or economically driven triage system. Consequently, much recovery funding is directed at species with the least likelihood of recovery success, such as forest birds with low population numbers, that are subject to threats not readily ameliorated. This approach to conservation stands in stark contrast to the model taken for granted in public health, in which one rightly tries to save the most people, not the sickest.

**Creating a Climate for the Soluble**

*"If politics is the art of the possible, research is surely the art of the soluble. Both are immensely practical-minded affairs."*- Medawar 1967

It is not our intention to propose a research agenda (though a partial one is implicit in what we have covered above) but to suggest six broad areas where change could help create a research and management culture that would help rectify many shortcomings identified above and would more effectively protect the native biodiversity remaining in Hawai`i.

*Focusing the Research Agenda*
We need to stop open-ended applied research financed by conservation and natural-resource agencies. Instead we need tightly focused research agendas having benefits (answers) clearly identified with costs. That does not mean that all research will be guaranteed to yield answers but research should be aimed at specific, solvable problems. Instead of broadcasting general requests for proposals and funding the most relevant of those tendered, identifying research priorities a priori and soliciting investigators to do the identified projects might better guarantee relevance of research to managers. Identification of research priorities could perhaps utilize an agenda-setting process conducted jointly by scientists and managers at regular (say, 3-year) intervals. This process should include personnel from outside Hawai`i so as to broaden perspectives.

*Teaching "The Art of the Soluble"*
Conservation science also needs to be applied in an explicit "art of the soluble" paradigm (Medawar 1967). Graduate students having the interest need formal courses that provide training in the skills required once those students enter conservation management professions, such as planning, dealing with human conflict, and dealing with uncertainty. Getting faculty and graduate students involved in hands-on recovery/restoration programs would help keep research grounded in practical concerns. In Hawai`i, United States Forest Service researchers have provided good examples of the benefits of this approach for both basic research and practical conservation (e.g. Scowcroft & Jeffrey 1999; Cabin et al. 2000). State and federal agencies need to invest in institution-building, supporting such students and their graduate programs as these will be their future employees. Also needed is a commitment by the administration of the state-funded university system to provide the recognition and credit to faculty who conduct research directly applicable to resolving conservation problems. A fundamental expansion of institutional values is needed to ensure that studies of the Hawaiian environment are valued as much as those of Mars.

*Publishing*
More needs to be done to ensure that when science is completed, it gets used by managers. The first step toward achieving this is ensuring that results are published and disseminated to managers. To encourage the former, funding agencies should evaluate the publication records of those applying for funding and factor that information into granting decisions. To achieve the latter, the Hawaiian Conservation Alliance could profitably provide single-paragraph summaries of each of the previous year's relevant research papers to attendees at its annual conservation conference, which is a focal point for interaction of the two communities in Hawai`i.

*Incorporating Science in Management*
State and federal land-management programs should institute regular peer-reviewed processes by which joint teams of scientists and managers ensure that the best available scientific knowledge is available and being applied in the field (cf. Meffe et al. 1998). Peer-review is widely accepted as denoting that minimum standards of scientific credibility have been met; similar standards should be in place for ensuring that land managers are using best available information and practices.

*Field Stations*
We need one or two larger stations covering wet, mesic, and dry forest ecosystems, open to all qualified researchers whose projects meet clear criteria of not interfering with others or damaging the environment. The stations need to be large enough to have a critical mass of researchers present, but only require simple lab facilities, communal eating facilities, dorms for visiting classes, and private quarters for longer stays. In addition managers of natural areas might consider establishing simpler field stations to attract researchers, remembering that one such humble facility, now know as "the Shack", was one of the birthplaces of restoration ecology and of much of current ecological thought (e.g. Leopold 1949).

*Funding*
We need strategically targeted funding to close the knowledge gaps identified in this paper. Increased state and federal funding for natural-resource and conservation biology is likely to be difficult to obtain, however, unless the links between cost and benefit can be more clearly demonstrated than they are in the present open-ended campaigns against invasive species and on behalf of endangered species. It may sound cynical to say that so many dollars will buy one species removed from the Endangered Species list, but such an approach may be more likely to receive funding than current efforts. Funding for the environment can also help advertise Hawai`i, much as the publicity resulting from scientific research in Galapagos helped make those islands a premier ecotourism destination in the world. But such marketing has yet to be attempted.

