

Assessing ecosystem services in perennial intercropping systems – participatory action research in Swedish modern agroforestry

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Abstract: The focus of this paper is on how to assess ecosystem services in complex agroforestry systems using a case of edible forest gardens. Benefits of doing these assessments in a participatory learning and action research (PLAR) context are elaborated, as well as difficulties and questions that this has raised. The PLAR group comprised farmers on 13 smallholdings, researchers and a facilitator, which through collaboration and participatory methods have developed a general design of a forest garden, 60 m² in size and established it on all 13 participating farms. Important values of the work are that ecosystem services are related to specific local contexts and that a methodology for multi-criteria assessments of the generation of ecosystem services on a farm scale are being developed. Farmers engaged in formulating research questions, development of field trial designs, sampling and analysis of results improves the relevance and quality of the research as well as advance the adoption of new knowledge.

Keywords: Edible forest gardens, participatory learning and action research (PLAR), sustainable agriculture, transdisciplinary research

Introduction

Present agriculture contributes significantly to the environmental problems we are not only facing, but already find ourselves in (Tilman et al., 2002, Millennium Ecosystem Assessment, 2005, Rockström et al., 2009). We need to reduce our dependency on fossil resources in food production drastically, to mitigate climate change and delay “*peak oil*” and “*peak phosphorus*” (Cordell, 2010, International Energy Agency, 2012). For future agriculture production it is required not only to fulfil the human need for food, fuel and fibre, but also to improve the generation and use of ecosystem services (IAASTD, 2009, DeSchütter, 2011, Foley, et al. 2011).

Perennial cropping systems hold the prospect to be more productive and in the same time generate ecosystem services crucial for sustained production as well as for society at large (Thevathasan et al., 2004, Pretty et al., 2006, Tschardt et al., 2011). Agroforestry is a collective name for a variety of perennial production systems that integrate trees and shrubs in plantations and pastures. The World Agroforestry Centre (ICRAF) (2013) defines agroforestry as “*inclusion of trees in farming systems and their management in rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability*”.

An essential characteristic of agroforestry systems is multifunctionality. The systems are designed so that all components, both planned and associated, are integrated in a way to benefit each other. The systems provide different commodities (such as edible products, fibre, fuel wood, lumber, medicine and ornamentals), and they provide a range of regulating, supporting and cul-

tural ecosystem services (e.g. carbon sequestration, biological regulation, maintenance of soil fertility, educational resources and symbolic values) (Verchot et al., 2004, Goncalves, 2007, Jose 2009, Tscharncke et al., 2011).

Although most of the practical and theoretical knowledge about agroforestry systems originates from tropical areas and low-income countries, such systems are often suggested to be an opportunity in the development of sustainable food production systems also in temperate areas (Dupraz et al., 2005). Scientific arguments based on agro-ecological theories from studies of structure and functions of natural ecosystems are raised e.g. *sustainable agriculture* (Lefroy et al. 2000; Gould 2009) *natural systems agriculture* (Jackson, 1985, Ewel, 1999) and *eco-agriculture* (Scherr and McNeely, 2008). Local ecological knowledge of farmers also supports this. Furthermore, studies have shown strong benefits of the introduction of trees in agricultural systems, as they may improve the microclimate, sequester carbon, maintain mycorrhizal fungi, fixate nitrogen, and act as a nutrient and water pump from deeper parts of the soil (Jose, et al., 2004, Shibu et al., 2007, Ravinder Kumar et al., 2007).

A recent European study; *Silvo-arable Agroforestry For Europe* (SAFE), show that modern agroforestry systems such as alley farming and wooded pastures are more profitable than separate tree and cropping systems (Dupraz et al., 2005, Udawatta & Godsey, 2010). This study further indicates that there may be great potential in perennial crops for the transition to a more energy efficient and less greenhouse gas emitting food production.

Ecosystem services, meaning the “*conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life*” (Daly, 1997), are threatened globally and several are extremely degraded (Millennium Ecosystem Assessment, 2005). The ecosystems services concept was originally coined by ecological economics, to illustrate and facilitate the communication of our ultimate dependence of nature (Costanza et al., 1997, Daly 1997). Its ethical foundation is anthropocentric, with the argument to conserve nature for the continuation of its deliverance to humans (Fischer, 2008).

