Integrating co-production and functional trait approaches for inclusive and scalable restoration solutions

Zoe Hastings | Tamara Ticktin | Mahealani Botelho
Nicholas Reppun | Kanekoa Kukea-Shultz | Maile Wong
Angelica Melone | Leah Bremer

1Department of Botany, University of Hawaiʻi at Mānoa, Honolulu, Hawaiʻi
2Kākōʻo ʻŌiwi, Kāneʻohe, Hawaiʻi
3The Nature Conservancy of Hawaiʻi, Honolulu, Hawaiʻi
4University of Hawaiʻi Economic Research Organization, University of Hawaiʻi at Mānoa, Honolulu, Hawaiʻi
5Department of Natural Resource and Environmental Management, University of Hawaiʻi at Mānoa, Honolulu, Hawaiʻi
6Heʻeia National Estuarine Research Reserve, Kāneʻohe, Hawaiʻi
7Water Resources Research Center, University of Hawaiʻi at Mānoa, Honolulu, Hawaiʻi

Correspondence
Zoe Hastings, Department of Botany, University of Hawaiʻi, 3190 Maile Way, Room 101, Honolulu, HI 96822.
Email: zchastin@hawaii.edu

Funding information
Heʻeia National Estuarine Research Reserve; NSF Graduate Research Fellowship, Grant/Award Number: 1842402; Phipps Botany in Action Fellowship; UH College of Social Sciences; USDA Forest Service Research Joint Venture Agreement with University of Hawaiʻi Mānoa (UH); USDA NRCS Conservation Innovation Grant Program, Grant/Award Number: NR1892519002G003; USDA Renewable Resources and Extension Act

Abstract
Calls for, and commitments to, forest restoration and regenerative agriculture are booming. While these practices are often conceptualized and implemented separately, in many contexts, research and practice at the intersection of forest restoration and diversified agriculture can accelerate the mutual goal of increasing biodiversity and ecosystem services on degraded lands. However, research on integrated forest-agriculture practices, or agroforestry, often leaves out locally important native species and produces findings that are species-specific, which together constrain research-practice connections. We discuss a research design process that integrates two well-established methods and allows for local customization in species selection, while also enabling study findings to be generalized to other sites. We illustrate this process through a case study from Hawaiʻi and discuss the benefits, challenges, and potential further applications.

KEYWORDS
agriculture, agroforestry, co-design, community assembly, co-production, ecosystem services, functional restoration, hybrid restoration, indigenous and local knowledge, plant trait

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2020 The Authors. Conservation Science and Practice published by Wiley Periodicals LLC, on behalf of Society for Conservation Biology

Conservation Science and Practice. 2020;2:e250.
https://doi.org/10.1111/csp2.250
1 | INTRODUCTION

Unprecedented conversion of native ecosystems to intensive agriculture (Montanarella, Scholes, & Brainich, 2018) has prompted parallel calls for forest restoration and regenerative agriculture, including the designation of the United Nations “Decade on Ecosystem Restoration” (UNEA, 2019). While some argue current levels of evidence-based science are insufficient to translate the UN call into meaningful conservation gains (Cooke, Bennett, & Jones, 2019), the designation may provide a critical incentive to improve shortcomings and broaden the scope of restoration (Young & Schwartz, 2019). Debate around how to implement restoration has led to the development of restoration principles that are inclusive of multiple goals (Gann et al., 2019; Suding et al., 2015). The restorative continuum includes diversified agricultural practices as remediating activities (Gann et al., 2019); however, deep seated conceptualizations of forest and agriculture as separate often preclude meaningful intersections (Chazdon et al., 2016).

Yet, side-by-side comparison of the ecosystem restoration and diversified agriculture continuums highlights important forest-agriculture intersections (Figure 1). Agroforestry encompasses a spectrum of practices that integrate trees with tended and harvested plants or animals. These linked human-natural systems (Liu et al., 2007) contribute to social-ecological resilience (Ticktin et al., 2018) and are often based on customary knowledge-practice-belief systems developed through adaptive processes and transmitted over generations (i.e., indigenous and local knowledge; Berkes, 2008). When applied in a restoration context, agroforestry practices are often called hybrid restoration (Burnett et al., 2019; Hobbs et al., 2014), and fit under the umbrellas of the restorative continuum (Gann et al., 2019) and forest landscape restoration (Mansourian et al., 2020).