We suggest that dedicated sources of new funding are required to provide proof-of-concept for problem-based research and to support investigation into crucial but locally unfashionable topics such as invertebrate inventories and ecosystem "services". Such funds are unlikely to come from traditional state and federal sources because existing programs merely cater to pre-existing research values. Well-focused support by private institutions could help jump-start eventual increased governmental funding in this area, as the conservation pay-off becomes clear. A longer-term view would be the development of a new National Science Foundation program with a mandate to foster rigorous hypothesis-driven research to basic and applied conservation problems, thereby providing a rigor and independence not always apparent in agency-funded science.

**Conclusion**

Conservation in Hawai`i is sometimes viewed as a lost battle (cited in Mooney 2005). This pessimistic view stems from recognition of the hundreds of native species already lost, the thousands of invasive species introduced, and the fact that that tide of aliens is not being stemmed. Such pessimism ignores both the thousands of native species that remain and the fact that some of the major ecological

perturbations driving these losses (e.g. ungulates, fire, habitat alteration) are amenable to human control. We suggest that many of Hawai`i's conservation problems are solvable and that their future social costs may be avoided by sustained, informed action taken now. But conservation management and its supporting science must change how they do business, becoming more accountable to each other and for the resources they represent. They need to focus on explicit planning that adequately reflects biological and fiscal realities, rather than impractical, unfocused, and unachievable wish lists.

Conservation biology must provide both relevant basic biology and hypothesis-driven problem-solving on which to base management decisions, as well as focusing and measuring the outcome of management efforts. Managers in turn must be open to having their work assessed objectively and must be willing to respond accordingly. An explicit problem-solving approach provides a method to assess and justify the total costs of species recovery or ecosystem restoration. This in turn will make it easier for the public and their representatives to support conservation of species, as they will have an idea of their return on investment.

Too many recovery, restoration, and invasive-species-control efforts in Hawai`i are failing at present, but failure is not inevitable. If insanity is repeating the same behavior while expecting a different result, it is time to end the insanity and instead to cultivate the art of the soluble.

*Acknowledgements*

*We thank Cathleen Bailey, Marie Bruegmann, Betsy Gagne, Bryan Harry, Darcy Hu, Art Medeiros, Gary Ray, Philip Thomas, and Tim Tunison for discussions over the years. In addition to helpful advice, Earl Campbell, Joan Canfield, Sheila Conant, Don Drake, Michael Hamnett, Wendy Kuntz, Lloyd Loope, Steve Miller, Cliff Smith, as well as several anonymous reviewers provided helpful comments on the manuscript. We would be disappointed if they agree with everything expressed here. This work was an outgrowth of lessons learned from NSF DEB-00-83944, but the views here do not represent those of the National Science Foundation.*

