Restoration Ecology
THE JOURNAL OF THE SOCIETY FOR ECOLOGICAL RESTORATION

OPINION ARTICLE

Quandaries of a decade-long restoration experiment trying to reduce invasive species: beat them, join them, give up, or start over?

Susan Cordell[1,2], Rebecca Ostertag[3], Jené Michaud[4], Laura Warman[1]

We evaluate the outcomes and consequences of a decade-long restoration project in a Hawaiian lowland wet forest as they relate to long-term management actions. Our initial study was designed both to promote native biodiversity and to develop knowledge that would enable land management agencies to restore invaded forests. Our premise of success followed the prevalent perception that short-term management, such as removal of invasive species, ideally translates into long-term and sustainable restoration. We were therefore disappointed and perhaps discouraged in our results—little recovery of native biodiversity despite ongoing and labor-intensive management. Not only did we fail to return the invaded forest to a native-dominated system but also our efforts lead to recruitment of new non-native species assemblages. The sobering truth of many restoration projects in Hawaii and elsewhere is that we can never completely walk away and "consider the job finished," or we have to accept that some ecosystems cannot be returned to an all-native state. Essentially, costs of restoration may outweigh the accomplishment. This setback gave us an opportunity to reconsider and modify our initial approach. By starting over with a new direction using both native and non-invasive but non-native species, we have adopted a new philosophy of "join them." In our revision, we changed the players in the game by following invasive species removal with outplantings of native and non-invasive non-native species that will functionally fill missing roles in the ecosystem. We link social interest in the new experiment to changing attitudes about naturalness.

Key words: **Hawaii, hybrid ecosystems, invasive species, long-term research, tropical lowland wet forest**

Implications for Practice

- The adaptive management concept should be applied to restoration because achieving "success" in a restoration project is relative, subjective, and may change over time.
- Practicing "adaptive restoration" requires a long-term view, acknowledging that achievement of short-term restoration goals does not guarantee a desired long-term outcome.
- Non-native but non-invasive species, when used appropriately such as in highly modified ecosystems, can enhance ecosystem functions and services and may actually provide resistance to invasion by effective competition for space and resources.

Introduction

Restoration achievement is relative. This is particularly true in ecologically based restoration research where the premise is often based on scientific curiosity rather than compliance, in which restoration mandates and funding are often the result of satisfying legal requirements. Restoration objectives can be quantified when clear metrics are proposed at the outset (i.e. percentage of plant survival or increased species abundance), however, it is much more difficult to evaluate whether a project meets overarching goals such as sustainably restoring ecosystem functions. Zedler (2007) advises restoration ecologists to omit or clarify usage of the terms "success" and "failure" because the ways projects are viewed and evaluated are time and evaluator-dependent. Thus, a quantitative approach that clarifies what expectations in the project are met or unmet is much more valuable, and allows projects to evolve and adapt to changing conditions or knowledge rather than to just succeed or fail (Hughes et al. 2012).

In this context, we present and appraise our decade-long restoration experiment in a Hawaiian lowland wet forest (LWF) as a case study with elements of success and failure as well as adaptation to a new forward-thinking vision. As part of our reflections and evaluation of our restoration project, we also present the backstory that accompanies a restoration effort but does not often make it into peer-reviewed journal articles. This perspective comes from following the same small plots for a decade (Cordell et al. 2009; Ostertag et al. 2009). Our study

Author contributions: SC, RO, JM, LW conceived the concepts; all authors wrote and edited the manuscript.

[1]Institute of Pacific Islands Forestry, USDA Forest Service, Hilo, HI 96720, U.S.A.
[2]Address correspondence to S. Cordell, email scordell01@fs.fed.us
[3]Department of Biology, University of Hawaii at Hilo, Hilo, HI 96720, U.S.A.
[4]Department of Geology, University of Hawaii at Hilo, Hilo, HI 96720, U.S.A.

© 2016 Society for Ecological Restoration
doi: 10.1111/rec.12321

was designed both to promote native biodiversity and to provide land management agencies with effective knowledge and tools to restore forest threatened by invasive species. Despite the clear importance of following restoration research projects longer than a traditional grant cycle of 3–4 years (Hobbie et al. 2003; Robertson et al. 2012), the long-term consequences of management actions often remain unclear.

