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A criteria and indicators monitoring framework for food forestry embedded in the principles of ecological restoration

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Abstract Food forestry is a burgeoning practice in North America, representing a strong multifunctional approach that combines agriculture, forestry, and ecological restoration. The Galiano Conservancy Association (GCA), a community conservation, restoration, and educational organization on Galiano Island, British Columbia in Canada, recently has created two food forests on their protected forested lands: one with primarily non-native species and the other comprising native species. These projects, aimed at food production, education, and promotion of local food security and sustainability, are also intended to contribute to the overall ecological integrity of the landscape. Monitoring is essential for assessing how effectively a project is meeting its goal and thus informing its adaptive management. Yet, presently, there are no comprehensive monitoring frameworks for food forestry available. To fill this need, this study developed a generic Criteria and Indicators (C&I) monitoring framework for food forestry, embedded in ecological restoration principles, by employing qualitative content analysis of 61 literature resources and semi-structured interviews with 16 experts in the fields of food forestry and ecological restoration. The generic C&I framework comprises 14 criteria, 39 indicators, and 109 measures and is intended to guide a comprehensive and systematic assessment for food forest projects. The GCA adapted the generic C&I framework to develop a customized monitoring framework. The Galiano C&I monitoring framework has comprehensive suite of monitoring parameters, which are collectively address multiple values and goals.

Keywords Ecosystem services · Forest restoration · Systematic and comprehensive assessment · Forest garden · Conservation · Sustainable forest management

Introduction

Agriculture is a key driver of global deforestation; as a result, promoting positive interactions between agriculture and forestry has drawn attention to sustainable agroforestry practices (FAO 2016). In tropical regions, agroforestry systems have been examined for their potential for restoring or managing forested landscapes while sustaining livelihoods and local economy (Dawson et al. 2013; Jose 2012; Lander and Boshier 2014; McNeely and Schroth 2006; Montagnini et al. 2011; Vieira et al. 2009). One of the oldest agroforestry systems, *homegarden*, is typically found in tropical, rural regions of Mesoamerica, Asia, Pacific Islands, Caribbean Islands, and West and North Africa. Tropical homegardens are generally planted with high diversity of trees, shrubs, and herbaceous species around homesteads, including root crops and/or vines, in a way that maximizes favorable plant interactions for direct uses

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(e.g., food, medicine, fodders, building, art), as well as for ecological benefits (e.g., improved soil organic C, litter decomposition, pollination, low soil erosion and nutrient leaching, soil water holding capacity) (Hills 1988; Kumar and Nair 2006). Due to high native and non-native plant diversity of homegardens and high intraspecific variability and genetic diversity, Kumar and Nair (2006) suggest the use of homegardens as in situ conservation.

Originating in tropical homegardens, food forests (also referred as forest gardens) are emerging in temperate-to-cold regions of Canada, the USA, and the UK, where they have not traditionally been practiced as a major means of food production (Crawford 2010; Park et al. 2017). Emerging food forestry practiced by both households and communities is promoted for its multifunctionality in providing locally produced diverse food and opportunities for education and microenterprises, reconnecting people with nature, creating habitat for wildlife species, and enhancing regulating ecosystem services such as carbon sequestration (Clark and Nicholas 2013; Jacke and Toensmeier 2005; McLain et al. 2012). A growing body of scientific literature discusses the potential of food forests in assisting biodiversity conservation and eco-cultural restoration (Park et al. 2017; Rohwer and Marris 2016). Food forests are a type of "designed" ecosystem, which has a particular relationship with ecological restoration (Higgs 2017). Recently, the Galiano Conservancy Association (GCA), a community conservation organization on Galiano Island, British Columbia, Canada, has planted two food forests on one of their protected forested lands: one with primarily non-native plant species and the other with native species. The two projects are aimed at food production, education, and promotion of local food security and sustainability while contributing to the overall ecological integrity of the protected forest landscape.

Yet, few studies have assessed the ecological, social, and economic contributions of these emerging food forests in temperate regions. Reliable systematic monitoring is critical for assessing the effectiveness of projects over time and allowing the comparison of projects. At this early stage of development of temperate food forestry, monitoring protocols have the potential to strengthen the evidence-based case for additional implementation (Park et al. 2017). Only few individual food forestry practitioners have measured yields, soil organic carbon, or wildlife species such as birds and amphibians, depending on their personal or academic interests (e.g., Toensmeier 2013). At the International Permaculture Conference 2015 in London, the UK, food forestry practitioners and researchers reiterated the need for concerted efforts to develop monitoring frameworks that encompass multiple aspects of a food forest system. The GCA expressed the importance of assessing how effectively the projects are achieving their multiple goals in order to inform their adaptive management of the projects, and asked us to help to develop monitoring indicators (Erickson, Galiano Conservancy Association, personal communication, 2015). For broader application of food forests, long-term monitoring is essential to assess what benefits and risks are involved in integrating food forestry to restoring and managing a landscape.

In contributing to the international and local interests in understanding food forests in temperate regions, this study advances a Criteria and Indicators (C&I) monitoring framework that is primarily intended to guide a comprehensive and systematic assessment of food forest projects. We present the specific implementation of the framework by the GCA in the context of adaptive management of agroforestry projects in protected lands. The C&I framework was adapted by the GCA in order to develop their own tailored monitoring program (Erickson, Galiano Conservancy Association, personal communication, 2016). Yet, the generic C&I framework should be further tested, adapted, and improved by other researchers, practitioners, and environmental groups for their own specific purposes and interests.