**Literature Cited**

Allen, J. 1997. Pre-contact landscape transformation and cultural change in windward O`ahu. Pages 230-247 in P. V. Kirch and T.L. Hunt,editors. Historical ecology in the Pacific Islands. Yale University Press, New Haven.
Anonymous. 2003. Conservation of biological resources in Hawai`i. Baseline and status summary for 2003. Hawai`i Conservation Alliance, Honolulu.
Anonymous. 2004. Conservation cliffhanger. Science 306:2036.
Armstrong, D. P. 2005. Integrating the metapopulation and habitat paradigms for understanding broad-scale declines of species. Conservation Biology 19:1402-1410.
Asquith, A. 1995. Alien species and the extinction crisis of Hawai`i's invertebrates. Endangered Species Update 12 (6).
Athens, J. S. 1997. Hawaiian native lowland vegetation in prehistory. Pages 248-270 in P. V. Kirch and T. L. Hunt, editors. Historical ecology in the Pacific Islands. Yale University Press, New Haven.
Atkinson, I. A. E. 1977. A reassessment of factors, particularly Rattus rattus L., that influenced the decline of endemic forest birds in the Hawai`ian Islands. Pacific Science 31:109-133.
Banko, P. C., P. T. Oboyski, J. W. Slotterback, S. J. Dougill, D. M. Goltz, L. Johnson, M. E. Laut, and T. C. Murray. 2002. Availability of food resources, distribution of invasive species, and conservation of a Hawaiian bird along a gradient of elevation. Journal of Biogeography 29:789-808.
Beavers, A. M., and R. E. Burgan. 2002. Analysis of fire history and management concerns at Pohakuloa Training Area. CEMML TPS 02-02. Center for Environmental Managment of Military Lands, Colorado State University, Fort Collins.
Benning, T. L., D. La Pointe, C. T. Atkinson, and P. M. Vitousek. 2002. Interactions of climate change with biological invasions and land use in the Hawaiian Islands: modeling the fate of endemic birds using a geographic information system. Proceedings of the National Academy of Science 99:14246-14249.
Bomford, M. 2003. Risk assessment for the import and keeping of exotic vertebrates in Australia. Bureau of Rural Sciences, Canberra.
Bomford, M., and J. Glover. 2004. Risk assessment model for the import and keeping of exotic freshwater and estuarine finfish. Bureau of Rural Sciences, Canberra.
Bomford, M., and Q. Hart. 1998. Risk assessment for importing and keeping exotic vertebrates. Pages 406-410 in R. O. Baker, and A. C. Crabb, editors. Proceedings of the 18th Vertebrate Pest Conference, University of California, Davis.
Bomford, M., F. Kraus, M. Braysher, L. Walter, and L. Brown. 2005. Risk assessment model for the import and keeping of exotic reptiles and amphibians. Final report to Australian Department of Environment and Heritage, 110 pp.
Burney, D. A., H. F. James, L. P. Burney, S. L. Olsen, W. Kikuchi, W. L. Wagner, M. Burney, M. D. McCloskey, D. Kikuchi, F. V. Grady, R. Gage, and R. Nishek. 2001. Fossil evidence for a diverse biolat from Kaua`i and its transformation since human arrival. Ecological Monographs 71:615-641.
Busenberg, G. J. 2004. Adaptive policy design for the management of wildfire hazards. American Behavioral Scientist 48:314-326.
Cabin, R. J., S. G. Weller, D. H. Lorence, T. W. Flynn, A. K. Sakai, D. Sandquist, and L. J. Hadway. 2000. Effects of long-term ungulate exclusion and recent alien species control on the preservation and restoration of a Hawaiian tropical dry forest. Conservation Biology 14:439-453.