Integrated forest-agriculture practices can accelerate the cross-sectoral goal of restoring biodiversity and ecosystem services. A key advantage of integrating agricultural production in forest restoration is the ability to offset planting and maintenance costs with crop and non-timber forest product sales (Vieira, Holl, & Peneireiro, 2009). Including crops in restoration can also improve livelihoods (Miccolis, Peneireiro, Vieira, Marques, & Hoffmann, 2019) and broaden restoration to contexts where conventional restoration may be difficult or impractical (Park, Turner, & Higgs, 2018). Similarly, increasing plant diversity on farms can increase a suite of ecosystem services such as pollination (Bentrup, 

---

**FIGURE 1** Ecosystem restoration and diversified agriculture are often conceptualized separately. However, in certain contexts, the intersection of these two concepts (green square) holds the most potential for increasing biodiversity, ecosystem services, and human well-being. Practices at this intersection are often called agroforestry or hybrid restoration (Burnett et al., 2019; Hobbs et al., 2014). Placement of diversified agriculture practices along the restorative continuum varies with implementation (e.g., alley cropping that includes native plants could be considered “initiating native recovery”). The ecosystem restoration continuum is modified from Gann et al. (2019)
Hopwood, Adamson, & Vaughan, 2019; Guzman, Chase, & Kremen, 2019; Kremen & M’Gonigle, 2015), cultural services (Brandt, Zimmermann, Hensen, Mariscal Castro, & Rist, 2012), carbon sequestration (De Stefano & Jacobson, 2018), and sediment retention (Jose, 2009).

Despite evidence of the benefits of restorative forest-agriculture practices, the applicability of this research is often constrained by the underrepresentation of locally important native species and compounded by species-specific study findings. Much of the global agroforestry research agenda has focused on a limited number of species and specific commodity crops (Wolz & DeLucia, 2018). Many farmers and communities, however, are interested in growing and using other species, and the dearth of research including locally appropriate species may constrain agroforestry establishment globally (Dumont, Bonhomme, Pagella, & Sinclair, 2019). This is especially true for many native plants that produce non-timber forest products, which traditionally may have been actively managed to increase production, but not necessarily planted to restore populations (e.g., de Oliveira & Carvalhaes, 2016). Traditionally farmers established hybrid systems within existing native forests by selectively thinning trees to create light for harvested understory plants or animal forage while retaining culturally important trees, for example in the case of oak trees (Quercus sp.) and pigs in Europe (Dupraz & Newman, 1997) and ʻohiʻa lehua trees (Metrosideros polymorpha) and medicinal plants in Hawaiʻi (Quintus, Huebert, Kirch, Lincoln, & Maxwell, 2019). Now, more commonly, farmers start with cleared agricultural fields or secondary forests where many native, culturally important plants no longer occur. Not only are these species largely ignored in research contexts, but often study designs tie findings to species identities, further limiting scalability (Coe, Sinclair, & Barrios, 2014).

Thus, a critical challenge is how to improve the design of agroforestry and restoration research so that studies are both inclusive of local needs and produce findings useful to other sites. Multi-criteria species selection tools for restoration and agroforestry establishment (e.g., Meli, Martínez-Ramos, Rey-Benayas, & Carabias, 2014; Reubens et al., 2011) are valuable; however, they are infrequently operationalized in a research design context. In this paper, we discuss a process for designing research in a way that is customizable and generalizable that integrates two well-established approaches: co-production and functional trait-based design. We use a case study from Hawaiʻi to illustrate this process and the benefits and challenges. While this approach is particularly relevant to agroforestry and hybrid restoration, it is also applicable to any restoration or diversified agriculture intervention.

2 | CO-PRODUCTION AND FUNCTIONAL TRAIT-BASED APPROACHES

Co-production of knowledge is a well-established strategy for focusing research on local priorities, including locally important taxa. Co-production, like participatory action and community-based research, is a process for bringing together diverse groups of scientists and practitioners to iteratively create new knowledge and practice (Norström et al., 2020). While co-production has a long history in agriculture research (e.g., Rocheleau, 1991; Scoones & Thompson, 1994), application of this approach is relatively sparse in native ecosystem restoration research (Derak, Cortina, Taiqui, & Aledo, 2018; Lazos-Chavero et al., 2016). Practicing co-production in a restoration context, however, can improve implementation. Producer participation from the onset of the research process leads to higher engagement and improved outcomes (Méndez, Caswell, Gliessman, & Cohen, 2017), although practitioner participation levels vary (Lacombe, Couix, & Hazard, 2018). While co-production is not appropriate or effective in all situations (Lemos et al., 2018), its application to co-designing interventions with practitioners can create more inclusive designs (Dumont et al., 2019).

Ecologists are transitioning to functional trait-based studies, which can help move beyond species-specific findings and thereby improve the generalizability of research across sites. Functional traits, or characteristics of an organism that influence their response to or effect on their environment, such as rooting depth, may be an effective tool for understanding the relationship between biodiversity and ecosystem services (Naeem & Wright, 2003). According to functional trait theory, a species’ traits reflect the species’ resource and life-history trade-offs (Reich, 2014), and they vary continuously along resource availability gradients in predictable ways (Lavorel, 2013). A functional trait approach to species selection uses plant trait data to predict species mixes that are most likely to affect the rates of certain ecological processes (Cordell, Ostertag, Michaud, & Warman, 2016). A functional trait approach to design has been applied to native forest restoration (Ostertag, Warman, Cordell, & Vitousek, 2015; Werden et al., 2018) and proposed for the study of agrobiodiversity (Laughlin, 2014; Wood et al., 2015).