To assess ecosystem services in such complex systems as agroforestry, with a fundamental principle to maximize useful variation in species and habitats and to be adjusted to local contexts, is time consuming and afflicted with large difficulties. Variables of concern are often slow processes (e.g. soil carbon storages, species compositions, mycorrhiza) and to be statistically reliable, many repetitions are needed when variables are plenty. Relevant references points need to be defined, moreover, the level of detail appropriate for the assessments of the ecosystem services has to be decided. The focus of this paper is to contribute to the knowledge on how to assess ecosystem services in such complex systems as agroforestry systems; using the case of edible forest gardens as example. Benefits of doing these assessments in a participatory learning and action (PLAR) research context will also be elaborated, as well as difficulties and questions that this has raised.

Methodology

PLAR methodology has been used as a way to increase practical and theoretical knowledge within the new area of Swedish modern agroforestry. The methodology aims at simultaneous research, development and change in farming systems through collaboration between scientists, farmers and other stakeholders (Eksvärd & Rydberg, 2010). The approach has been developed to deal with research and development in issues that are multifaceted and ambiguous (Chambers, 2008). It has made it possible to engage in transdisciplinary discussions needed to cover the complex issues of agroforestry.

Participants and farms

The farmers on 13 smallholdings and farms constitute the core of the PLAR-group. These participants entered the group with expertise from a diversity of areas and some were also trained researchers and one as facilitator. Close to the core group are a handful of researchers contributing with knowledge inputs to the work of the group from their special disciplines when needed. Bachelor students have also been offered the opportunity to investigate questions of interest raised by the group and so far two theses were produced.

All farms are located in the southern parts of Sweden, from the west coast to the Baltic Sea on the east coast, in the Swedish hardiness zones system II – IV (Riksförbundet Svensk trädgård, http://www.tradgard.org/svensk_tradgard/zonkarta/index.html, visited 131218). The size of the farms range between 3 and 200 ha, except for a participating agricultural high school comprising 4000 ha.

Most farms are private owned. The two agricultural high schools are owned by the public sector. One of the farms is owned and ran by a foundation, which means that no one either lives or work there regularly. Still this is the place with the longest experience in edible forest gardens in Sweden, with six groves established in 2003, comprising 200m² each. On the different farms there are both full time and part time farming for subsistence, commercial or a mix of the purposes. A few of the farms were re-established more or less simultaneously with this project.

Some farmers are engaged in forestry and some have animals such as sheep, cattle, hens and pigs. About half also develop other kinds of agroforestry such as silvo-pasture or alley farming, which is another part of the project work, however not within the scope of this paper. Besides production of food and fibers communication seems to be a common interest. Nine out of 13 farms are already active in outreach and arrange different activities for visitors; cafés, restaurants, small-scale tourism, courses or opportunities for voluntary workers.

Environmental or ecological concerns are crucial for all farmers. It's expressed in quotes like "*farming is a part of the solution for a transition to a sustainable society*". Some have experience from organic farming, and permaculture thinking influences many. Interests in exploring and learning are high, as the willingness to experiment with new ideas.

Process, Group work and Case studies

The PLAR process started in 2012. During 2012 and 2013 the group has met twice a year for two day long workshops and held 9 complimentary telephone meetings. The group has, through collaboration and participatory methods, analysed the situation, decided on issues to focus on, phrased research questions, planned the investigations and started to discuss outputs and outcomes.

Based on iterative group discussion the participants elaborated a statement for the work that is done within the group including ; that the participants have the power to make all decisions, that they perform the work together with temporary affiliated researchers and students, that the target group apart from the them self is persons and groups interested in agroforestry, farming and sustainable development, that the work is based on that all humans have to take responsible actions to make live styles sustainable, that life is a constant learning process and that development improves by collaboration, the work is also based on the knowledge of the connectivity of systems and that natural ecosystems may work as models for system development.

With the intention of making both locally adapted and generalised knowledge development possible, a case study approach has been used for the edible forest gardens. The same basic design in the 13 gardens gives a repetition pattern to be used for the evaluation and validation of the results.