Cole, F. R., A. C. Medeiros, L. L. Loope, and W. W. Zuehlke. 1992. Effects of the Argentine ant on arthropod fauna of Hawaiian high-elevation shrubland. Ecology 73:1313-1322.
Conant, S., H. D. Pratt, and R. J. Shallenberger. 1998. Reflections on a 1975 ornithological expedition to the lost world of the Alaka`i and other notes on the natural history, systematics and conservation of Kaua`i birds. Wilson Bulletin 110:1-22.
Cox, P. A., and T. Elmqvist. 2000. Pollinator extinction in the Pacific Islands. Conservation Biology 14:1237-1239.
Crooks, J. A., and M. E. Soulé. 1999. Lag times in population explosion of invasive species: causes and implications. Pages 103-123 in O. T. Sandlund, P. J. Schei, and A. Viken, editors. Invasive species and biodiversity management. Kluwer Acad. Publ., Dordrecht, Netherlands.
Cuddihy, L. W., and C. P. Stone. 1990. Alteration of native Hawaiian vegetation: effects of humans, their activities and introductions. University of Hawai`i Press, Honolulu.
Daehler, C. C., and D. A. Carino. 2000. Predicting invasive plants: prospects for a general screening system based on current regional models. Biological Invasions 2:93-102.
Daehler, C. C., J. S. Denslow, S. Ansari, and H. C. Kuo. 2004. A risk-assessment system for screening out invasive pest plants from Hawai`i and other Pacific Islands. Conservation Biology 18:360-368.
Darwin, C. 1881. The formation of vegetable mould, through the action of worms, with observations on their habits. John Murray, London.
Denslow, J., C. W. Smith, and S. Hight. 2002. Biological control of invasive plants in native Hawai`ian ecosystems. Synthesis and conclusions. Pages 117-122 in C. W. Smith, J. Denslow, and S. Hight, editors. Proceedings of a Workshop on Biological Control of Invasive Plants in Native Hawaiian Ecosystems. Technical Report 129. Pacific Cooperative Studies Unit, University of Hawai`i, Honolulu.
Duffy, D. C. 1992. Biodiversity and research on seabirds. Colonial Waterbirds 15:155-158.
Eldredge, L. G., and N. L. Evenhuis. 2003. Hawai`i's biodiversity: a detailed assessment of the numbers of species in the Hawaiian Islands. Bishop Museum Occasional Papers 76:1-28.
Ellis, S. C. Kuehler, R. Lacy, K. Hughes, and U. S. Seal. 1992. Hawaiian forest birds conservation assessment and management plan, final report. Proceedings of the Hawaiian forest birds conservation assessment and management plan workshop, 7-12 December 1992, Hilo, Hawai`i. Published by the Captive Breeding Specialist Group, IUCN-The World Conservation Union/Species Survival Commission.
Farnsworth, E. J. 2004. Forging research partnerships across the academic-agency divide. Conservation Biology 18:291-293.
Freed, L. A. 2001. Significance of old-growth forest to the Hawai`i `Akepa. Pages 173-184 in J. M. Scott, S. Conant, and C. van Riper III, editors. Evolution, ecology, conservation, and management of Hawaiian birds: a vanishing avifauna. Studies in Avian Biology 22.
Gagne, W.C., and F. G. Howarth. 1985. Conservation status of endemic Hawai`ian Lepidoptera. Pages 74-84. Proceedings of the 3rd Congress of European Lepidopterists 1982, Karlsruhe. Cambridge.
Gambino, P., A. C. Medeiros, and L. L. Loope. 1987. Introduced vespids Paravespula pensylvanica prey on Maui's endemic arthropod fauna.