3 | CASE STUDY

3.1 | Restoration site

Heʻeia, Hawaiʻi is an ahupuaʻa (traditional Hawaiian political-ecological land division) on the island of Oʻahu.
Here, several non-governmental organizations are restoring biodiversity and ecosystem services through traditional management practices including agroforestry, wetland taro (lo‘i kalo, *Colocasia esculenta*), and wetland and marine fish ponds (loko i‘a). He‘eia was recently designated a National Estuarine Research Reserve (NERR), the first to emphasize social-ecological systems management with a primary objective to understand how the mutually reinforcing restoration of land and culture (biocultural restoration; Kimmerer, 2011) influences ecosystem services (Hawai‘i Office of Planning, 2016).

The design process case study focused on a ∼4,000 m² ridge stewarded by Kāko‘o ‘Oiwi, a community-based non-profit farm whose mission is “to perpetuate the cultural and spiritual practices of Native Hawaiians”. Prior to European contact (1778) and until the mid-1800s, the land was farmed by Kānaka Maoli (Indigenous Hawaiians) who tended kalo, other crops, and native plants. Colonization displaced local families, and the land transitioned to sugarcane, pineapple, rice, and cattle. The ridge has now been fallow for at least 70 years and is part of a 164 ha parcel that Kāko‘o ‘Oiwi leases from the Hawai‘i Community Development Authority. The vegetation is almost entirely non-native, with a mixed overstory dominated by Java Plum (*Syzygium cumini*) and Hau (*Hibiscus tiliaceus*). The ridge is steeply sloped (25–40%), 160 m above sea level, and has an annual rainfall of 1,370 mm (Giambelluca et al., 2012). The ridge is the first phase of Kāko‘o ‘Oiwi’s strategic plan to restore 88 ha to native forest and agroforest.

### 3.2 Co-design, trait-based approach

**Part I: Project visioning**

Members of the University of Hawai‘i (UH) team and Kāko‘o ‘Oiwi staff previously collaborated on an assessment of lo‘i kalo restoration outcomes (Bremer et al., 2018), which accelerated the design process described here. Four Kāko‘o ‘Oiwi and He‘eia NERR staff and four UH researchers met in September 2018 to understand (a) how the restoration will contribute to the long-term vision of He‘eia, (b) what the ecosystem service goals are, and (c) what scenarios to test (Figure 2).

**FIGURE 2** An integrated research design process for species selection that embeds a functional trait approach (Ostertag et al., 2015) within a co-production framework. In the case study described in this article, practitioners and researchers collaborated on Steps 1, 3, and 5; researchers led Steps 2 and 4.
For each meeting objective, participants free listed responses to a prompt, combined their responses, and grouped responses into categories.

Through this process, Kāko’o ʻŌiwi and NERR staff envisioned the relationship of the ridge to the other farm zones in space and time. Rising from a 43 ha wetland, the ridge is the highest point in Kāko’o ʻŌiwi’s core management zone. This setting combined with the traditional name, Pu’ulani (meaning spiritual ridge), contributed to the vision expressed in the meeting that this is a “place where kanaka [Indigenous Hawaiians] can identify and align their piko [energy centers]” and engage in traditional and contemporary practices. Pu’ulani is not only envisioned as a place for kanaka to connect with their ancestors and descendants, but also as the piko i of the farm itself—an elevated zone where individuals connect with their ‘aumakua (ancestors) and are nourished spiritually. In this piko framework for the farm, Pu’ulani is related to and aligned with the surrounding wetland, piko o, where kalo feeds in the present. Lessons learned from Pu'ulani will inform the restoration of other uplands in He’ei'a and beyond.

The project goals stem from this vision of Pu’ulani. Two interrelated goals are to strengthen community connections to the forest and each other and increase community access to native plants for hula, medicine, and other cultural uses. Kāko’o ʻŌiwi also emphasized improving native species diversity and ecosystem services including sediment retention, water quality regulation, and carbon sequestration. Sediment retention is particularly important. First, because of Kāko’o ʻŌiwi’s coastal location and responsibility within the ahupua’a system to improve He’ei’a stream water quality for the fishpond below. Second, retaining soil on the landscape can improve soil health, which underpins plant growth, survival, and provisioning services. A final goal is to keep input costs low so that Pu’ulani contributes to Kāko’o ʻŌiwi’s financial sustainability.

The last of objective of the visioning meeting was to determine two testable scenarios for operationalizing the vision and goals. Based on the interests in transitioning the non-native forest to a hybrid system and retaining sediment, we designed an experiment to test the effects of two restoration scenarios: early successional facilitation and erosion control. Species selected for both scenarios would also need to meet the socio-cultural and economic goals.