Findings

This paper focuses on the PLAR groups work on edible forest gardens. Edible forest gardens are systems composed of perennial edible crops that are placed in a structural design with the aim of receiving the highest degree of beneficial interactions to generate an optimal mix of the desirable outcomes of food and other useful raw materials as well as ecosystem services (Jacke & Toensmeier, 2005).

The development of relevant research questions

The following subjects were developed to be focus areas of the overall group work: 1) Potential production from an area (provisioning ecosystem services), in total biomass, in edible products and in economic benefits. 2) The culinary, energetic and nutritional value of the food that are produced 3) To scientifically test local ecological knowledge that the group contain about interaction between plant species, between plants, animals and other organisms, as well as about self-generative fertility and recirculation. 4) Energy efficiency in the system. 5) Environmental aspects, such as the systems' impact on biodiversity, and on the generation of supportive, regulative and cultural ecosystem services. 6) Questions about how to make the whole succession of an agroforestry system economically productive. These areas were formulated into specific research questions and methods for there assessment were suggested and discussed. (First to third workshop, April 2012, October 2012 and March 2013). An important task for the project was to test key species and varieties of these in practical designs, to generate an optimal combination of edible products and other outputs and outcomes. Furthermore to learn what it takes for a highly productive agroforestry system to work in practice, in terms of sales and regulations in the Swedish food system, were considered as crucial.

Establishment of a common design and field trials

One of the participating farms, Holma in Scania, had already developed a set of forest gardens with different designs of which one, the "Hardy grove" was decided to be employed as a model for a general design of a forest garden, 60 m² in size, to be set up on all participating farms. The argument to chose the "Hardy grove" was that the plants in this forest garden were thought to be possible to grow in all of the farms considering the climatic conditions, although not yet tested everywhere. (First workshop, April 2012).

The perennial plants to be established in the field trial garden were selected based on desired functions (Table 1). Plants at all structural levels; high and low canopy trees, scrubs, herbaceous perennials, ground cover plant, underground layer as well as climbers, was included (Crawford, 2010). The exact location and species of ground cover plants was not strictly planned but a voluntary list was jointly established.

Table 1. Perennial plants included in a forest garden, selected to receive important to key functions and with consideration of vegetation zone.

Key function	Perennial plant
Nitrogen fixators	<i>Caragana arborescens</i> , <i>Elaeagnus commutata</i>
“Nutrient accumulators” (plants that increase the nutrient availability in the profile)	<i>Symphytum x uplandicum</i> , <i>Alnus glutinosa</i>
High value as edible – (protein, fat, carbon hydrates, minerals and vitamins). Fruits, berries, nuts, lettuce, vegetables, herbs	<i>Hippophae rhamnoides</i> , <i>Amelanchier alnifolia</i> , <i>Fragaria x ananassa</i> , <i>Chaenomeles japonica</i> , <i>Malus domestica</i> , <i>Corylus avelana</i> , <i>Agastache Foeniculum</i> , <i>Chenopodium bonus-henricus</i> L., <i>Mentha spp.</i> , <i>mynta</i> , <i>Hablitzia thamnoides</i> Bieb., <i>Myrrhis odorata</i> (L.) Scop.
High quality pollinator feed	<i>Agastache Foeniculum</i> , <i>Caragana arborescens</i> , <i>Symphytum x uplandicum</i>
Climbers	<i>Rubus laciniatus</i> , <i>Vitis vinifera</i> , <i>Actinidia arguta</i> , <i>Hablitzia thamnoides</i> Bieb. <i>Apius americana</i>
Fast growing	<i>Alnus glutinosa</i>
Carbon sequestrators	<i>All perennial crops</i>
“Nurse trees” (giving protection to other plants in early stages)	<i>Alnus glutinosa</i>
Timber producers	<i>Alnus glutinosa</i>

Methods and analysis contributing with answers to the research questions

Documentation, reference points and reference values

The choice of reference states, crucial for the interpretation of the results, has been discussed profoundly during different stages in the work. Firstly, as the edible forest garden field trial design was originally established at all farms, previous land use at the site was a natural reference point. Permanent sampling sites, inside and outside of the trial area was established the year of plantation (2013). Secondly, when making a general analysis of different aspects, such as productivity, carbon sequestration or maintenance of biodiversity, of an edible forest garden different reference systems could be employed, among them forests or mono-cultured fields.