Background

Galiano Island

Galiano Island is located on the west side of the Strait of Georgia between Vancouver Island and the west coast mainland of Canada (Ewonus et al. 2011; Fig. 1). The Island is situated within the Coastal Douglas-fir biogeoclimatic zone (CDF), which is one of the rarest ecosystem types listed in BC; its primary plant association is of global and provincial conservation concern (Austin et al. 2008; Forest Practices Board 2010). In 2012, the GCA purchased a 76-hectare (ha) parcel on the central west coast of Galiano Island and established it as the Millard

Learning Centre. The acquisition protected approximately 20 ha of old growth and mature forest along 2 km of shoreline, two small stream systems with accompanying wetland and riparian habitats. This coastal Douglas-fir (*Pseudotsuga menziesii*)-forested property is part of the Mid-Galiano Island Protection Network for conservation, which protects the Island's ecological diversity and functions as a critical ecological corridor for island plants and animals under the integrated conservation planning program (Galiano Conservancy Association (GCA) 2013). In the heart of the coastal Douglas-fir forested landscape of the Centre lies approximately 13.06 ha of Agricultural Land Reserve (ALR), where forestry and agricultural activities had taken place in the past. The two food forest projects are housed in the ALR but managed under the same conservation planning and monitored by same indicators.

Galiano Community Food Forest

The Galiano Community Food Forest (GCFF) aims to be a sustainable, resilient food production system that feeds participants in educational programs at the Centre, to provide educational opportunities, and to sell and donate food to the local community. Different from a community forest which is collectively managed by a community, the GCFF is managed by the GCA and adopts a social enterprise approach, attempting to generate base revenue for project operation while supporting further conservation and restoration on GCA's property. The GCFF was planted in a primary agriculture zoning area (1.64 ha) within the ALR, which is designated for food production and horticulture (Fig. 2). It is largely an open, dry graminoid-dominated land with little regeneration occurring due to series of clear-cut and grazing until the time the GCA purchased the land. Within this area, a demonstration site of 750 m^2 in size was planted with over 50 plant species on woody debris mounds (Fig. 3), including the following: 5 tree species (e.g., *Castanea mollissima*, *Diospyros kaki*); 8 shrub species (e.g., *Ribes nigrum*, *Elaeagnus multiflora*); 28 herbaceous perennials (e.g., *Helianthus tuberosus*, *Perovskia atriplicifolia*); 4 vines (e.g., *Vitis* spp., *Actinidia arguta*); 11 self-sowing annuals (e.g., *Amaranthus cruentus*, *Raphanus sativus*); and different varieties of *Allium sativum* as a cash crop to help with initial operational costs. If the project is ecologically and socioeconomically successful, the demonstration site will be expanded in the future.

Restoration Forage Forest

The Restoration Forage Forest (RFF) was planted with native plant species in a parcel of approximately 1 ha in size in the integrated management zoning area within the ALR (Fig. 4). In this zoning area, more emphasis is placed on restoration of ecological processes and conservation of native species than the agricultural zoning area that houses the GCFF (Galiano Learning Centre Management Committee 2013). The goals of the RFF are similar to those of the GCFF but emphasize revitalization of traditional culture and plant uses. The area was originally planned for the GCFF, but there was heated debate at a public design workshop over the importance of a single residual old-growth western red cedar (*Thuja plicata*; the "grandmother tree"). The Conservancy had to decide whether to remove the tree (including some of the native plants surrounding it) for maximum food productivity, or to compromise productivity by keeping them and honoring the ecological and cultural legacy of the site. In the end, the GCA changed the location of the GCFF to its current location, which is a primary agricultural zoning area, and decided to create the RFF surrounding the grandmother tree. This debate illuminates the tension which may arise when food forestry is practiced on lands intended for biodiversity conservation.

Methods and materials

To develop the monitoring framework for the food forest projects of the GCA, we first defined the hierarchical structure and conceptual foundations of the monitoring framework based on best available practices in the literature. Second, we conducted qualitative content analysis (Hsieh and Shannon 2005) of monitoring parameters collected from a total of 61 literature sources and developed an inventory of monitoring parameters. With this inventory, we interviewed 16 experts in ecological restoration and food forestry and distilled ones that are relevant for food forestry and GCA's food forest projects. Finally, we discussed candidate parameters derived from the interviews with the GCA stakeholders, and the GCA selected monitoring parameters for their own monitoring program.

Fig. 1 Galiano Island map (produced by Daniel Brendle-Moczuk)