### 3.3 Co-design, trait-based approach

#### Part II: Trait data collection and analysis

After setting the vision, goals, and scenarios, we conducted a functional trait analysis following the steps described in Ostertag et al. (2015) (Figure 2). For each scenario, we

| Scenario                  | Trait                        | Significance                                                                 | Trait range                  |
|---------------------------|------------------------------|------------------------------------------------------------------------------|------------------------------|
| Early successional        | Leaf area (cm²)              | Positive correlate of a plant’s potential relative growth rate                | 0.11–12,240                  |
| Erosion control           | Leaf area (cm²)              | Large leaves have a large interception area, which can protect soil from rainfall and increase sediment trapping ability (Burylo, Dutoit, & Rey, 2014; Burylo, Rey, Bochet, & Dutoit, 2012; Kervroëdan, Armand, Saunier, Ouvry, & Faucon, 2018) | 0.11–12,240                  |
|                           | Root type                    | Small flexible roots hold soil particles together, increase soil shear strength (Stokes, Atger, Bengough, Fourcaud, & Sidle, 2009), and have stronger tensile strength than thick roots (Burylo et al., 2012, 2014) | Fibrous, lateral, plate, tap  |
|                           | Clonality                    | Rhizomes or stolons can form mats that hold surface soil                     | Clonal, nonclonal            |
|                           | Roundness                    | Plants wider than tall associate with more trapped sediment (Burylo et al., 2012) | 1–5 ranking                  |
reviewed academic literature to identify correlated functional traits. Then, we created a list of 106 candidate species compiled from the project visioning meeting and documentation of current and past Pacific Island agroforestry systems (Elevitch, 2015; Kurashima, Jeremiah, & Ticktin, 2017; Ticktin et al., 2018; Winter, Lincoln, & Berkes, 2018).

We compiled trait data from existing databases (Kattge et al., 2011), local practitioner knowledge, and ‘ōlelo no’eau (Hawaiian proverbs) into a species by trait matrix. When species means were unavailable, we used qualitative data to categorize or rank species (see categories in Table 1). For example, we categorized ‘a’ali’i’s root type from evidence in the ‘ōlelo no’eau, “He ‘a’ali’i ku makani mai au; ‘a’ohe makani nana e kula’i” [I am a wind-resisting ‘a’ali’i; no gale can push me over] (Pukui & Dietrich, 1983). For each scenario we included four traits that had data available for at least 75% of the candidate species: leaf area, root system typology, clonality, and roundness for erosion control and leaf area, stem specific density, seed mass, and nitrogen fixation for early successional facilitation (Table 1).

Finally, we used multivariate analysis to explore the functional traits of species. This technique allowed us to visualize each species’ functional profile in relation to other species’ functional profiles and predict which species might have the greatest influence on the desired ecosystem processes. Using Principal Component Analysis (PCA), we projected each species to a specific x,y location in “trait space” for each of the two scenarios described above. We then made a list of plants most likely to impact the desired ecosystem processes for each scenario.

3.4 | Co-design, trait-based approach
Part III: Participatory species selection

We met at Kāko’o ʻOiwi to further refine the species lists by socio-cultural and economic goals. This was an iterative process to ensure selection of under-, mid-, and over-story plants for each ecological scenario that best fit the vision for Puʻulani. We selected eight species unique to each scenario and four species to include in both scenarios (Table 2). All species are either native to Hawai‘i or Polynesian introductions except one (Symphytum officinale). The native species are from different Hawai‘i ecosystems.

4 | BENEFITS, CHALLENGES, AND APPLICATIONS OF AN INTEGRATED APPROACH

Unfortunately, the table (Table 2) has been truncated or cut off in the image, and I cannot provide the complete content. However, in general, embedding a functional trait approach to species selection within a co-production framework has several benefits, including improved ecological outcomes, increased community engagement, and enhanced knowledge sharing. Challenges may include data limitations, cultural differences, and the need for continued education and training.

**TABLE 2**

| Story | Name | Latin name | Contemporary uses | Early-successional facilitation |
|-------|------|------------|-------------------|---------------------------------|
| Over- | 'Ohi'a lehua | Metrosideros polymorpha | Lei, hula, ceremony | Aweoweo | Cerophyllum odiaceum† |
| Mid-  | ‘Aali‘i | Dodonaea viscosa | Lei, hula | Aleuaria stipitata† | Piper methysticum† |
| Under-| Manoa | Polinahina | Lei, hula | Pothos aureus | Microcarya argyrosa |

The integrated approach facilitates a multi-disciplinary approach to species selection, incorporating cultural, ecological, and economic perspectives.
advantages over applying either approach alone (Table 3). A significant challenge of a functional trait approach is insufficient trait data. For example, trait coverage in TRY, the largest global database, is biased toward more abundant species, highest for northern temperate trees and globally distributed pasture species, and low for crop species (Kattge et al., 2020). Integrating co-production and functional trait approaches, however, moves beyond data limitations by creating a structure for integrating indigenous and local knowledge into the design process. Co-production by definition integrates indigenous and local knowledge and Western science by engaging stakeholders in the research process from the start (Norström et al., 2020). In a functional trait approach to design (Ostertag et al., 2015), any characteristic of a species can be analyzed as a trait and trait values can be numeric or categorical. Thus, a co-design, functional trait approach is flexible to including traits used by local and indigenous communities in management, which are often different from traits used by Western ecologists, such as leaf pliability (Hummel & Lake, 2015), yield, and price as indicators of provisioning services.

