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Towards more sustainable agricultural landscapes: Lessons from Northwestern Mexico and the Western Highlands of Guatemala☆

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ABSTRACT

A systematic process for assessing progress toward landscape sustainability goals is developed and tested. Application of the approach builds capacity and promotes continual improvements in management practices, thus enabling timely action to address changing conditions while progressing toward locally defined goals. We consider how the approach applies to agricultural landscapes, that is farm ecosystem interactions with the environment and human well-being. We present lessons learned from applying the assessment approach in two contrasting situations: large, high-input, commercial agriculture in northwestern Mexico and small, low-input family farms in the Western Highlands of Guatemala. Applying the approach reveals five attributes required for success and the means to achieve those conditions. (1) Having a capable local champion for the project is critical. (2) Implementation of the approach must be in concert with local people and organizations as well as with regional and national policies and programs. (3) Identification and engagement of key stakeholders is essential. (4) Application of the approach is not meant to be a one-time effort but rather an ongoing and systematic process. (5) Engagement and buy-in from stakeholders including multiple agency levels is essential for allocation of necessary resources and logistic support in the continuing implementation of the approach.

1. Introduction

Landscape science focuses on place as a means to understand interactions between ecosystem services and human well-being under changing conditions (Musacchio, 2013; Pearson & McAlpine, 2010; Wu, 2013). Landscapes work across scales by playing an important

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role in buffering global and regional trends (e.g., in climate change and market failures) as well as demonstrating the potential impact of local practices and trends (e.g., how cropping practices can affect nutrition and poverty). A landscape perspective can influence attitudes and thus lead to adaptation of actions (Gantar & Golobič, 2015).

Here the focus is on agricultural landscapes, which include farm ecosystems as well as the environmental and socio-economic factors that interact with them (FAO (Food & Agriculture Organization), 2018a, 2018b). The extent of agricultural landscapes exceeds that of farm production systems and includes the location and condition of farmers' families and support systems including access to inputs and networks facilitating health, education, transportation, and markets.

Agricultural landscapes affect human and environmental health, incomes, and climate change and are influenced by those conditions as well (Fig. 1). For example, low diversity in crops can result in little dietary diversity and poor nutrition [World Health Organization(WHO) (2010)]. Improper use of agricultural chemicals can contaminate food and water, thereby impairing human health (Alavanja & Bonner, 2012). Droughts, heat waves, unseasonable frosts, and other climate related disturbances can compromise agricultural productivity and indirectly affect farmer's income and nutrition (Dwivedi, Sahrawat, Upadhyaya, & Ortiz, 2013). Farmer health impacts demand for and productivity of farm labor (Omotayo, Aremu, & Alamu, 2016). If natural resources are contaminated or depleted, the rural communities that depend on agricultural economies suffer. Thus, the interconnections between health, poverty, and climate change affect and are affected by agricultural landscapes. Of note, the United Nations' Sustainable Development Goals (SDGs) include targets to eradicate poverty and hunger and promote health, clean water, and sanitation as well as to combat climate change and its impacts (United Nations, 2019). Agricultural landscapes play a crucial role in attaining those SDG targets.

To quantify progress toward landscape sustainability and to help users advance toward shared goals, we developed a structured assessment framework (Dale, Kline, Parish, & Eichler, 2019), hereafter called the *approach*. This *approach* engages stakeholders to identify essential features of the landscape and determine steps to be taken to attain or maintain beneficial conditions. The *approach* is designed to be generic enough so that it can be adapted to a variety of situations that have distinct constraints, opportunities, and stakeholders with different values and priorities (Cebrián-Piquerasa, Karraschb, & Kleyera, 2017; Johnson, Lilja, & Ashby, 2003; Ness, Urbel-Piirsalu, Anderberg., & Olsson, 2007; Sydorovych & Wossink, 2008).

Here we summarize the *approach* and lessons learned from initial steps to apply it to determine progress in two situations: large, high-input, commercial agriculture in northwestern Mexico and small, low-input, family farms in the Western Highlands of Guatemala. Practical indicators for agricultural landscapes are suggested based on what was discovered from the two cases and the literature. Lessons learned focus on attributes that are required for success in application of the assessment *approach* and means to improve landscape conditions. The final section of the paper discusses the benefits and difficulties encountered in using this *approach* to measure progress toward sustainable agricultural landscapes.