Journal of Tropical Ecology 3:169-170.
Gambino, P., A. C. Medeiros, and L. L. Loope. 1990. Invasion and colonization of upper elevations on east Maui (Hawai`i) by Vespula pensylvanica (Hymenoptera: Vespidae). Annals of the Entomological Society of America 83:1088-1095.
Gaston, K. J., and R. M. May. 1992. The taxonomy of taxonomists. Nature 356:281-281.
Gillespie, R.G., and N. Reimer. 1993. The effect of alien predatory ants (Hymenoptera: Formicidae) on Hawaiian endemic spiders (Araneae: Tetragnathidae). Pacific Science 47:21-33.
Goldberg, S. R., and C. R. Bursey. 2000. Transport of helminthes via the Brown Anole, Anolis sagrei (Polychrotidae). Journal of Parasitology 86:750-755.
Hart, P. J. 2001. Demographic cvomparisons between high and low density populations of Hawai`i `Akepa. Pages 185-193 in J. M. Scott, S. Conant, and C. van Riper III, editors. Evolution, ecology, conservation, and management of Hawaiian birds: a vanishing avifauna. Studies in Avian Biology 22.
Hobbs, R. J., and S. E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. Conservation Biology 9:761-770.
Holdobler, B., and E. O. Wilson. 1990. The ants. Belknap Press. Cambridge, MA.
Hughes, K., C. Mirande, C. Kuehler, R. Lacy, S. Ellis, and U. Seal. 1992. `Alala (Hawaiian Crow) Corvus Hawaiiensis population and habitat viability assessment report. Captive Rearing Specialist Group, Species Survival Commission, Apple Valley, MN.
Hulme, P. E. 2003. Biological invasions: winning the science battles but losing the conservation war? Oryx 37:178-193.
Innes, J., R. Hay, I. Flux, P. Bradfield, H. Speed, and P. Jansen. 1999. Successful recovery of North Island kokako Callaeas cinerea wilsoni populations, by adaptive management. Biological Conservation 87:201-204.
Jacobi, J. D. 1990. Distribution maps, ecological relationships, and status of native plant communities on the island of Hawai`i. Ph.D. dissertation, University of Hawai`i, Honolulu.
James, H. F. 1995. Prehistoric change to diversity and ecosystem dynamics on oceanic islands. Pages 87-101 in P. Vitousek, L. Loope, and H. Adsersen, editors. Biological diversity and ecosystem function on islands. Springer-Verlag, Heidelberg.
Janis, I. L. 1982. Groupthink : psychological studies of policy decisions and fiascoes. Houghton-Mifflin, Boston.
Joyce, C. R. 1961. Potentialities for accidental establishment of exotic mosquitoes in Hawai`i. Proceedings of the Hawai`ian Entomological Society 17:403-413.
Kaiser, B. A. in press. Economic impacts of non-indigenous species: Miconia and the Hawaiian economy. Euphytica
Kilpatrick, A. M., Y. Gluzberg, J. Burgett, and P. Daszak. 2004. Quantitative risk assessment of the pathways by which West Nile virus could reach Hawai`i. EcoHealth 1:205-209.
Klooster, D. J. 2002. Toward adaptive community management: Integrating local forest knowledge with scientific forestry. Economic Geography 78:43-70.
Kraus, F. 2002. New records of alien reptiles in Hawai`i. Bishop Museum Occasional Papers 69:48-52.
Kraus, F. 2003. Invasion pathways for terrestrial vertebrates. Pages 68-92 in Carlton, J., G. Ruiz, and R. Mack, editors. Invasive species: vectors and management strategies. Island Press, Washington, D.C.
Kraus, F., and D. Cravalho. 2001. The risk to Hawai`i from snakes. Pacific Science 55:409-417.
Krushelnycky, P. D., L. L. Loope, and S. M. Joe. 2004. Limiting spread of a unicolonial invasive insect and characterization of seasonal patterns of range expansion. Biological Invasions 6:47-57.
Lacy, R. K. Hughes, C. Kuehler, S. Ellis, and U. Seal. 1992. Palila Loxoides bailleui population and habitat viability assessment report. Captive Rearing Specialist Group, Species Survival Commission, Apple Valley, MN.
Leopold, A. 1949. A Sand County Almanac. Oxford University Press, Oxford.
Loh, R. 2004. Early plant test establishment following experimental removal of invasive Morella faya (Ait.) Wilbur stands in a Hawai`ian Forest. Ph.D. dissertation. University of Hawai`i Manoa, Honolulu.
Long, J. L. 1981. Introduced birds of the world. Universe Books, New York.
Loope, L. L. 1998. Hawai`i and the Pacific Islands. Pages 747-774 in M. J. Mac, P. A. Opler, C. E. Puckett Haecher, and P. D. Doran, editors. Status and trends of the nation's biological resources. United States Geological Survey, Department of the Interior, Reston, Virginia.