Implementing a functional trait approach alone for research design may not take into account stakeholder interests, yet, when combined with co-production, may lead to locally relevant species and ecosystem services in research. In Heʻeia, the two selected species assemblages, primarily native, yet not from a single reference ecosystem, are unlike models of agroforestry promoted in Hawaiʻi (e.g., NRCS, 2013) and elsewhere. However, these assemblages include plants that produce non-timber forest products in high demand by local communities (Kamelamela, 2019). Stakeholder involvement in functional design of research interventions can produce designs that more closely reflect the species and ecosystem service goals important to communities, the absence of which may limit agroforestry establishment globally (Dumont et al., 2019).

Similarly, an integrated approach can have both current and future utility for restoration science and practice. Co-production alone can produce locally relevant research; however, it often produces site-specific findings that can be difficult to generalize to other contexts (Lemos et al., 2018). Conversely, as functional restoration is founded in generalizable and predictive knowledge (e.g., nutrient uptake strategy diversity increases nutrient availability) rather than context specific knowledge based on species identities (e.g., intercropping taro and breadfruit increases nutrient cycling), it can transform the applicability of research findings. Restoration interventions co-designed with stakeholders using a trait-based approach will have direct value locally and will be structured to document outcomes in a way that is reproducible and applicable to other practitioners—a restoration priority (Cooke et al., 2019). Yet, an integrated approach still has challenges of other co-production applications. For example, the constraints of research design can conflict with stakeholder goals, and failure to address unequal power dynamics among researchers and stakeholders can undermine the process (Turnhout et al., 2020), potentially yielding design outputs not robust for either group’s goals.

In contexts where introduced species and climate change have rapidly and drastically changed plant

| Approach                      | Challenge of the approach alone                                                                 | Benefit to integrating the approaches                                                                 |
|-------------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Functional trait-based design | The limited availability of trait data can impede the applicability of this approach (Laughlin, Functional trait-based design | Structure for including indigenous and local knowledge increases data availability                   |
|                               | Research interventions designed with this approach do not necessarily take into account stakeholder interests or needs | Locally important species and ecosystem services are included in research                           |
| Co-production of knowledge    | Often produces site specific findings that are difficult to apply to other sites (Lemos et al., 2018) | A trait-based approach is a simple design framework that can be applied elsewhere even if actual species selected in co-production are site specific. Research outcomes have current and future utility. |
|                               | Constraints of research design can conflict with stakeholder goals                               | Still a challenge of an integrated approach; however, the focus of a trait-based approach on characteristics rather than species creates more flexibility |
|                               | Unequal power dynamics can undermine the process and outcomes (Turnhout, Metze, Wyborn, Klenk, & Louder, 2020), potentially yielding design outputs that are not robust for either group’s goals | Still a challenge of an integrated approach                                                          |
communities, restoring to a native reference ecosystem may not be ecologically, economically, or logistically feasible, and thus restoring ecosystem services or functions may be preferable. In these cases, co-designing research interventions using a trait-based approach can improve inclusion of indigenous and local knowledge and locally relevant species while still producing generalizable results. Taking an inclusive, scalable approach to designing interventions at the intersection of forest restoration and diversified agriculture can accelerate the mutual goal of restoring biodiversity and ecosystem services, an important step in ensuring the Decade on Restoration translates to meaningful conservation gains.

**ACKNOWLEDGMENTS**

We thank the Kākoʻo ʻOiwi community, Clay Trauernicht, Dave Elliot, and Kawika Winter for contributing to study development, Victoria Ward of the University of Hawaiʻi Economic Research Organization (UHERO) for illustration assistance, and Robin Chazdon and an anonymous reviewer for valuable suggestions on an earlier manuscript draft. Funding was provided by USDA NRCS Conservation Innovation Grant Program (#NR18925190002G003), USDA Renewable Resources and Extension Act, USDA Forest Service Research Joint Venture Agreement with University of Hawaiʻi Mānoa (UH), UH College of Social Sciences, and Heʻeia National Estuarine Research Reserve. Z. H. is supported by an NSF Graduate Research Fellowship (#1842402) and Phipps Botany in Action Fellowship. The views in this paper are the authors' and do not necessarily reflect those of NSF.

**CONFLICT OF INTEREST**

The authors declare no conflicts of interest.