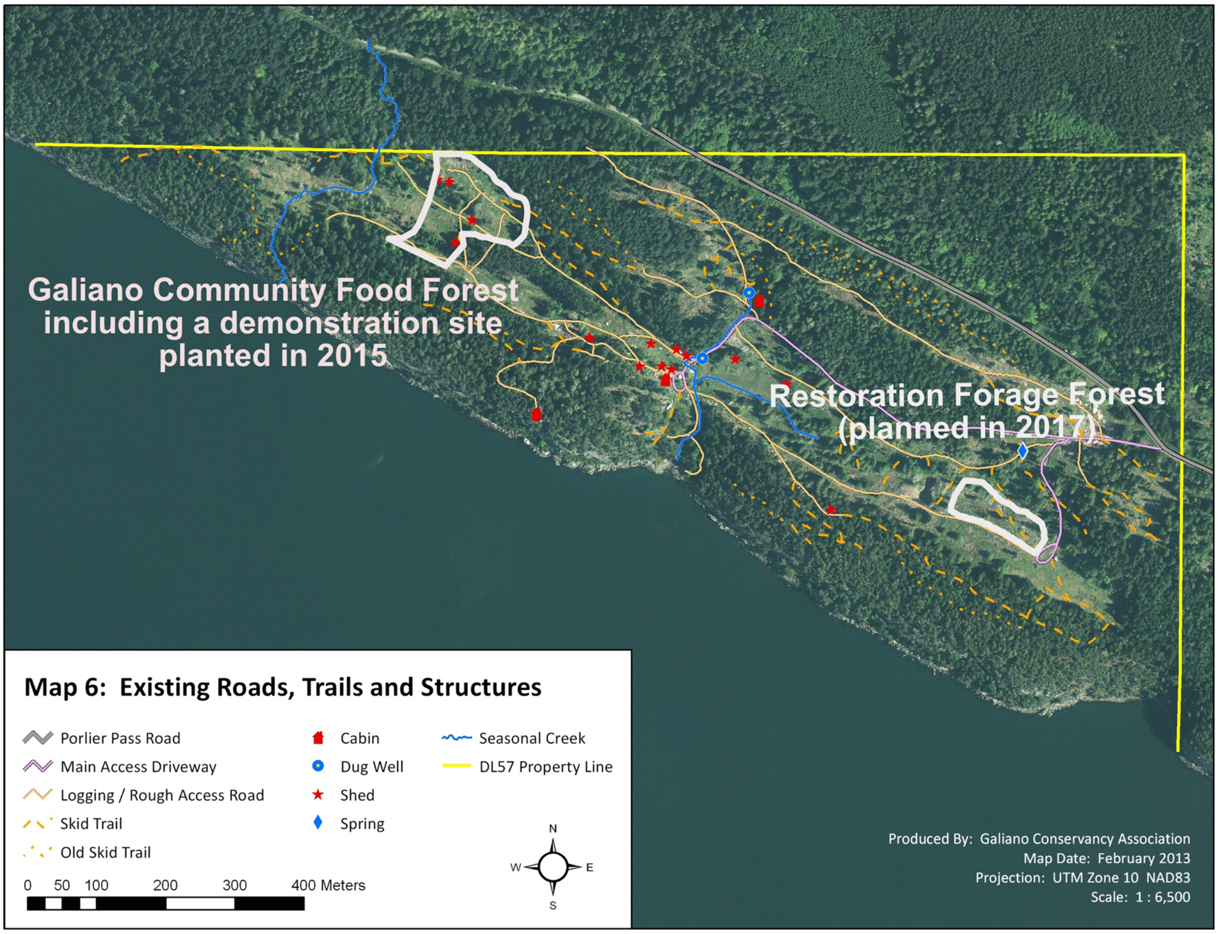

Fig. 2 Galiano food forest sites

Hierarchical structure of a Criteria and Indicators (C&I) framework

A C&I framework is a "hierarchical framework to help to design sets of indicators for sustainability monitoring programs" and is used as an organizational tool for identifying parameters of sustainability and assessing progress (Wright et al. 2002). We adapted the hierarchical structure of the Forest Service Local Unit Criteria and Indicators Development (LUCID) C&I, which was developed by six interdisciplinary forest teams in order to systematically monitor social, economic and

Fig. 3 A GCFF demonstration site of 750 m^2 in size was planted with over 50 plant species on woody debris mounds

Fig. 4 The Restoration Forage Forest (RFF) was planted with native plant species in a parcel of approximately 1 ha in size in the integrated management zoning area within the ALR

ecological aspects of local forest management in the USA (Wright et al. 2002). The LUCID C&I lays out the ontology of sustainable forest management and transparent relationships among hierarchical parameters. For the purposes of the present research, we simplified an original six-level hierarchical structure to a four-level hierarchy: principle, criterion, indicator, and measure (Table 1) as the other two subsequent levels—data element (i.e., specific method) and reference value—require more time for the organization to assess and determine those. Our aim was to provide a tool for diverse organizations that may lack significant capacity for planning, design, implementation, and monitoring. Thus, where possible, we emphasized simplicity in the development of the framework.

Conceptual foundation of a C&I framework

Prabhu et al. (1996) emphasized that assessment systems be conceptualized from the "top-down" principles and criteria so as to ensure that assessment parameters selected are "conceptually and scientifically" integrated with the principles. In order to develop the monitoring framework for GCA's food forests situated in a protected landscape, the monitoring framework was built upon comprehensive restoration principles that embrace the diverse and distinctive characteristics of social-ecological systems and that are applicable for the two projects of the GCA. Suding et al. (2015) developed guiding principles for ecological restoration to address

Table 1 Components, definitions, and examples of the LUCID C&I framework (adapted from Wright et al. 2002)

Component	Definition	Example
Principle	A fundamental law or rule serving as a basis for reasoning and action. An explicit element of the sustainability goal	Ecological integrity is maintained
Criterion	A component of the structure or function of the ecological, social, or economic systems, which should be in place as result of adherence to a principle. Criteria form the conceptual architecture of the systems under investigation	Landscape structure/composition
Indicator	A quantitative or qualitative parameter that can be assessed in relation to a criterion	Landscape patterns
Measure	The methodology and source of information for the indicator. The form, scale, timing, and units of data that are gathered are specified	Density and distribution of human developed features by use class (e.g., number of road crossings)

the "ecological, cultural, and socio-economic values of complex natural-human systems" in pursuit of creating sustainable and resilient systems (Table 2). These principles are extended from existing ecological restoration guidelines, including those issued by the World Commission on Protected Areas (Keenleyside et al. 2012) and provided in the Society for Ecological Restoration Primer (2004). Key attributes for each principle identified by Suding et al. (2015) were used as "top-down" criteria, which was subsequently complemented by "bottom-up" criteria resulted from an extensive literature review (Prabhu et al. 1996).