In the case of Hawaiian LWF, it is unknown if the obvious course of action—removal of non-native plant species—is effective in the long term to maintain and restore native plant biodiversity. Research has shown that, in the short-term, non-native species management (i.e. mechanical, chemical, or biological control methods) can be a successful tool to increase native vegetation especially in situations where native seed dispersal mechanisms are intact and/or native species form long-term seed banks (Bakker et al. 1996). Yet few studies monitor the long-term effects of management practices, making it difficult to conclusively determine the usefulness of a particular management approach. In fact, many studies have revealed that unexpected outcomes can result from restoration based management decisions to return a system to a historic state. For example, non-native species removal may not only increase non-native abundance but may also potentially introduce or facilitate new invaders into the system (Zavaleta et al. 2001; D'Antonio & Meyerson 2002; Suding et al. 2004; Mason et al. 2007), and modify ecosystem processes (Mack et al. 2001; Mack & D'Antonio 2003; Cordell & Sandquist 2008; Ostertag et al. 2009). Although these sorts of unintended consequences can be expected in the context of complex ecological systems, their exact nature and long-term impacts are difficult to identify or predict, especially for resource managers with limited budgets and time. In this article, we ask applied questions about the long-term sustainability/feasibility of such intensive management for native biodiversity.

The Hawaiian LWF communities we work in are so impacted that less than 10% of their original extent remains (Wagner et al. 1999; Price et al. 2007) and these remnants are highly fragmented as a result of human activities related to agriculture and urbanization. Given the habitat rarity, the overarching objectives in our restoration experiment were to: (1) promote native species regeneration, (2) identify a feasible LWF restoration prescription for Hawaii's land managers, and (3) assess whether restoration is achievable by removing invasive species that impede the natural recovery of LWF (Morrison & Lindell 2011). As the journal *Restoration Ecology* acknowledges in their Setbacks and Surprises section, there is not enough publication of negative results, or of results that do not meet initial restoration objectives (see those results in Cordell et al. 2009; Ostertag et al. 2009; Schulten et al. 2014).

By some measures, our experiment was a success but by others it was also a failure. In synthesizing the results of 10 years of experimentation, it became obvious that it is necessary to incorporate adaptive management strategies to realistically address the evaluation and sustainability of similar restoration efforts. In this article, we ponder the results of our previous experiments to address: (1) the role of seedling recruitment in our restoration effort, (2) whether continued management can exhaust non-native seedling recruitment, and (3) how restoration management varies over time, and importantly—can we ever really walk away?

Geographic Area of Interest

Hawaii provides a unique setting for the study of restoration ecology and represents an outstanding system in which to understand both the impacts of invasive species and the outcome of their management on native biodiversity (Vitousek et al. 1997; Pimentel et al. 2005). Complex interactions between climate, substrate age, and elevation, in addition to a depauperate flora due to extreme isolation have played large roles in shaping ecological communities that are perhaps more vulnerable to the effects of invasion and less resilient to recover once disturbed than their mainland counterparts. The LWF in Hawaii may be particularly open to invasion because: (1) more than half the plants are non-native (Wagner et al. 1999); (2) resources for plant growth are abundant; (3) the dominant native flora does not exhibit classic pioneer species traits (Drake & Mueller-Dombois 1993); and (4) Hawaii has serious invasion issues and LWF has been heavily modified, used, and inhabited since the arrival of the Polynesians (Kirch 1982). As a result, there is little to no information on the historic composition, structure, and functioning of this forest type. Consequently, there is no clear blueprint for which techniques and approaches are most appropriate to follow to restore the biodiversity and ecosystem processes of Hawaiian LWF. To determine the potential for restoration of invaded Hawaiian LWF, we opted for a sequential approach where we first removed the major threats to see whether the forest could recover once they were removed. Then, given the outcome we followed with increasing degrees of effort (Cordell et al. 2009; Ostertag et al. 2009).