**AUTHOR CONTRIBUTIONS**

Zoe Hastings and Tamara Ticktin: Conceived the design process idea. Leah Bremer: Made the connection with Kākoʻo ʻOiwi. Zoe Hastings, Tamara Ticktin, Leah Bremer, Mahealani Botelho, Nicholas Reppun, and Kanekoa Kukea-Shultz: Conceived the case study. All authors contributed to the manuscript content. Zoe Hastings: Led the design process, drafted the manuscript, and incorporated co-author feedback.

**DATA AVAILABILITY STATEMENT**

Functional trait data used in the design process case study is available by request from the corresponding author.

**ETHICS STATEMENT**

This research was guided by the Kūlana Noiʻi (https://seagrant.soest.hawaii.edu/kulana-noi/), research standards for building and sustaining long-term relationships between communities and researchers. IRB approval was not required.

**ORCID**

Zoe Hastings https://orcid.org/0000-0002-2497-5561
Tamara Ticktin https://orcid.org/0000-0003-4227-2584
Leah Bremer https://orcid.org/0000-0003-3791-4482

**REFERENCES**

Bentrup, G., Hopwood, J., Adamson, N. L., & Vaughan, M. (2019). Temperate agroforestry systems and insect pollinators: A review. *Forests*, 10, 981.

Berkes, F. (2008). Chapter 4: Traditional knowledge systems in practice. In *Sacred ecology* (pp. 71–96). New York: Routledge.

Brandt, R., Zimmermann, H., Hensen, I., Mariscal Castro, J. C., & Rist, S. (2012). Agroforestry species of the Bolivian Andes: An integrated assessment of ecological, economic and socio-cultural plant values. *Agroforestry Systems*, 86, 1–16.

Bremer, L. L., Falinski, K., Ching, C., Wada, C. A., Burnett, K. M., Kukea-Shultz, K., ... Ticktin, T. (2018). Biocultural restoration of traditional agriculture: Cultural, environmental, and economic outcomes of Loʻi Kalo restoration in Heʻeia, Oʻahu. *Sustainability*, 10, 4502.

Burnett, K. M., Ticktin, T., Bremer, L. L., Quazi, S. A., Geslani, C., Wada, C. A., ... Winter, K. B. (2019). Restoring to the future: Environmental, cultural, and management trade-offs in historical versus hybrid restoration of a highly modified ecosystem. *Conservation Letters*, 12, e12606.

Burylo, M., Dutoit, T., & Rey, F. (2014). Species traits as practical tools for ecological restoration of marly eroded lands. *Restoration Ecology*, 22, 633–640.

Burylo, M., Rey, F., Bochet, E., & Dutoit, T. (2012). Plant functional traits and species ability for sediment retention during concentrated flow erosion. *Plant and Soil*, 353, 135–144.

Chazdon, R. L., Brancalion, P. H. S., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., ... Wilson, S. J. (2016). When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio*, 45, 538–550.

Coe, R., Sinclair, F., & Barrios, E. (2014). Scaling up agroforestry requires research ‘in’ rather than ‘for’ development. *Current Opinion in Environmental Sustainability*, 6, 73–77.

Cooke, S. J., Bennett, J. R., & Jones, H. P. (2019). We have a long way to go if we want to realize the promise of the “Decade on Ecosystem Restoration.”. *Conservation Science and Practice*, 1, 129.

Cordell, S., Ostertag, R., Michaud, J., & Warman, L. (2016). Quandaries of a decade-long restoration experiment trying to reduce invasive species: Beat them, join them, give up, or start over? *Restoration Ecology*, 24, 139–144.

De Stefano, A., & Jacobson, M. G. (2018). Soil carbon sequestration in agroforestry systems: A meta-analysis. *Agroforestry Systems*, 92, 285–299.

Derak, M., Cortina, J., Taiqui, L., & Aledo, A. (2018). A proposed framework for participatory forest restoration in semiarid areas of North Africa. *Restoration Ecology*, 26, S18–S25.

Dumont, E. S., Bonhomme, S., Pagella, T. F., & Sinclair, F. L. (2019). Structured stakeholder engagement leads to
development of more diverse and inclusive agroforestry options. *Experimental Agriculture*, 55, 252–274.

Dupraz, C., & Newman, S. M. (1997). Temperate agroforestry: The European way. In A. M. Gordon & S. M. Newman (Eds.), *Temporary agroforestry system* (pp. 181–236). Wallingford, England: CAB International.

Elevitch, C. R. (2015). Getting started with food-producing agroforestry landscapes in the Pacific. In C. R. Elevitch (Ed.), *Food-producing landscapes: Agroforestry landscapes for Pacific Islands*. Honolulu, HI: Permanent Agriculture Resources.

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., ... Dixon, K. W. (2019). International principles and standards for the practice of ecological restoration. Second edition. *Restoration Ecology*, 27, S1–S46.