Preliminary C&I monitoring framework through extensive literature review

There are no systematic monitoring frameworks for food forestry in temperate regions, which led us to collect a total of 988 monitoring parameters from 61 literature resources on standards, principles, and assessment and monitoring drawn from five relevant fields: ecological restoration, agriculture/agroecology, agroforestry, sustainable forest management, and permaculture (Table 3) until no new parameters emerged. Using qualitative content analysis (Hsieh and Shannon 2005) and Atlas.ti (qualitative data analysis software), we inductively coded the 988 parameters and categorized them to criterion, indicator, and measure according to the guidelines of LUCID C&I (Wright et al. 2002). Monitoring criteria that were found across three different fields or more were selected as bottom-up criteria, which complemented the top-down criteria drawn from Suding et al. (2015). Using the analyzed monitoring parameters, we generated a preliminary C&I monitoring framework, which was employed as a response instrument for subsequent semi-structured interviews with restoration and food forestry experts.

Table 2 Principles and key attributes for guiding comprehensive ecological restoration (adapted from Suding et al. 2015)

Principles	Description and attributes
P1 Restoration increases ecological integrity	Recovery of biological assemblages including species composition, functional groups, and ecological processes to sustain the these biota and ecosystem function
P2 Restoration is informed by the past and future	Consideration of both historical knowledge and likely ecosystem/landscape trajectories, especially under conditions of rapid change
P3 Restoration benefits and engages society	Enhancement of ecosystem services; quality of human life and communities; participation; and understanding of ecosystems and their benefits
P4 Restoration is sustainable in the long-term	Establishment of self-sustaining and resilient system with minimum human intervention over time with the consideration of landscape contexts

Generic C&I framework for food forestry through semi-structured interviews

We conducted semi-structured interviews with 16 experts from the fields of food forestry (FF; $n = 8$) and ecological restoration (ER; $n = 8$) to identify monitoring parameters used in practice and to select candidates that may be valuable for food forest projects like ones of the GCA. The participants were practitioners, researchers or both recruited through a purposive, snowball sampling method (Cohen and Arieli 2011). The participants had professional experience in their field ranging between 6 and over 40 years (averaging 27.5 years in restoration and 24.5 years in food forestry) in Canada, the USA, and the UK; among them, seven had experiences in both fields. The interviews took place in the period from September 2015 to June 2016 via phone, online video chat, or in person; they were audio-recorded and fully transcribed. The interview process followed the Ethics Protocol (15-233) approved by the University of Victoria (consistent with Canada's Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans). Using the preliminary C&I framework as a response instrument, the participants discussed monitoring parameters in three ways:

a) What they monitor.
b) What they wish to monitor if given more resources.
c) What they think might be useful for the GCA.

We coded inductively the interview transcripts in Atlas.ti after reading them four times each, and compared coded monitoring suggestions against the monitoring parameters of the preliminary C&I framework. The monitoring parameters of the preliminary framework that were recommended by the experts were kept,

Table 3 A total of 61 literature resources include peer review articles, books, proceedings, and international/national reports

Nature of literature resources		
Field (# of literature resources)	Guidelines Standards Review of practices (20)	Monitoring and assessment (39)
Ecological restoration (25)	Burton 2014; DeLuca et al. 2010; Díaz et al. 2007; Hallett et al. 2013; Keenleyside et al. 2012; Ordóñez and Duinker 2012; SER 2004; Shackelford et al. 2013; Suding et al. 2015; Woodley 2010	Egan and Estrada 2013; Environment Canada 2003; Faber-Landgenden et al. 2006; Feld et al. 2009; Garry Oak Ecosystems Recovery Team 2011; Gomontean et al. 2008; Herrick et al. 2006; LaPaix et al. 2009; Lee and Rudd 2003; Mason et al. 2005; Noss 1990; Parks Quebec Network 2014; Ruiz-Jaen and Aide 2005; Spellerberg 2005; Tierney et al. 2009
Agriculture/Agroecology (13)	Cassman and Wood 2005; CGSB 2008; OECD 2001a; Webster 1999	Bockstaller et al. 1997; Hayati et al. 2010; McRae et al. 2000; OECD 2001b; Rigby et al. 2001; Sands and Podmore 2000; Tellarini and Caporali 2000; Van Cauwenbergh et al. 2007; Zhen and Routray 2003
Agroforestry (9)	Araujo et al. 2012; Atangana et al. 2014; Hart 1996; Hills 1988; Jose 2012; Montagnini et al. 2011; Szymanski and Colletti 1998	Casanova et al. 2012; CIFOR 2013
Sustainable forest management (10)		Balana et al. 2010; CCFM 2003; Kirby et al. 2005; MCPFE 2003; Montréal Process Working Group 2009; Mrosek et al. 2006; Pei et al. 2009; Prabhu et al. 1996; Williamson and Edwards 2014; Wright et al. 2002
Permaculture (4)	Jacke and Toensmeier 2005	Louvain 2015; Remiarz 2014; Warburton-brown and Kemeny 2015

and new parameters that were recommended were added to a generic C&I framework for food forestry. In addition to the monitoring parameter suggestions, we coded challenges of monitoring food forests in protected lands that emerged from the interviews.