Step One—Removing the Existing Pressures Causing LWF Biodiversity Degradation

We conducted the invasive species removal experiment at the Keaukaha Military Reservation located in a LWF fragment on the Island of Hawaii (see Cordell et al. 2009; Ostertag et al. 2009; Schulten et al. 2014 for detailed methodology and results). The canopy of this forest is dominated by native species but the under and mid-stories are highly invaded by numerous non-native species. In 2004, we established eight plots of 100 m^2, pairing four control plots with four plots in which all non-native species were removed. We maintained a weed-free environment in these removal plots, tracked the ongoing weeding effort and monitored seedling recruitment. We assumed all recruitment resulted from either the seed rain or the seed bank.

Passive Approach—Lessons Learned

The results of our efforts confirmed that invasive species put such great pressure on native biodiversity in these systems, that restoration using traditional approaches of tropical forest restoration is not feasible. We measured the initial and maintenance effort required to reduce the biomass of non-native species, and our metrics of success included the existence of a native seed bank, effective native seedling regeneration with growth rates that should exceed those of the problematic invaders, and a return of forest conditions such as appropriate light quantity and microclimatic variables, which favor native vegetation. Conversely, our results revealed a completely non-native seed bank despite a native-dominated seed rain, minimal native species germination in the first 5 years, and a substantial management effort to maintain a weed-free environment (Cordell et al. 2009; Ostertag et al. 2009).

Given that the native canopy tree species *Metrosideros polymorpha* (Myrtaceae) vastly dominates the seed rain at the site (>90%, see Cordell et al. 2009), and our efforts to keep the removal site free of non-native species decreased almost 20-fold 3 years following the initial removal, we were initially optimistic that our weeding efforts might exhaust the non-native seed bank and tip the balance toward native regeneration. However, as time went on and the weeding effort increased, it became apparent that *Metrosideros* does not form a seed bank and the long lived non-native seed banks continued to persist. These results contradict the relative success associated with restoration efforts in continental tropical LWF systems where removal of threats can facilitate canopy closure by fast-growing pioneer species within the first 2–3 years (Tucker & Murphy 1997). Canopy closure is an important juncture for success given its importance for suppressing weed growth and promoting a favorable micro-environment for forest growth (Goosem & Tucker 1995).

In our experiment, we measured successful native species recruitment after 10 years, and this satisfied one of our desired metrics. However, the most successful species (*M. polymorpha*) is very conservative in its growth and has diameter growth rate of approximately 1 mm/year (Ostertag et al. 2014). In contrast, some of the non-native species can achieve diameter growth rates of 10 mm/year and are capable of reaching heights of 2–3 m between annual weedings (Cordell 2015, personal observation). This sobering reality highlights the vulnerability and risk of non-native species only restoration efforts. In response to these outcomes, in 2010 we began actively outplanting native species into the removal plots. Eight years following planting close to 70% of the seedlings had survived but less than 20% reached a meter in height, indicating a potential height growth rate of 0.2 m/year (Schulten et al. 2014). Despite relatively high survival rates in the removal plots, the relative growth rates of these seedlings 2 years later were not greater than those of the naturally recruited indicating that many LWF native species are likely not adapted to effectively or efficiently take advantage of resources associated with a gap environment following disturbance.

Next Steps

Under ideal circumstances, short-term management translates into long-term restoration efforts that require little to no intervention. The level of management required in Hawaiian LWF 10 years after initial weeding began, highlights the need to re-evaluate the original goals and assumptions of the project.

The daunting reality is that ongoing control of non-native species has not transformed this highly invaded system into a native-dominated one, but rather has resulted in the recruitment of new non-native species assemblages. Our results indicate that invasive species management in Hawaiian LWF must be maintained, perhaps perpetually, to reduce or exhaust overall non-native recruitment. Our data further imply that resource managers in Hawaii cannot rely on the seed bank to assist in restoration of native biodiversity as the bulk of the seed bank is dominated by non-native species, and does not necessarily reflect the native seed rain or standing vegetation (Cordell et al. 2009). It could be assumed that additional labor-intensive strategies, such as native species outplanting and controlling the seed rain, would be necessary to shift the balance in favor of native species. But even these strategies have proven unsustainable over time, given the difference in growth rates between native and non-native species. Furthermore, the economic and labor costs of such strategies are very high, and would have to be rigorously evaluated in order to make restoration decisions. In a nutshell, adopting a zero-tolerance policy for non-native species was neither biologically nor economically realistic. Should we then admit defeat and conclude that a return to native assemblages is not possible in this ecosystem type? When does the cost of restoration outweigh the success?