2. Overview of the approach

When applied to agricultural landscapes, the landscape sustainability assessment process described below can be used to evaluate costs and benefits of farm systems on the environmental, social, and economic systems that support them. One or more scenarios are often used to explore alternative situations. Scenarios are useful, for they can help challenge assumptions, identify new lines of inquiry, and enable novel lines of research to emerge (Ramirez, Mukherjee, Vezzoil, & Kramer, 2015). Each scenario assumes a certain set of decisions, policies, and environmental, social, and economic conditions. Assumptions for each scenario should be documented to facilitate interpretation of results and replication of the assessment process. One common scenario is continuation of the current

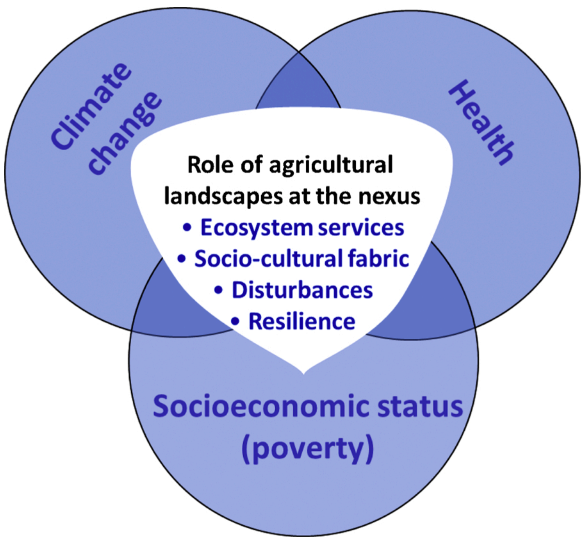

Fig. 1. Influences of agricultural landscapes on human and environmental health, poverty, and climate change showing key attributes of the nexus.

situation, sometimes called baseline, business as usual, or reference conditions. Another scenario may involve an increase or decrease in production, pollution, climate change, economic conditions, human health, or a combination of these and other conditions. Potential management options under each scenario should consider stakeholders' objectives as well as what is feasible.

The process can be divided into six steps (Fig. 2) as described below. While some of these steps can occur simultaneously, the first steps must be completed before later steps are finalized. Interactions among the steps naturally occur as new information is available and knowledge gained, which may require a review and adaptation of decisions made during prior steps. Furthermore, if goals are adjusted in light of changing conditions, priorities, or information, the entire assessment process may be reinitiated. Working with counterparts in Mexico and Guatemala, we applied and documented results from the initial steps of the *approach*. The final steps of making decisions and reassessment take additional time and have not yet been completed in the case studies.

2.1. Step 1: defining the scope

Defining the scope of an assessment requires specifying the plans and goals for the activity and the major stakeholders. A key aspect is determining for whom or for what purpose the assessment is being developed (Wiens, 2013). The context of the assessment process affects definition of the scope and the selection of indicators (Efroymson et al., 2013; Heink & Kowarik, 2010). Context includes the system boundaries or the temporal and spatial scale of the assessment, which are set by the location and the extent of costs and benefits. For example, in agricultural systems, products (or wastes) are often exported far beyond the area of production. It is also important to understand past trends and current conditions and to consider potential decisions that are pertinent for the assessment (Efroymson et al., 2013; Petersen, Aslan, Stuart, & Beier, 2018). Stakeholders should be engaged throughout this initial step of defining the scope as well as in subsequent steps, for they can help determine what is realistic and how activities within a local landscape relate to regional and global phenomena that interact with that system (Opdam, Luque, Nassauer, & Verburg, 2018).

2.2. Step 2: prioritizing indicators

Indicators can be used to assess the condition of the system, monitor trends over time, provide an early warning of changes, or determine causes of change (Cairns, McCormick, & Niederlehner, 1993; Dale & Beyeler, 2001). Furthermore, they can (1) provide information pertinent to priorities of stakeholders and decision makers, (2) identify costs and benefits across the entire supply chain, (3) expedite measurement, or (4) point to corrective actions (Cairns et al., 1993; Dale, Efroymson, Kline, & Davitt, 2015; Iacovidou et al., 2017). However, the tendency to be comprehensive and catalogue all potential indicators should be balanced by the need to keep the process doable with respect to available time, budget, expertise, and information. Therefore, indicators should be prioritized to be the minimum set of measures that address key concerns of stakeholders (e.g., Rasmussen, Bierbaum, Oldekop, & Agrawal, 2017) while recognizing that having too few metrics can omit significant information and thus make it difficult to interpret observations (Landres, Verner, & Thomas, 1988).