Galiano C&I framework through a workshop

A key for developing a local C&I framework is to undertake active stakeholder consultation and to focus on a small number of principal indicators relevant to management and monitoring goals of a project (Hickey and Innes 2008). We conducted a 3-hour workshop with five staff and one board member of the GCA on Galiano Island in February 2016. Our aim was to refine the C&I such that it would be suitable for long-term use by a small (< 10 staff), community-based organization with limited resources and no laboratory facilities. We first discussed the generic C&I framework drawn from the previous interview analysis. Then, the GCA stakeholders qualitatively examined the indicators and measures, based on the following: (1) importance/relevance to their food forest project goals, (2) resources available (e.g., staff hours), and (3) ease of the use (e.g., level of expertise needed). Based on the discussion and our notes from the workshop, we refined the generic C&I framework by identifying the parameters that were considered important by the workshop participants and by categorizing the monitoring parameters to three groups: “easy to measure” group, “difficult to measure” group, and “lab required” group. The GCA staff reviewed the refined generic framework and finalized monitoring parameters for their use (referred as Galiano C&I framework in this paper). In addition to the workshop, one of us (HP) participated in initial site assessments, design workshop, vegetation survey, and planting of the GCFF from April 2015 to August 2016. Such first-hand participation and engagement with stakeholders gave a good

Table 4 Generic C&I monitoring framework for food forestry (excluding measures)

Principle 1 Ecological integrity	
Criterion (6)	Indicator (18)
Integrity of the biotic community	Plant diversity (species and structure) Trophic structure (food web/chain) from decomposer, invertebrates to birds
	Regeneration and reproduction
Habitat quality	Habitat structural diversity
	Landscape connectivity
Ecological processes	Productivity
	Carbon sequestration
	Succession
	Nutrient cycling
Soil	Physical characteristics
	Biological characteristics
	Chemical characteristics
	Soil erosion
Hydrology	Water storage and flow
	Water quality
Disturbance	Diseases and pests
	Environmental factors including fire, windstorms
	Herbivory
Principle 2 Informed by past and future	
Criterion (2)	Indicator (3)
Historical knowledge	Historical biological community or processes
	Traditional and/or local knowledge of the forest
Climate change	Weather patterns
Principle 3 Social benefits and engagement	
Criterion (3)	Indicator (10)
Cultural values and social equity	Food security (high-quality, reliable, affordable food for a community)
	Local community access to forest-related livelihood opportunities
	Cultural identity and spiritual values
	Life quality of a farmer and a family
Economic benefits	Yield
	Employment
	Local business
	Contribution to the community
Outreach, education, and training	Acquisition of knowledge and skills Research and science
Principle 4 Long-term sustainability	
Criterion (3)	Indicator (8)
Resilience and stability	Prepared and resilient to extreme weather
	Self-regulating (in the absence of maintenance)
	Functional diversity
Economic self-sufficiency	True yield (output–input) Product energy/input energy ratio (EROI)
Governance	Collaborative participation
	Continuity in management
	Stewardship

understanding of the local ecological, social, and cultural settings of the two projects on Galiano Island.

Results

The preliminary C&I framework, resulted from the literature review, consists of 4 principles, 13 criteria, 46 indicators, and 161 measures. It was then refined by the food forestry and restoration experts and distilled to the generic C&I framework of 4 principles, 14 criteria, 39 indicators, and 109 measures (Table 4; details in the Online Resource 1). As few monitoring indicators are available for food forest projects in temperate regions, particularly ones that are run by conservation organizations in protected landscapes, the semi-structured interviews with the experts in ecological restoration and food forestry provided first-hand knowledge that has been little explored in scientific literature. This contributed significantly to making operational the socio-economic aspects of long-term sustainability and resilience at a project level. Hence, the broader C&I framework is generally applicable, but is also readily customized to meet needs of specific organizations.

Ecological integrity

The concept of ecological integrity encompasses a suite of ecosystem attributes from ecosystem health, biodiversity, ecological processes, native species, stressors, and resilience, to self-maintenance. These attributes are weighted differently for different restoration projects. Some monitoring systems (e.g., Tierney et al. 2009; Wright et al. 2002) further divide the concept of ecological integrity into composition, structure, and function. As a result, interpretation of ecological integrity varies across social, ecological, and environmental contexts (Andreasen et al. 2001; Ordóñez and Duinker 2012; Suding et al. 2015).

Biodiversity, soil, ecological process (or function), and disturbance were identified as key ecological criteria across all five fields of the literature resources reviewed, and landscape and hydrology across the four fields. Among these criteria, the expert interviews highlighted plant diversity, complex trophic structure, soil, and ecological process as essential ecological aspects for monitoring. For plant diversity, ER-6 suggested measuring richness and abundance of all plant species or ones of dominant species of each forest structural layer. The food foresters observed birds, amphibians, invertebrates and/or fungi as a proxy for a trophic structure. FF-1 had recorded 21 bird species nesting in his food forest and 25 bird species visiting (occasionally and frequently) over the last 5 years, in addition to over a total of 100 pollinator, spider, snail, beetle, and earthworm species (available from http://grahambell.org). Yet, mobile species such as birds should be carefully chosen for a small-scale food forest project like the GCFF, as monitoring results can be significantly influenced by co-variables of surrounding landscapes and forests (ER-6). Alternately, less mobile species could be used (ER-7); for example, forest-dependent indicator species (e.g., *Scarabaeinae* communities) were used for comparing biodiversity among monoculture, agroforestry, and primary forest systems (Jose 2012; McNeely and Schroth 2006).