Loope, L. L., and P. G. Scowcroft. 1985. Vegetation response within exclosures in Hawai`i: a review. Pages 377-402 in C. P. Stone, and J. M. Scott, editors. Hawai`i's terrestrial ecosystems: preservation and management. Cooperative National Park Studies Unit, University of Hawai`i, Honolulu.
Loope, L., F. Starr, and K. Starr. 2004. Protecting endangered plant species from displacement by invasive plants on Maui, Hawai`i. Weed Technology 18:1472-1474.
McClung, A. M. 2005. A population viability analysis of the Laysan finch (Telespiza cantans). Unpublished doctoral dissertation, University of Hawai`i, Honolulu.
Medawar, P. S. 1967. The Art of the Soluble. Methuen, London.
Meffe, G. K., P. D. Boersma, D. D. Murphy, B. R. Noon, H. R. Pulliam, M. E. Soulé, and D. M. Waller. 1998. Independent scientific review in natural resource management. Conservation Biology 12:268-270.
Mooney, H. A. 2005. Battling bioinvaders. A book review of Out of Eden: an odyssey of ecological invasion. American Scientist 93:
Nakahara, L. 1999. Priority lists of weeds for FY 2000. (unpublished memorandum. Nov. 16. Hawai`i Department of Agriculture, Honolulu.
Nelson, J. T, B.L Woodworth, S.G Fancy, G. D Lindsey, and E. J Tweed. 2002. Effectiveness of rodent control and monitoring techniques for a montane rainforest. Wildlife Society Bulletin 30:82-92.
Owen, S. J. 1998. Department of Conservation strategic plan for managing weeds. Department of Conservation, Wellington.
Parman, T. R., and K. Wampler. 1976. The Hilina Pali fire: a controlled burn exercise. Technical Report 18. Cooperative National Park Resources Studies Unit, University of Hawai`i, Honolulu.
Peterson, M. N., M. J. Peterson, and T. R. Peterson. 2004. Conservation and the myth of consensus. Conservation Biology 19:762-767.
Pheloung, P. C., P. A. Williams, and S. R. Halloy. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. Journal of Environmental Management 57:239-251.
Pickett, S. T. A., and J. N. Thompson. 1978. Patch dynamics and the design of nature reserves. Biological Conservation 13:27-37.
Pimentel, D., L. Lach, R. Zuniga,, and D. Morrison. 2000. Environmental and Economic Costs of Nonindigenous Species in the United States. BioScience 50:53-65.
Pimentel, D., R. Zuniga,, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:\273-288.
Reed, J. M., C. S. Elphick, and L. W. Oring. 1998. Life-history and viability analysis of the endangered Hawai`ian Stilt. Biological Conservation 84:35-45.
Reimer, N. J. 1994. Distribution and impact of alien ants in vulnerable Hawai`ian ecosystems. Pages 11-22 in D. F. Williams, editor. Exotic ants: biology, impact, and control of introduced species. Westview Press, Boulder.
Reynolds, M.H. 2002. The foraging ecology, habitat use, and population
dynamics of the Laysan teal (Anas laysanensis). Ph.D. dissertation,
Virginia Polytechnic Institute and State University, Blacksburg, VA.
Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D`Erchia, T. C. Edwards, Jr., J. Ullman, and R. G. Wright. 1993. GAP analysis: a geographic approach to protection of biological diversity. Wildlife Monographs 123:1–41.
Scowcroft, P.G., and J. Jeffrey. 1999. Potential significance of frost, topographic relief, and Acacia koa stands to restoration of mesic Hawai`ian forests on abandoned rangeland. Forest Ecology and Management 114:447-458.
Seal, U., S. Ellis, R. Lacy, K. Hughes, and C. Kuehler. 1992. Akohekohe (Crested Honeycreeper) Palmeria dolei population and habitat viability assessment report. Captive Rearing Specialist Group, Species Survival Commission, Apple Valley, MN.
Shindler, B., and K. A. Cheek. 1999. Integrating citizens in adaptive management: a propositional analysis. Conservation Ecology 3: http://www.consecol.org/vol3/iss1/art9/
Smith, C. W. 1985. Impact of alien plants on Hawai'i's native biota. Pages 180-250 in C. P. Stone, and J. M. Scott, editors. Hawai'i's terrestrial ecosystems: preservation and management. Cooperative National Park Resources Studies Unit, Honolulu.
Solem, A. 1990. How many Hawai`ian land snail species are left? and what we can do for them. Bishop Museum Occasional Papers 30:27-40.