It would be easy to give up at this point and end the experiment. Most of the key data sets were published, and quite frankly, field work at this site was difficult. In addition to the standard elements of tropical heat, rain, and mosquitoes, the field site boasts dense thickets of clonal invasive species, vines, and a very sharp and unstable, rocky substrate that make field work hard to negotiate. Our research was not mandated by a government agency for compliance to environmental regulations, and as such we had no clearly defined quantifiable targets at the start. Instead, we undertook this research because we had the experiences of a privileged few—inspiring visits to rare remaining LWF sites in much better condition (although by no means pristine). As an added bonus, the field site is within a 10-minute drive of home institutions, simplifying logistics and cutting down significantly on funding needs. The site was an easy place to involve volunteers and university classes in service learning, and to provide research experience for undergraduates. Thus, the experiment was a personal and intellectual challenge, motivated by our sincere passion for native-dominated Hawaiian ecosystems. Little to nothing was known about LWF restoration when we started, and our approach was based on a combination of knowledge, observation, and educated guesses. Looking back, it is evident why many assumed that these forests were non-restorable. Such a tremendous amount of physical energy has gone into creating the removal plots that it became clear why most removal experiments are done in herbaceous communities (Loh & Daehler 2007; Lavorel et al. 2013).

The enormous amount of personal investment that had gone into the experiment made the option of "giving up" not one that we wanted to accept. Given that a more pragmatic approach seemed necessary, we decided to adopt a hybrid strategy that tolerates or even embraces certain non-invasive, non-native species whereas highly invasive species are deemed unacceptable. These new combinations may arise via the spread of non-native species, range shifts due to climate change, agriculture, forestry, or other means of species movement and manipulation.

We designed a new experiment—the Liko Nā Pilina Project, which represents a compromise between the "beat them" and the "join them" viewpoints. The name of the project effectively translates to "budding or new relationships and/or connections" in the Hawaiian language, because the focus still remains on removing invasive species, but in the new experiment these are replaced with combinations of native species and non-native species deemed to be non-invasive (based on assessments such as the Hawaii Weed Risk Assessment) (Daehler et al. 2004). Rather than trying to return to an all-native state, Liko Nā Pilina aims to reclaim ecosystem functioning and this restoration is carried out through the creation of novel communities (Morse et al. 2014), based on the functional traits of different species. As discussed elsewhere (Ostertag et al. 2015), candidate species were evaluated based on their traits, and groupings of species were chosen as assemblages that could collectively provide specific functional outcomes (such as increased carbon sequestration, shading, etc.).

A key finding has been that the native species collectively differ from non-native species in their functional trait profiles (Van Kleunen et al. 2010). Native species tended to be clustered in trait space suggesting a limited range of trait combinations. This result implies that in Hawaiian lowland ecosystems where invasion is a more prevalent problem than other tropical systems, native-only restoration projects may not be effective in resisting problematic invaders than when relevant non-native species are added to the mix. In a tropical dry system restoration experiment, Questad et al. (2012) found that the restoration treatments that most benefitted native species success were the same treatments that favored invasion. In the short term, and with management of non-native species, appropriate site treatments in this study enhanced native species survival—but when weed management ceased—the longer-term outcome was a net decrease in native biodiversity. This example highlights the idea that in Hawaii trait selection to maximize resource use optimization of a site may be more important in the long term than species selection toward a historical assemblage (Ostertag et al. 2015). Although a restoration effort that leads to a novel ecological community may be contentious, we would argue that this pragmatic approach aligns with restoration theory, as it restores ecosystem processes which have been lost as a result of species invasions. The results of Questad et al. (2012) persuaded us that restoration to promote invasive species resistance may require effectively filling functional/niche/trait space rather than native species diversity. With this in mind it is important to stress that for the Liko Nā Pilina Project we also included non-native species that are culturally important to humans in some way—either canoe plants brought by early Hawaiians (e.g. breadfruit [*Artocarpus altilis*], kukui nut [*Aleurites moluccanus*], coconut [*Cocos nucifera*]) or species introduced by later colonists (e.g. mango [*Mangifera indica*] and avocado [*Persea americana*]).