There is little consensus on a few indicators appropriate to measure sustainability. The 17 Sustainable Development Goals of the United Nations (2020) have defined 232 unique indicators to measure progress toward 169 different targets. Hundreds of indicators have been identified for agricultural systems alone (Rasmussen et al., 2017). Yet a long list of guidelines and metrics is the antithesis to consistent measurements and unambiguous results (Vörösmarty, Rodríguez, Koehler, & Klop, 2018).

We applied an established framework for selecting and prioritizing indicators (e.g., Dale et al., 2019) designed to (1) identify key indicators appropriate for the context, (2) provide adequate information relative to the cost of obtaining it, (3) build agreement around stakeholders' goals for desired future conditions, (4) consider important stakeholder concerns, and (5) identify a suite of indicators

Fig. 2. Approach to engaging stakeholders for improving landscape management (simplified version adapted from Dale et al., 2019).

that is monitored over time (Garrick et al., 2017; Dale et al., 2015). Ideally those indicators are practical, reliable, and provide timely information (Dale & Beyeler, 2001).

2.3. Step 3: establishing targets

A target is established as a goal that can be compared to the observed status to facilitate measurement of progress toward a desired state. Targets should be identified for each indicator with input from stakeholders using available information (Dale et al., 2016; Hunter, Smith, Schipanski, Atwood, & Mortensen, 2017) and considering both long-term and near-term needs (Dale, Kline, Kaffka, & Langeveld, 2013). Targets can be identified based on established goals, literature reviews, expert opinion, analysis of similar systems, regulations, or consensus among informed stakeholders (Moldan, Janoušková, & Hák, 2012) (e.g., see examples described by Tarter et al., 2016). The target for each indicator relates to the baseline condition as well as alternative conditions under consideration. Baseline conditions for each indicator provide references for comparison and can be derived from historical information, scientific literature, or measurements made before the assessment is implemented.

2.4. Step 4: calculating indicator values

In conjunction with selecting indicators, setting targets, and defining scenarios, indicator values need to be established for each scenario to allow comparison of conditions under alternative management conditions. Indicator values can be derived from empirical measures, secondary data or statistics, data from similar situations, model results, expert knowledge and, most commonly, a combination. For example, if the indicator for soil quality is the area at risk of compaction or salinization by soil type and tenure regime, that information is often available from government sources (see Eichler, Kline, Ortiz-Monasterio, Lopez-Ridaura, & Dale, 2020). Rapid assessments have been used to document indicator values under constrained resources and information (Eichler et al., 2020). To foster transparency, it is important be clear about the means of calculating indicator values. For example, when conditions are simulated using models, variability in estimated values and uncertainties in the underlying data and modeling should be documented [e.g., Dale & Kline, 2013; American Society for Testing and Materials ASTM E(3066)-20 (2017)].

2.5. Step 5: analyzing trends and tradeoffs

Changes and trends in indicator values under different scenarios or conditions can be measured using empirical data, historical information, model projections, or inferences from similar situations. Any directional changes that are identified should be analyzed in view of intra- or inter-annual variability and cycles, which may confound interpretation of those trends in indicator values.

Trends also provide evidence that can help identify causes of changes in indicator values even though attribution takes time, knowledge, and resources that may be difficult to obtain (Efroymson et al., 2016). Documenting cause and effect via experiments and models is challenging (De Boeck et al., 2015). Methods to test the weight of evidence using causal analysis can help distinguish the share of effects that results from certain activities (Efroymson et al., 2016). Applying this process over time ultimately clarifies cause-and-effect relationships and helps identify improved practices.