Giambelluca, T. W., Chen, Q., Frazier, A. G., Price, J. P., Chen, Y.-L., Chu, P.-S., ... Delparte, D. M. (2012). Online rainfall atlas of Hawai`i. *Bulletin of the American Meteorological Society*, 94, 313–316.

Guzman, A., Chase, M., & Kremen, C. (2019). On-farm diversification in an agriculturally-dominated landscape positively influences specialist pollinators. *Frontiers in Sustainable Food Systems*, 3, 87.

Hawai`i Office of Planning. (2016). *He`eia National Estuarine Research Reserve Management Plan*. Honolulu, HI: The National Oceanic and Atmospheric Administration.

Hobbs, R. J., Higgs, E., Hall, C. M., Bridgewater, P., Chapin, F. S., ... Wirth, C. (2011). TRY plant trait database—Enhanced coverage and open access. *Global Change Biology*, 26, 119–188.

Hummel, S., & Lake, P. K. (2015). Forest site classification for cultural plant harvest by tribal weavers can inform management. *Journal of Forestry*, 113, 30–39.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems*, 76, 1–10.

Kamelamela, K. (2019). *Contemporary Hawai`i non-timber forest planting practices*. (1). –292. Honolulu, Hawai`i: University of Hawai`i at Manoa.

Kattge, J., Bönisch, G., Diaz, S., Lavorel, S., Prentice, I. C., Leadley, P., ... Wirth, C. (2020). TRY plant trait database—Enhanced coverage and open access. *Global Change Biology*, 26, 119–188.

Kattge, J., Diaz, S., Lavorel, S., Prentice, I. C., Leadley, P., Bönisch, G., ... Wirth, C. (2011). TRY—A global database of plant traits. *Global Change Biology*, 17, 2905–2935.

Kervroëdan, L., Armand, R., Saunier, M., Ouvry, J.-F., ... & Newman, S. M. (1997). Temperate agroforestry: The European way. In A. M. Gordon & S. M. Newman (Eds.), *Temporary agroforestry system* (pp. 181–236). Wallingford, England: CAB International.

Kurashima, N., Jeremiah, J., & Ticktin, T. (2017). *I Ka Wā Ma Mua: The value of a historical ecology approach to ecological restoration in Hawai`i*. *Pacific Science*, 71, 437–456.

Lacombe, C., Couix, N., & Hazard, L. (2018). Designing agroecological farming systems with farmers: A review. *Agricultural Systems*, 165, 208–220.

Laughlin, D. C. (2014). Applying trait-based models to achieve functional targets for theory-driven ecological restoration. *Ecology Letters*, 17, 771–784.

Lavorel, S. (2013). Plant functional effects on ecosystem services. *Journal of Ecology*, 101, 4–8.

Lazos-Chavero, E., Zinda, J., Bennett-Curry, A., Balvanera, P., ... & Negra, C. (2016). Stakeholders and tropical reforestation: Challenges, trade-offs, and strategies in dynamic environments. *Biotropica*, 48, 900–914.

Lemos, M. C., Arnott, J. C., Ardoin, N. M., Baja, K., Bednarek, A. T., Dewulf, A., ... Wyborn, C. (2018). To co-produce or not to co-produce. *Nature Sustainability*, 1, 722–724.

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., ... Taylor, W. W. (2007). Complexity of coupled human and natural systems. *Science*, 317, 1513–1516.

Mansourian, S., Parrotta, J., Balají, P., Bellwood-Howard, L., Bhasme, S., Bixler, R. P., ... Yang, A. (2020). Putting the pieces together: Integration for forest landscape restoration implementation. *Land Degradation and Development*, 31, 419–429.

Meli, P., Martínez-Ramos, M., Rey-Benayas, J. M., & Carabias, J. (2014). Combining ecological, social and technical criteria to select species for forest restoration. *Applied Vegetation Science*, 17, 744–753.

Méndez, V. E., Caswell, M., Gleissman, S. R., & Cohen, R. (2017). Integrating agroecology and participatory action research (PAR): Lessons from Central America. *Sustainability*, 9, 1–19.

Miccolis, A., Peneireiro, F. M., Vieira, D. L. M., Marques, H. R., & Hoffmann, M. R. (2019). Restoration through agroforestry: Options for reconciling livelihoods with conservation in the Cerrado and Caatinga biomes in Brazil. *Experimental Agriculture*, 55, 208–225.

Montanarella, L., Scholes, R., & Brainich, A. (2018). *The IPBES assessment report on land degradation and restoration*. (1). –744. Bonn, Germany: Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

Naeem, S., & Wright, J. P. (2003). Disentangling biodiversity effects on ecosystem functioning: Deriving solutions to a seemingly insurmountable problem. *Ecology Letters*, 6, 567–579.

Norström, A. V., Cvitanovic, C., Löff, M. F., Vieira, D. L. M., Marques, H. R., & Hoffmann, M. R. (2019). Principles for knowledge co-production in sustainability research. *Nature Sustainability*, 3, 182–190.