We designed treatments in the Liko Nā Pilina Project to vary in carbon (C) turnover rates and in the functional similarity of species (i.e. species combinations incorporate either functional complementarity or redundancy). Based on our previous results and observation of Hawaiian LWF's, we chose species whose traits foster slower carbon and nutrient cycling because this mimics native Hawaiian systems. We expect this will likely favor native biodiversity and further discourage the vicious cycle which favors invasive species (Ostertag et al. 2015). Results of the study will provide a quantitative assessment of the value of designing self-sustaining combinations of species that balance tradeoffs between supporting native biodiversity, resistance to invasion by non-desirable plants, and fostering human needs (such as C storage or food availability). We fully expect to recapitulate our previous experience—there will be a series of successes and failures, and adaptive restoration practiced—but at least this time we can set more realistic criteria for determining "compliance," rather than "success" (sensu Zedler (2007).

It is important to state explicitly that we are not advocating a global abandonment of traditional restoration approaches in favor of alternative approaches like ours. We present the functional trait approach as one that can be potentially adaptable in other ecosystems (Ostertag et al. 2015), but the fact is that it is likely that the relevance of a hybrid ecosystem approach that mixes native and non-native species is only useful and necessary in extremely modified, already novel systems and cases like ours, where recovery processes left to natural succession are ineffective.

On this journey, there have already been surprises. Unexpectedly, and by thinking creatively, we were able to align the restoration of our site, a military reservation, with the objectives of the military, whose training of soldiers was impeded by the existing dense forest understory of invasive species. Often opposing mandates require a partitioning of the landscape, but in this case the proposed hybrid system offers both a suitable tropical forest structure for training and a suite of species quantitatively selected to develop into systems that resist invasion and promote native habitat and biodiversity (Ostertag et al. 2015). Another surprise has been the amount of local interest that has been generated by the approach. During presentations of our project in public forums, we have received interest from kindergarten to high school groups, Hawaiian organizations, media outlets, academics, and resource managers; many individuals and organized groups have volunteered their services in the field. The level of community excitement and engagement in the project has been a very rewarding experience, in contrast with the reception received from other "fenced off" research projects. Such community support may stem from the fact that historically and culturally many accessible native forests were intentionally managed and likely enhanced to increase utility (Kirch 1982, 1997; Berkes et al. 2000; Athens et al. 2002). Native biodiversity is a critical component required to sustain cultural identity, and some species (such as *Metrosideros polymorpha*) serve as both biological and cultural keystone species

(Garibaldi & Turner 2004; Gomes 2013). Likewise, introduced species in Hawaii especially those brought from Polynesia have always had similarly important cultural roles to those of the native species. The melding of both elements, and particularly the choice of canoe plants and food plants, is appealing. Furthermore, society's concept of "naturalness" is changing in great part due to necessity (Hobbs 2004; Hobbs et al. 2013). The vast human imprint on ecosystems globally has made practitioners realize that we cannot resist change (e.g. accomplish complete restoration), but rather we can accept or guide landscape change (Aplet & Cole 2010). In human-dominated small island systems where land will always be limiting, the idea of using a forest for multiple objectives (i.e. watershed protection, sustenance, and recreation) is more readily accepted and supported.

Conclusion

Our efforts to restore native species to Hawaiian LWF have required a significant amount of resources and continued management; we anticipate that management must continue indefinitely. We can never completely walk away from management, and we have to accept that some ecosystems cannot be returned to an all-native state. This insight is important because we are in a place (Hawaii) and a forest type that is the worst-case scenario.

Tracking the results of our management actions over time made our initial successes seem less substantial, and highlighted the lack of sustainability over time, as well as the difficulty in scaling these efforts to larger landscapes. New and novel strategies must therefore be introduced to sustainably protect and preserve biocultural diversity. The perspective gained from long-term data collection is sobering but valuable, teaching us that in future projects adaptive management and a plan for sustainability need to be considered from the outset.