For monitoring ecological processes, the experts highlighted productivity, succession, carbon sequestration, and nutrient cycling. For example, productivity can be measured by DBH (ER-6) or the amount of yield (FF-1). Successional changes may indicate a habitat quality (ER-3) and/or can be qualitatively monitored through repeat photography and video-recording (FF-1). Both expert groups underscored the importance of monitoring of soil quality, in particular soil microbiology and soil organic matter, for its association with productivity, nutrient cycling, water conservation, and resilience to extreme weather events such as drought or extended rainy season. In collaboration with a graduate student (West 2006), FF-2 compared the composition of soil microbiology in his food forest against its neighboring woodland in England. ER-7 suggested mushrooms as an indicator for soil health, decomposition, and symbiosis of plant-fungus species as well as indicator plant species (e.g., *Lysichiton americanus*) for soil moisture and nutrient. Having no bare soil was proposed as a proxy for soil erosion prevention (ER-7), which helps to moderate changes in soil temperature that influences soil microbial activity (FF-1). Restoration experts (ER-1; ER-3) cautioned that a food forest should not leach nutrients into other systems or cause undesirable changes in hydrology of a landscape.

Informed by past and future

Historical knowledge in any form can indicate how systems have functioned in the past (Suding et al.

2015; Boivin et al. 2016). Ecosystem and landscape legacies may help to understand historic conditions and to discuss desired trajectories of the systems (ER-4). For example, pollen cores provide information on long-term plant community dynamics (Wright et al. 2002); but such measurement can be costly (ER-7). Alternatively, traditional ecological knowledge, which is associated with local plants and environments and accumulates throughout generations, may be more accessible and practical to use in order to understand the site history. In addition, the process of incorporating traditional ecological knowledge may engage a local community and indicate the degree of community participation and the level of cultural identity integrated in a practice (Pei et al. 2009). Meanwhile, a distinction was made between traditional ecological knowledge and local knowledge depending on a local history of human settlement and immigration (ER-7; FF-1). In conjunction with historical knowledge, information on weather patterns and climate variables, such as length of a growing season (Williamson and Edwards 2014) and blooming times over time, can be used to guide adaptive management in the wake of climate change (Hallett et al. 2013).

Social benefits and engagement

All food forestry experts highlighted the educational value of food forests in various forms (e.g., workshop, tour, research), and most recorded the numbers of educational events, of readers of their publication and/or of site visitors as well as feedbacks from visitors (FF-3; FF-6). Further, how and what people contribute to a community after acquiring knowledge and skills from a food forest project could serve as a measure of the educational impacts of the project on a community (ER-5). Stewardship reflects the level of community engagement in the project, which is critical for building sustainability and achieving long-term success of local conservation projects that often lack adequate human and financial resources and ongoing public or community support (ER-6).

Economic benefits of social enterprise projects like the GCFF may be measured in two ways: economic returns to the project itself and a broader spin-off to local businesses and community (ER-6). One could record the total (potential) sales income from all crops, the weight of each food crops, and/or total weight of all crops. Additionally, incomes from other activities such as nursery, workshops, and tours can be added up to measure economic benefits (FF-1). For the broader economic spin-off to the community, recommended measures include the following: the number of bed nights of people staying in local accommodations because of the food forest project (FF-1) and number of local businesses created due to a food forest (ER-5). Local food security can be measured by the amount of or the monetary value of yields donated to the community, or local consumption/purchase of the products (ER-7).

Long-term sustainability

Ecological resilience is a key criterion for long-term sustainability of ecological restoration (Suding et al. 2015). Resilience indicators include genetic diversity, species interaction, functional redundancy, and response diversity (Keenleyside et al. 2012). Yet, these are complex and often hard to measure, and it is yet difficult to understand to what degree resilience of terrestrial systems is affected by these factors (Bestelmeyer et al. 2011). In food forestry, practitioners observed signs of pests and disease, mortality and survival rate of plants, and crop productivity, in particular after extreme weather events or the absence of or decrease in maintenance as a proxy of system resilience (FF-2; FF-7).

Sustainability results from the concerted outcomes of social and economical management (e.g., Montréal Process Working Group 2009; Wright et al. 2002). The generic C&I framework includes economic self-sufficiency and systematic governance as sustainability criteria. Economic self-sufficiency emphasizes that a project be financially viable and/or able to operate without relying on external funds over time (ER-6). All costs for maintaining a food forest (e.g., irrigation, labor, and electricity) and all incomes from the project (e.g., product sales and workshop fees) may be considered (FF-4). In terms of systematic governance, a project should have the capacity to sustain or adapt in the midst of changes in management. Does a project rely on one champion, a few people who dedicate their whole time, or a larger pool of dependable volunteers? Can a project be sustained in the absence of a champion? (ER-6; ER-7). Therefore, the experts stressed collaborative participation, continuity in management, and stewardship as critical attributes of a project that is socially resilient and sustainable (ER-4; ER-6; ER-7; FF-4). In addition, as a food forest evolves the goals and objectives of the project may change over time and influence appropriate

Table 5 Galiano C&I Monitoring Framework. The framework consists of 4 principles, 13 criteria, 31 indicators, 19 core measures, and 28 optional measures. The core measures are the ones that the GCA has the capacity to monitor over time on either an annual basis or every 3 to 5 years as appropriate. Optional measures are pertinent to the projects and may be employed when additional expertise and/or time commitment available. Measures in italics are those used more than once