The initial vegetation and soil characteristics were considered important to document. The parameters that would be most important to focus on, considering trade-offs of costs and outcome, were discussed and decided on in the group. The group also anticipated that measurements taken in the initiation of the study might be crucial for the usefulness of the research in a longer timespan of 10 to 20 years.

Following measurements were decided to be taken on a permanent line transect with five sample sites at two depths (0-10 cm and 15 -25 cm) in the field trials (First workshop, 2012): biotope inventory – flora and fauna (only flora was performed), soil types, carbon content and organic matter, bulk density, plant available potassium and phosphorus, biological activity and general soil fertility. Discussions among the researchers also resulted in that total nitrogen content was furthermore added. The first analyses and synthesis of the result fostered a discussion whether to concentrate on more samples at one depth at each sites with fewer parameters and more statistically secure data, or to continue with the present sampling intensity analysing all the measurements. The decision was to intensify the sampling at one depth and focus only on soil carbon, nitrogen and biologic activity. However, infiltration as a way to assess soil structure was added, as it was perceived to be easy to perform while providing a lot of information (Forth workshop, 2013).

The group decided that all farmers were allowed to manage their trial site in a way to provide the best conditions for the establishment of the plants in their forest gardens. Because of the background of the participants the limitations of not using fertilizers and biocides were perceived as a

matter of course. This resulted in a variety of soil management, soil covering materials and organic matter input. All actions taken have to be carefully documented. The common documentation included; photographic documentation at permanent point at set dates, documentation of in- and outputs, accounting of labour hours and a diary with notations on important observation.

Methods for assessment of ecosystem services relevant in agroforestry systems

The group started the work to decide on which ecosystem services to be important to assess in the project with a theoretical discussion on the subject informed by two of the researchers in the group (Third workshop, 2013). Based on this a list of services was compiled and possible methods for their assessment were discussed and further elaborated by one of the researchers in the group and in two bachelor theses (Bodö, 2013 and Andersson Hylander, 2013) (Table 2).

Table 2. Ecosystem services and relevant methods to assess them in a PLAR process

Ecosystem service	Methods that will be employed	Motivation
The provision of productive ecosystem services from an area	Total yield of harvestable products, as well as energy and nutrient content in edible parts - described as Land Equivalent Ratio (LER) (Meed & Willey, 1980). Standing biomass - total harvest of plots in the set transect and alorimetric equations to estimate biomass of e.g. trees (Pearson et al., 2007)	A large knowledge gap exists on harvest potentials of specific forest garden plants as well as of entire gardens. Assessment on standing biomass without using destructive methods is also an inexact but important basis for other assessments e.g. of carbon sequestration capacity.
Carbon sequestration	Carbon accounting - counting the amount of C in standing biomass, both above and below ground, weight or alorimetric methods (Pearson et al., 2007, Nair, 2012). Assessment of total soil carbon - using Mass Spectrometer	Assessment of total soil carbon in the initiation of the project is motivated by the need of reference values in a long time frame, as changes in soil carbon are slow. Carbon accounting in standing biomass is useful in a short time frame but needs to be related to relevant reference points.
Biodiversity-Regulation of biotic environment	Wild and domestic flora, pollinators and natural enemies to important pest - inventories and traps for insects on set transect (Belfrage et al., 2005, Östman, 2001, Nielsen, 2011)	Measuring the actual ecosystem services; pollination or predation in the amount of places and in the PLAR setting might be too time consuming and expensive, instead the presence and richness of the species performing these services will be assessed, with the presumption that if the species is present the service will be performed. Biodiversity in it self also relates to the ecosystem service; resilience. The small size of the trials place restrictions on species that could be assessed.
Maintenance of soil fertility - Nutrient recirculation	Soil fertility - spade diagnosis Total soil organic matter - assessment of total soil carbon (see above) Biological activity -respiration measurements, earthworm accounting and use of litter bags (Schroth and Sinclair, 2002) Soil structure - bulk density and accounting of fine rots to a depth of one metre (Dupraz et al., 2005), Water infiltration capacity (Olsson, SLU, pers. comm. 2013) Nutrients - content of plant available nutrients and nutrient balances (Granstedt et al., 2008)	Spade diagnosis is a structured way to describe the soil and to get a general indication of the soil status, suitable in a PLAR process as all participants could easily do it. Indications of distribution of organic matter in more stable chemical compounds in lower levels of the soil in systems with perennial woody plants than is the case in annual systems put an urge on measurement at a depth of at least on meter. Infiltration might be more reliable than assessments of bulk density in this context, which however would be necessary for expression of results on an area basis.
Health aspects and nutritional values	Nutritional content in relation to the daily needs for humans (Bodö, 2013)	An indicative assessment of daily nutritional needs that could be meet by a garden and potential nutrients deficiency
Culinary aspects	Sensory panels (Albinsson et al., 2013)	Processed and fresh products ought to be tested in relation to nutritional aspects