Acknowledgments

This research was funded and facilitated through NSF EPSCoR Awards 0237065, 0554657, and 0903833, NSF TCUP 0223040, NSF CAREER 0546868, NSF REU Awards 0139379, 1005186, and 0453630, and Strategic Environmental Research and Development Program for funding (Project RC-2117). The authors recognize staff, students, and interns from the University of Hawaii and the USDA Forest Service Institute of Pacific Islands Forestry for logistical and technical support. We thank our partners in the Hawaii Army National Guard Environmental Office (currently, Angela Kieran-Vast and Craig Blaisdell) and staff at Keaukaha Military Reservation for facilitating the establishment of the Liko Nā Pilina project.

LITERATURE CITED

Aplet G, Cole D (2010) The trouble with naturalness: rethinking park and wilderness goals. Pages 12–29. In: DN Cole, Yung L (eds) Beyond naturalness: rethinking park and wilderness stewardship in an era of rapid change. Island Press, Washington D.C.

Athens S, Tuggle D, Ward V, Welch J (2002) Avifaunal extinctions, vegetation change, and Polynesian impacts in prehistoric Hawai'i. Archaeology in Oceania 37:57–78

Bakker J, Poschlod P, Strykstra R, Bekker R, Thompson K (1996) Seed banks and seed dispersal: important topics in restoration ecology. Acta Botanica Neerlandica 45:461–490

Berkes F, Colding J, Folke C (2000) Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10:1251–1262

Cordell S, Sandquist D (2008) The impact of an invasive African bunchgrass (*Pennisetum setaceum*) on water availability and productivity of canopy trees within a tropical dry forest in Hawaii. Functional Ecology 22:1008–1017

Cordell S, Ostertag R, Rowe B, Sweinhart L, Vasquez-Radonic L, Michaud J, Colleen T, Schulten J (2009) Evaluating barriers to native seedling establishment in an invaded Hawaiian lowland wet forest. Biological Conservation 142:2997–3004

D'Antonio C, Meyerson L (2002) Exotic plant species as problems and solutions in ecological restoration: a synthesis. Restoration Ecology 10:703–713

Daehler CC, Denslow JS, Ansari S, KUO HC (2004) A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific Islands. Conservation Biology 18:360–368

Drake DR, Mueller-Dombois D (1993) Population development of rain forest trees on a chronosequence of Hawaiian lava flows. Ecology 74:1012–1019

Garibaldi A, Turner N (2004) Cultural keystone species: implications for ecological conservation and restoration. Ecology and Society 9:1

Gomes T (2013) Novel ecosystems in the restoration of cultural landscapes of Tl'ches, West Chatham Island, British Columbia, Canada. Ecological Processes 2:15

Goosem S, Tucker N (1995) Pages 71. Repairing the rainforest—theory and practice of rainforest re-establishment in North Queensland's wet tropics. WTM Authority, Cairns, Australia

Hobbie J, Carpenter S, Grimm N, Gosz J, Seastedt T (2003) The U.S. long term ecological research program. BioScience 53:21–32

Hobbs R (2004) Restoration ecology: the challenge of social values and expectations. Frontiers in Ecology and the Environment 2:43–48

Hobbs RJ, Higgs ES, Hall C (2013) Novel ecosystems: intervening in the new ecological world order. John Wiley & Sons, Oxford, United Kingdom

Hughes F, Adams W, Stroh P (2012) When is open-endedness desirable in restoration projects? Restoration Ecology 20:291–295

Kirch P (1997) Feathered gods and fishhooks: an introduction to Hawaiian archaeology and prehistory. University of Hawaii Press, Honolulu

Kirch PV (1982) The impact of the prehistoric Polynesians on the Hawaiian ecosystem. University of Hawai'i Press, Honolulu

Lavorel S, Storkey J, Bardgett R, de Bello F, Berg M, Le Roux X, et al. (2013) A novel framework for linking functional diversity of plants with other trophic levels for the quantification of ecosystem services. Journal of Vegetation Science 24:942–948