Staples, G. W., D. Herbst, and C. T. Imada. 2000. Survey of invasive or potentially invasive cultivated plants in Hawai'i. Bishop Museum Occasional Papers 65:1-35.
Steiner, W. W. M. 2002. Evaluating the cost of saving Native Hawai`ian birds. Conservation status and recovery strategies for endemic Hawai`ian birds. Pages 377-383 in J. M. Scott, S. Conant, and C. van Riper III, editors. Evolution, ecology, conservation, and management of Hawai`ian birds: a vanishing avifauna. Studies in Avian Biology 22.
Stone, C. P., and J. M. Scott. 1985. Hawai`i`s native ecosystems: importance, conflicts, and suggestions for the future. Pages 495-534 in C. P. Stone and J. M. Scott, editors. Hawai`i's terrestrial ecosystems: preservation and management. Cooperative National Parks Resources Studies Unit, University of Hawai`i Press, Honolulu.
Stone, C. P., and D. B. Stone, Editors. 1989. Conservation biology in Hawai`i. Cooperative National Parks Resources Studies Unit, University of Hawai`i Press, Honolulu.
Taylor, B., L. Kremsater, and R. Ellis. 1997. Adaptive management of forests in British Columbia. British Columbia Ministry of Forests, Forest Practices Branch, Victoria, B.C.
Tomich, P. Q. 1986. Mammals in Hawai'i: a synopsis and notational bibliography, 2nd ed. Bishop Museum Press, Honolulu.
Tunison, J. T. 2002. A resource manager's perspective on the role of biocontrol in conservation areas in Hawai`i. Pages 103-108 in C. W. Smith, J. Denslow, and S. Hight, editors. Proceedings of a workshop on biological control of invasive plants in native Hawai`ian ecosystems. Technical Report 129. Pacific Cooperative Studies Unit, University of Hawai`i, Honolulu.
Tunison, J. T., and C. P. Stone. 1992. Special ecological areas: an approach to alien plant control in Hawai`i Volcanoes National Park. Pages 781-798 in C. P. Stone, C.W. Smith, and J. T. Tunison, editors. Alien plant invasions in native ecosystems of Hawai`i: management and research. Cooperative National Park Resources Studies Unit, University of Hawai`i, Honolulu.
Tunison, J. T., C. M. D`Antonio, and R. K. Loh. 2001. Fire and invasive plants in Hawai`i Volcanoes National Park. Pages 122-131 in K. E. M. Galley, and T. P. Wilson, editors. Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11. Tall Timbers Research Station, Tallahassee, FL.
U.S. Fish and Wildlife Service. 2003. Draft recovery plan for Hawai`i forest birds. Region 1. Portland, OR.
VanderWerf, E. A. 2004. Demography of Hawai`i `Elepaio: variation with habitat disturbance and population density. Ecology 85:770-783.
van Riper, C., III, and J. M. Scott. 2001. Limiting factors affecting Hawaiian native birds. Pages 221-233 in J. M. Scott, S. Conant, and C. van Riper III, editors. Evolution, ecology, conservation, and management of Hawai`ian birds: a vanishing avifauna. Studies in Avian Biology 22.
van Riper, C., III, S. G. van Riper, M. L. Goff, and M. Laird. 1986. The epizootiology and ecological significance of malaria in Hawaiian land birds. Ecological Monographs 56:327-344.
Vogl, R. J. 1980.The ecological factors that produce perturbation-dependent ecosystems. Pages 63-94 in J. Cairns, Jr., editor. The recovery process in damaged ecosystems. Ann Arbor Science, Ann Arbor.
Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71:2060-2068.
Walton, C., N. Ellis, and P. Pheloung. 1999. A manual for using the Weed Risk Assessment system (WRA) to assess new plants. Australian Quarantine and Inspection Service, Canberra.
Wester, L. 1992. Origin and distribution of adventive alien flowering plants in Hawai`i. Pages 99-154 in C. P. Stone, C.W. Smith, and J. T. Tunison, editors. Alien plant invasions in native ecosystems of Hawai`i: management and research. Cooperative National Park Resources Studies Unit, University of Hawai`i, Honolulu.
Williams, J.M. 2000. New Zealand under siege: a review of the management of biosecurity risks to the environment. Office of the Parliamentary Commissioner for the Environment, Wellington.http://www.pce.govt.nz/reports/allreports/0_908804_93_8.shtml (accessed 27 August 2005).
Williams, P. A. 1997. Ecology and management of invasive weeds. Department of Conservation, Wellington.