Criterion	Indicator	Core measure	Optional measure
Principle 1 Ecological integrity			
Integrity of the biotic community	Plant diversity (species and structure)	Species richness and its cover (%) in each structural layer (including invasive species) Tree (10 m+) density (number of stems per unit area) *Native species richness and its cover*	
	Trophic structure (food web/chain) from decomposers, invertebrates to birds		Insect species diversity (e.g., pollinators, *Scarabaeinae*, *Carabidae*) Amphibian diversity and behavior (e.g., reproduction, migration, health) Bird diversity and behavior (e.g., nesting)
	Regeneration and reproduction		Percentage and number of seedlings (DBH < 5 cm) and saplings (5–10 cm)
Habitat quality	Habitat structural diversity	Volume of coarse woody debris, small woody debris, and snags	
	Landscape connectivity	Area (% of site) of roads and footpath	
Ecological processes	Productivity		*Biomass (allometric equations: dbh and species)*
	Carbon sequestration		*Biomass (allometric equations: dbh and species)* Soil organic carbon
	Succession	Repeat photography or video recording	
	Nutrient cycling		Presence of mycorrhizal mushrooms *Soil microbial biomass* Soil organic matter
Soil	Biological characteristics		Ratio of bacteria and fungi Signs of arbuscular mycorrhizae colonization

Table 5 (continued)

Criterion	Indicator	Core measure	Optional measure
			Soil microbial biomass
	Chemical characteristics		Soil pH
			Nutrient availability (e.g., nitrogen, phosphorous, calcium)
	Soil erosion	None or less than 5% exposed soil including roads/paths (or more than 95% vegetation cover)	
Disturbance	Disease and pest		Use of organic spray for pest control
			Areas disturbed by pest and disease (e.g., *leaf damage, plant mortality) within a food forest*
			Areas disturbed by pest and disease (e.g., leaf damage, plant mortality) in neighboring areas
Principle 2 Informed by past and future			
Historical knowledge	Historical biological community or processes	*Native species richness and its cover*	
Climate changes	Weather patterns		Solar radiation Temperature Precipitation Wind
Principle 3 Social benefits and engagement			
Cultural values and social equity	Food security (high-quality, reliable, affordable food for a community)	Destination of products and food produced (local or non-local)	
	Cultural identity and spiritual values	Aboriginal participation	Culturally important species used
	Life quality of a farmer and their family		Wage, income rates Satisfaction/enjoyment from work
Economic benefits	Yield	*Income from yield* (e.g., *food, value-added products) and other activities* (e.g., *workshop)*	Total annual quantity (e.g., weight or volume of each crop)
	Employment	Number of jobs created	Number of staff and wages
			Number of community residents employed by the project
	Local business		Local businesses created by the project (e.g., herbalists/honey production/mushrooms)
Outreach, education and training			

Table 5 (continued)

Criterion	Indicator	Core measure	Optional measure
	Acquisition of knowledge and skills	Number of education and outreach events Number and demographics of visitors: age (*youth and senior), locality, ethnic, level of knowledge, interest	Number of hours invested in education, training, project implementation, monitoring for youth and locals
	Research and science	Number of research/education projects and individuals studying the system (including nature of research)	
Principle 4 Long-term sustainability			
Resilience and stability	Prepared and resilient to extreme weather	Crop failure after extreme weather events (e.g., drought)	
	Self-regulating (in the absence of maintenance)	Outbreaks of disease	*Areas disturbed by pests and disease* (e.g., *leaf damage, plant mortality) within a food forest*
	Functional diversity		Evenness of the distribution of abundance in nutrient-cycling microbes (fungi, nitrogen-fixing bacteria, ammonia-oxidizing bacteria)
Economic self-sufficiency	True yield (output-input)	Input and cost (e.g., labor hours and wage, volunteer hours, fertility input, seeds, imported plants, tools, fuel/oil, irrigation, any investment in infrastructure) *Output: income from yield* (e.g., *food and value products) and other activities* (e.g., *workshop)*	
	Product energy/input energy ratio (EROI)		Labor hours, machinery, fuel/oil, electricity, irrigation, fertilizer (compost)
Governance	Collaborative participation	Number of collaborators involved in the project	
	Stewardship	Number of volunteers and volunteer hours	

monitoring indicators. Therefore, a monitoring program for food forestry should not be static; rather it can be refined, complemented or reorganized to reflect changes over time (FF-4).

Galiano C&I framework

From the generic C&I framework, the GCA selected a total of 13 criteria, 31 indicators, 19 core measures, and 28 optional measures based on the relevance to the projects and on their capacity to employ the measures (e.g., expertise, finance, time) (Table 5). Similar to the interview results, the GCA stakeholders were interested in monitoring plant diversity, trophic structure, ecological processes (e.g., carbon sequestration, succession, and nutrient cycling), soil organic matter, and soil biological conditions. Overall, social indicators manifested the goals of the GCA's projects: local food security and economy, cultural revitalization, education, and active research collaboration. All long-term sustainability criteria—resilience and stability, economic self-sufficiency, and governance—were all adopted, and one or more core measures were chosen from each criterion.

Monitoring food forests in protected landscapes

At the heart of the discussion on monitoring food forests in protected landscapes, a critical question was raised by the experts and the GCA: How can the concept of ecological integrity be interpreted in a food forest system, in particular one that has a different plant community from plant communities of its landscape or a native plant community? In addition, the importance of facilitating the movement of species and genetic interchange and/or linking various habitats may differ depending on the size of a food forest project and the condition of its surrounding landscape such as fragmentation, disturbance, and scale (ER-5). Only few mature food forests were studied in temperate climates, and it is unknown how similar or different a temperate food forest would be to a natural forest in the same area or in the same climatic zone over time (FF-7). The restoration experts hypothesized that the GCFF may exhibit different functions and habitat quality given different composition and structure of the neighboring forests (ER-1; ER-6). At the management level, one has to decide how essential it is for the project to have a food forest that is similar to late-successional forests, and how much of difference to natural mature systems is acceptable, given that the food forest is providing valuable benefits that other systems do not provide (ER-6).