Tradeoffs refer to (1) the balance achieved between two desirable but incompatible features, only partial achievement of each, or a compromise, (2) a situation in which a choice must be made between two things that cannot be achieved at the same time, or (3) a giving up of one thing in return for another. As such, tradeoffs are a part of every step in the assessment process, for defining the scope involves choices about context; selecting indicators requires balancing objectives; and establishing targets often invokes giving up one option for another. Even so, analyzing trends and tradeoffs is a step in the assessment process because comparing outcomes under different scenarios involves considering costs and benefits of different alternatives (Fisher et al., 2011; King et al., 2013; Parish, Dale, English, Jackson, & Tyler, 2016; Villa et al., 2014). Methods for evaluating trade-offs include optimization and simulations of alternative scenarios (Delmotte et al., 2016).

Identifying tradeoffs between potential benefits and negative impacts is challenging but necessary (Chapin et al., 2011; Kanter et al., 2018). The decision-making process requires choices be made about what result is more desirable (e.g. for agricultural landscapes, it may be between greater profit or cleaner water). Thus, priorities must be set with stakeholders in the initial steps of defining goals and selecting indicators. The assessment process should identify costs and benefits across diverse scenarios and a suite of indicators so that informed decisions can be made. In some cases, tradeoffs may be avoided. Synergies or "win/win" situations can also be sought and can avert some tradeoffs, for example, by strategic crop placement that produces multiple benefits (Parish et al., 2012) such as improving water quality while increasing pollinator habitat (Graham, 2017).

2.6. Step 6: identify good practices

The final step in this iterative assessment process is to identify "good practices." Rather than "best management practices," we refer to good or better practices to acknowledge the opportunity for continual improvement as conditions change. For each specific case study, good practices are identified by how the outcomes relate to the stakeholder goals that are established in Step 1 of the assessment. Practices in agricultural landscapes include farming, forestry, and other natural resource management activities that can improve crop, livestock, and fisheries production, conditions of workers and their families, and water, soil, and air quality. Good practices consider ways (1) to reduce impacts from extreme events such as drought, flood, fire, disease, economic downturns, and political upheaval (Dale et al., 2016) or (2) to implement practices for agricultural production that lead to improvements in soil, water, and biodiversity, climate-change mitigation, and the social and economic benefits [FAO (Food and Agriculture Organization) (2012); 2018a; 2018b].

Identifying successes, failures, and lessons learned is important to enhance continued learning and to better qualify and quantify risks (e.g., Lindenfeld, Smith, Norton, & Grecu, 2014; Seuring & Muller, 2008). Good practices should be supported by ongoing transparent and participatory monitoring (Dale et al., 2016). Finally, as new information, intervention opportunities, or regulations arise, the entire assessment may need to be revised in case adjustments are needed to update the goals, scope, indicators, or targets.

3. Applying the approach in two test cases

Initial steps in applying this assessment *approach* have been implemented in two contrasting case studies: large, high-input, commercial agriculture in northwestern Mexico and small, low-input, family farms in the Western Highlands of Guatemala. These cases were selected to test the general applicability of the framework under very different conditions. These cases differ in their agricultural practices, effects of climate change, and other evolving social, economic, and environmental conditions that influence health and poverty of the systems. Furthermore, it was understood at the outset that each landscape would involve access to different types of indicator data, both historical and recent.

Although progress has been made in applying the *approach* to these two cases, neither assessment is complete. Even so, it is worthwhile to present the status of the assessment for these two cases, as the process itself contributes to building capacity within the communities. Achieving a final result is not the goal, as the assessment process is meant to be part of an ongoing, iterative analysis, building on the work of Ostrom, 1994; Ostrom, 2008. Furthermore, identifying appropriate indicators of pending critical transitions is often seen as one of the biggest challenges in sustainability science (Levin, 2013). The two case studies offer insights on the topic of defining appropriate indicators as well as in discovering attributes that are required to improve conditions.

3.1. Large, high-input, commercial agriculture in the Yaqui Valley of northwestern Mexico

3.1.1. Background

The Yaqui Valley in the southern region of the northern state of Sonora, Mexico, has benefited significantly from being the birthplace of the Green Revolution based on the work of Borlaug and his colleagues in the middle of the 20th century (Matson, 2012). The applied research by Borlaug and his collaborators continues to improve varieties of wheat (*Triticum aestivum*) and supported transition to high yielding, intensive, irrigated agriculture. Today, while there is a range in social wellbeing, most people are in reasonably good health and have adequate nutrition and good job opportunities (Fig. 3). Challenges facing the region include how to maintain or improve social and economic conditions in the face of increasing populations, insecurity, changing environmental conditions that undermine the agricultural economy, and overuse of agricultural inputs (particularly nitrogen) that degrade the environment.