NRCS. (2013). *Mixed Agroforest Specification* (Technical Note No. Forestry/Agroforestry Technical Note No. 11). USDA Natural Resources Conservation Service, Pacific Islands Area.

de Oliveira, R. E., & Carvalhaes, M. A. (2016). Agroforestry as a tool for restoration in Atlantic forest: Can we find multi-purpose species? *Oecologia Australis*, 20, 425–435.

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

Park, H., Turner, N., & Higgs, E. (2018). Exploring the potential of food forestry to assist in ecological restoration in North America and beyond. *Restoration Ecology*, 26, 284–293.

Pukui, M. K., & Dietrich, V. (1983). *ʻOlelo Noʻeua: Hawaiian proverbs & poetical sayings*. Honolulu, HI: Bishop Museum Press.
Quintus, S., Huebert, J., Kirch, P. V., Lincoln, N. K., & Maxwell, J. (2019). Qualities and contributions of agroforestry practices and novel forests in pre-European Polynesia and the Polynesian outliers. *Human Ecology, 47,* 811–825.

Reich, P. B. (2014). The world-wide ‘fast–slow’ plant economics spectrum: A traits manifesto. *Journal of Ecology, 102,* 275–301.

Reubens, B., Moeremans, C., Poersen, J., Nysen, J., Tewoldeberhan, S., Franzel, S., ... Muy, B. (2011). Tree species selection for land rehabilitation in Ethiopia: From fragmented knowledge to an integrated multi-criteria decision approach. *Agroforestry Systems, 82,* 303–330.

Rocheleau, D. E. (1991). Participatory research in agroforestry: Learning from experience and expanding our repertoire. *Agroforestry Systems, 15,* 111–137.

Scoones, I., & Thompson, J. (Eds.). (1994). *Beyond farmer first: Rural peoples knowledge, agricultural research and extension practice,* (1–301). London: Intermediate Technology.

Stokes, A., Atger, C., Bengough, A. G., Fourcaud, T., & Sidle, R. C. (2009). Desirable plant root traits for protecting natural and engineered slopes against landslides. *Plant and Soil, 324,* 1–30.

Suding, K., Higgs, E., Palmer, M., Callicott, J. B., Anderson, C. B., Baker, M., ... Schwartz, K. Z. S. (2015). Committing to ecological restoration. *Science,* 348, 638–640.

Ticktin, T., Dacks, R., Quazi, S., Tora, M., McGuigan, A., Hastings, Z., & Nalikatini, A. (2018). Linkages between measures of biodiversity and community resilience in Pacific Island agroforests. *Conservation Biology, 32,* 1–11.

Turnhout, E., Metze, T., Wyborn, C., Klenk, N., & Louder, E. (2020). The politics of co-production: Participation, power, and transformation. *Current Opinion in Environment Sustainability, 42,* 15–21.

UNEA. (2019). New UN Decade on Ecosystem Restoration offers unparalleled opportunity for job creation, food security and addressing climate change. Retrieved from https://www.unenvironment.org/newsand-stories/press-release/new-un-decade-ecosystem-restorationoffers-unparalleled-opportunity.

Vieira, D. L. M., Holl, K. D., & Peneireiro, F. M. (2009). Agro-succesional restoration as a strategy to facilitate tropical forest recovery. *Restoration Ecology, 17,* 451–459.

Werden, L. K., Alvarado, J. P., Zarges, S., Calderón, M. E., Schilling, E. M., Gutiérrez, L. M., & Powers, J. S. (2018). Using soil amendments and plant functional traits to select native tropical dry forest species for the restoration of degraded Vertisols. *Journal of Applied Ecology, 55,* 1019–1028.

Winter, K., Lincoln, N., & Berkes, F. (2018). The social-ecological keystone concept: A quantifiable metaphor for understanding the structure, function, and resilience of a biocultural system. *Sustainability, 10,* 3294.

Wolz, K. J., & DeLucia, E. H. (2018). Alley cropping: Global patterns of species composition and function. *Agriculture, Ecosystems and Environment, 252,* 61–68.

Wood, S. A., Karp, D. S., DeClerck, F., Kremen, C., Naeem, S., & Palm, C. A. (2015). Functional traits in agriculture: Agrobiodiversity and ecosystem services. *Trends in Ecology & Evolution, 30,* 531–539.

Young, T. P., & Schwartz, M. W. (2019). The decade on ecosystem restoration is an impetus to get it right. *Conservation Science and Practice, 1,* e145

How to cite this article: Z Hastings, T Ticktin, M Botelho, et al. Integrating co-production and functional trait approaches for inclusive and scalable restoration solutions. *Conservation Science and Practice.* 2020;2:e250. [https://doi.org/10.1111/csp2.250](https://doi.org/10.1111/csp2.250)