In restoration, reference ecosystems are essential for setting goals and assessing the success of a project (Ruiz-Jaen and Aide 2005). These reference ecosystems are often historical and/or similar ecosystems "in the same life zone, close so the project" that are "exposed to similar natural disturbances" (Society for Ecological Restoration (International Science and Policy Working Group 2004). On the other hand, a cultural ecosystem often guides management and monitoring as a reference when a goal is to bring back a cultural landscape. Often, selecting multiple reference sites for monitoring is encouraged to include variations in the desired ecosystem attributes and outcomes (Ruiz-Jaen and Aide 2005). The GCA intends to monitor a similarly aged regenerating forest where no management is taking place as a control site and an unmanaged mature forest ecosystem as a reference or target "natural" system against which to compare the food forest sites.

Discussion

The study does not quantitatively validate or evaluate individual monitoring parameters. Instead, it qualitatively analyzes key thematic monitoring criteria for each restoration principle and collects a wide range of monitoring parameters from the fields of restoration, agroforestry, agriculture/agroecology, sustainable forest management, and permaculture as only a few monitoring indicators are developed for food forestry, particularly in the context of conservation and ecological restoration. The incorporation of quantitative methods in this study such as scoring, ranking, pair-wise comparison, or multi-criteria analysis may increase transparency of the process of selection of monitoring parameters during the workshop and the interviews (Balana et al. 2010; Convertino et al. 2013). Further, future evaluation of the GCA's experience with the monitoring framework and monitoring parameters after using the C&I framework may be valuable for improving the validity of the parameters (Prabhu et al. 1996).

The results of the study underline the salience of managing and monitoring both social and ecological resilience of food forests to future changes for achieving sustainability of proejcts. The four principles for restoration, in which the generic and Galiano C&I frameworks are embedded, allow consideration of environmental and ecological attributes (e.g., genetic diversity, tolerance to ecological communities to extreme events, landscape connectivity) and societal attributes (e.g., social learning, experimental learning, collective capacity, governance) of resilience (Davidson et al. 2016; Keenleyside et al. 2012). The interview results shed light on how resilience is translated by food forestry practitioners and the community-based conservation group that experiment food forestry. The generic C&I framework indirectly addresses some agroecosystem resilience indicators such as biological and cultural memory and incorporation of traditional cultivation techniques (Cabell and Oelofse 2012). However, a growing body of scientific literature attempts to operationalize resilience thinking to practical levels and assess the resilience of complex socio-ecological systems. The C&I frameworks may be improved by incorporating a growing body of resilience principles and monitoring parameters for social-ecological systems (e.g., Cabell and Oelofse 2012; Davidson et al. 2016; Fischer et al. 2009; Turner et al. 2003).

The applicability of four restoration principles may vary depending on goals and scales of food forest projects. The presence of a native plant community and habitat quality for wildlife species are important for monitoring changes in ecological integrity of a food forest system in the context of ecological restoration. Yet, this approach may not be directly applicable for other food forest projects in different landscape contexts from ones of the GCA. The principle of being informed by the past deemed less relevant to the GCFF than the RFF because of its different plant composition in comparison with their neighboring forests. The principle of social benefits and engagement is more relevant to community and public food forest projects than to household gardens that are managed to benefit family members or a small number of people. The four principles of ecological restoration should be further tested in other case projects, and individual C&I frameworks may be modified by incorporating goals of community forestry and agroforestry projects that are developed through bottom-up approaches (Gomontean et al. 2008).

Apart from goals, scales, and landscape contexts of a project, resources available and required for monitoring significantly influence the selection for monitoring parameters as monitoring involves a range of skills, knowledge, equipment and time, and each monitoring measure has distinct requirements (Niemeijer and de Groot 2008). For example, monitoring wildlife indicator species and *Scarabaeinae* communities might require high levels of identification skills or may need a specialist. Evaluating resources needed for employing a specific measure and the current capacity of an organization to employ measures helps to determine most efficient and effective measures (Niemeijer and de Groot 2008). Learning from the GCA' case, we recommend that selection of optional measures, which can be employed in the future or through research collaboration as time and opportunities permit, in addition to core measures that are viable under the current capacity. What we heard clearly from discussions with the GCA is that it is better to have fewer measures that contribute to realistic long-term monitoring than to have a long shopping list of measures for which there is little future practicality. A general C&I framework allows food forest practitioners to have overlapping measures that support comparison.

Conclusion

The Galiano Conservancy Association's food forests are ongoing experiments, demonstrating how a local conservation organization might use a food forest in temperate regions to maintain or improve the overall ecological integrity of a landscape while achieving social benefits and sustainability of a project. The generic C&I monitoring framework is aimed to be comprehensive and systematic, and at the same time adaptable to the specific needs and purposes of local environmental organizations such as the GCA. The four principles of restoration, on which the framework is, based (Suding et al. 2015) encompass a wide range of human values and address tensions between focuses on past and future and ecological integrity and human benefits. Transparent linkages among the parameters of the hierarchy make it easy to select or modify the criteria, indicators, or measures that are related to the goals and objectives of a food forest project. We propose that the generic and Galiano C&I frameworks be carefully and deliberately tested, adapted, and refined in order to achieve specific management objectives of a particular food forest project. Determining monitoring indicators and measures requires clear goals, objectives, and scale of the projects and careful assessment of environmental, ecological, and social landscape contexts. At the same time, a monitoring framework should not be static; it should be refined, complemented, or reorganized to reflect changes over time as a food forest project evolves.

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Compliance with ethical standards

The interview process followed the Ethics Protocol (15-233) approved by the University of Victoria (consistent with Canada's Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans).

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