Loh R, Daehler C (2007) Influence of invasive tree kill rates on native and invasive plant establishment in a Hawaiian forest. Restoration Ecology 15:199–211

Mack M, D'Antonio C (2003) Exotic grasses alter controls over soil nitrogen dynamics in a Hawaiian woodland. Ecological Applications 13:154–166

Mack M, D'Antonio C, Ley R (2001) Alteration of ecosystem nitrogen dynamics by exotic plants: a case study of C_4 grasses in Hawaii. Ecological Applications 11:1323–1335

Mason T, French K, Russell K (2007) Moderate impacts of plant invasion and management regimes in coastal hind dune seed banks. Biological Conservation 134:428–439

Morrison EB, Lindell CA (2011) Active or passive forest restoration? Assessing restoration alternatives with avian foraging behavior. Restoration Ecology 19:170–177

Morse N, Pellissier P, Cianciola E, Brereton R, Sullivan M, Shonka N, Wheeler T, McDowell W (2014) Novel ecosystems in the Anthropocene: a revision of the novel ecosystem concept for pragmatic applications. Ecology and Society 19:12

Ostertag R, Cordell S, Michaud J, Cole T, Schulten J, Publico K, Enoka J (2009) Ecosystem and restoration consequences of invasive woody species removal in Hawaiian lowland wet forest. Ecosystems 12:503–515

Ostertag R, Inman-Narahari F, Cordell S, Giardina CP, Sack L (2014) Forest structure in low-diversity tropical forests: a study of Hawaiian wet and dry forests. PLoS One 9:e103268

Ostertag R, Warman L, Cordell S, Vitousek PM (2015) Using plant functional traits to restore Hawaiian rainforest. Journal of Applied Ecology 52:805–809

Pimentel D, Zuniga R, Morrison D (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:273–288

Price J, Gon S III, Jacobi J, Matsuwaki D (2007) Modeling plant species ranges in the Hawaiian Islands: developing a methodology and associated GIS layers. Hawai'i Cooperative Studies Unit, University of Hawai'i at Hilo

Questad E, Thaxton J, Cordell S (2012) Patterns and consequences of re-invasion into a Hawaiian dry forest restoration. Biological Invasions 14:2573–2586

Robertson GP, Collins SL, Foster DR, Brokaw N, Ducklow HW, Gragson TL, et al. (2012) Long-term ecological research in a human-dominated world. BioScience 62:342–353

Schulten J, Cole C, Cordell S, Publico K, Ostertag R, Enoka J, Michaud JM (2014) Persistence of native trees in an invaded Hawaiian lowland wet forest: experimental evaluation of light and water constraints. Pacific Science 2:267–285

Suding KN, Gross KL, Houseman GR (2004) Alternative states and positive feedbacks in restoration ecology. Trends in Ecology & Evolution 19:46–53

Tucker NIJ, Murphy TM (1997) The effects of ecological rehabilitation on vegetation recruitment: some observations from the Wet Tropics of North Queensland. Forest Ecology and Management 99:133–152

Van Kleunen M, Weber E, Fischer M (2010) A meta-analysis of trait differences between invasive and non-invasive plant species. Ecology Letters 13:235–245

Vitousek PM, D'Antonio CM, Loope LL, Rejmánek M, Westbrooks R (1997) Introduced species: a significant component of human-caused global change. New Zealand Journal of Ecology 21:1–16

Wagner WL, Herbst DR, Sohmer SH (1999) Manual of the flowering plants of Hawai'i. University of Hawaii Press and Bishop Museum Press, Honolulu

Zavaleta ES, Hobbs RJ, Mooney HA (2001) Viewing invasive species removal in a whole-ecosystem context. Trends in Ecology & Evolution 16:454–459

Zedler JB (2007) Success: an unclear, subjective descriptor of restoration outcomes. Ecological Restoration 25:162–168

Coordinating Editor: Karel Prach

Received: 2 June, 2015; First decision: 21 July, 2015; Revised: 16 November, 2015; Accepted: 17 November, 2015; First published online: 6 January, 2016