Discussion

The development of edible forest gardens and the participatory research process performed by the PLAR group has been a pioneer work in several ways. Firstly, the focus has been on studying a production system that is new in Sweden and where there is a general lack of experience about such fundamental things as potential species to be used, breeding, establishment and management of different plants, potential yield or hardiness and culinary aspects of different varieties etc. Secondly, both skills and the long term tacit knowledge of farmers “living” with the system is lacking, as all, except one farm, started the development of their forest gardens when the work of the group started. The collaborative learning process therefore needs continuous rounds of planning, action and evaluation. Thirdly, the multitude of areas and questions identified by the group as important to learn about, the urgency of the issue, as well as the short time frames put by the research financing system, generated a need to screen methods, carefully select useful ones and combine them for multi-criteria assessments.

Finding methods to assess ecosystem services that benefits from farmers engaged in field trial designs, sampling and analysis of results has been a crucial issue in the process (Table 2). Transdisciplinary learning between the participants, students and researchers that this generates are important for both development and research in this field.

An important value of the work is also that ecosystem services are related to specific local contexts and that a methodology for multi-criteria assessments of the generation of ecosystem services on a farm scale are being developed. This is generally lacking in science and practice today. Conceptual knowledge and large-scale evaluations are plenty, but locally based assessments are few.

The concept of ecosystem services was, however, elaborated and discussed in the group. The anthropocentric approach was perceived to be in a contradiction a holistic base e.g. that everything coheres and that humans are a part of all this, making it impossible to evaluate different parts of that whole. The decision so far has been pragmatic; the group has agreed on using the concept as it is facilitating communication with society, still acknowledging the conflict.

As stated earlier, establishment of the gardens were done differently at the different sites. Group discussions, though, illuminated the trade-off between a common management of all sites, restricting the amount of variables, and by this probably increasing the quality in the research and assessments of ecosystem services and the possibility of giving generalizable results in the long term, and to optimize the different gardens, letting everyone manage their forest the best they could considering local contexts. This would probably result in important agronomic knowledge on how to create a forest garden and include it in the farm system. This discussion is to be continued in the group. The agreed on statements (see section; Process and Group work) for the work in the group might help to find a solution. Even if all participants will agree on continuing with the common management and design for the research forest garden, there is, however, still room for individual ideas and experimentation on other sites on each farms, which would enhances individual as well as joint learning.

Adding to this discussion is also that obvious shortcomings with the research edible forest garden design have been identified after only one year of field trials. Some of these shortcomings are that the area comprising the field trial is not large enough to include the amount of individuals needed to secure sufficient pollination and the small area also increases the edge zone effects, which might interfere with the results. Finally, the choice of design and of species was a compromise of what would be possible for all sites considering the local climatic conditions.

When starting a PLAR process, as in this case included an introduction of a new type of production system, the diversified knowledge held by the group as well as solid inputs from outsiders

has been crucial. It is important to not only focus on creating an area for the specific research trials needed, but a context for reference and learning on other types of issues of interest.

The question of scaling up the system to become a real alternative to present large scale, labour efficient, industrial agriculture as well as to make design appropriate in small urban areas is important issues to dwell on in further research. There is a growing interest in edible forest gardens and new gardens are developing at several places in the Nordic countries, that would contribute to important learning synergies if exchanging information and experiences. Distribution of knowledge on appropriate plant material, as well as breeding to increase availability, will be a critical issue for the development of the gardens in the group as well as at other places. The participating agricultural high schools could play an important role for this, providing area for starting nurseries and breeding sites.

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