The impressive agricultural productivity of the Yaqui Valley is due to high yielding wheat varieties, favorable climate, large-scale irrigation, and dedicated use of fertilizers and pesticides (Matson, 2012). It also benefits from access to global markets and extensive infrastructure. The Yaqui Valley supports about 250,000 ha of irrigated fields, which are largely cropped with wheat planted in the fall. This flat desert landscape is east of the Sea of Cortez and south of the Yaqui River. The land was used for gathering, hunting, fishing, and cultivation of maize (*Zea mays* subsp. *mays*), beans (*Phaseolus* spp.), and squash (*Cucurbita* spp.) for thousands of years by the Yaqui Amerindians prior to arrival of the Spanish (Matson, 2012). Large-scale irrigation first began in the region in the early 1900s. Today three large reservoirs in irrigation area "Distrito de Riego del Rio Yaqui" (henceforth, DRRY) provide over two billion cubic meters of water storage that support the Yaqui Valley society, economy, and environment.

Climate change and limited water and other resources can jeopardize crop production in the Yaqui Valley (Schoups, Addams, Battisti, McCullough, & Minares, 2012). High night-time temperatures and droughts decrease wheat yields. Hence heat tolerant and drought resistant varieties are being developed. On the other hand, extreme rainfall events cause destructive flooding, and the frequency of floods associated with cyclone activity in this region has increased in recent decade (Zuñiga & Magaña, 2018). Furthermore, productivity depends on external inputs of high yielding varieties, flood irrigation, fertilizers, herbicides, insecticides, fungicides, and mechanization. Hence alternative agronomic practices to improve resource-use efficiency are being developed.

Poverty and health concerns are also present in the region. Based on the *rezago* social index for the DDRY region in 2015, 12–25% of the population had no refrigeration and 4–14% of the people older than 15 were illiterate (Eichler et al., 2020). This index measures the degree of social lag relative to the overall population of Mexico based on information about access to water, sanitation, healthcare, electricity, and education and quality of housing relative to other households in Mexico (Government of Mexico, 2016). The index does not incorporate data on income or food (Andrés-Rosales, Lemus, Saraí, & Argumosa, 2018). Human health concerns related to agriculture include air quality and pesticide exposure (Kitze, 2005; Meza-Montenegro et al., 2013). However, there are only limited data available to document the extent of these problems.

3.1.2. Application of approach to the Yaqui Valley

Progress in applying the *approach* to the Yaqui Valley includes determining the context, stakeholders and their goals, and indicators and reviewing data on those indicators for which information are readily available. The assessment of trends and tradeoffs has helped to explore better practices for the region. Progress to date and proposed next steps are described below.

In the Yaqui Valley, the context is largely determined by the geographic extent of the assessment, which is the area under irrigation or DDRY, for intensive agriculture in this arid region is only possible where water is provided. This boundary means that stakeholders include not only farmers and those engaged in transport, markets, and consumption of agricultural products but also those managing

Environmental conditions
- Level
- Rich floodplain, alluvial and some clay soils
- Formerly dry coastal thorn-scrub
- Non-intensively farmed for >1000 years

Climate & disturbances
- Hot & arid, with limited winter rains
- Droughts (1997-2004)
- Crop diseases & pests prevalent

Agricultural practices
- Intensive mechanized tillage & irrigation
- High fertilizer & pesticide applications
- High yielding crop varieties
- Predominance of monoculture wheat
- Average field size: 20 ha

Economics
- Large-scale export of wheat
- Tight links to global markets

Social system
- Stable rural and growing urban population
- *Ejido* lands often rented
- Health concerns related to air and water quality (dust, smoke, agro-chemicals)

Fig. 3. Characteristics of large, high-input commercial agriculture in the Yaqui Valley of western Mexico (derived from Matson, 2012).

the irrigation system. Since intensive agriculture is practiced in the DDRY region, suppliers of fertilizers and pesticides are important stakeholders. Stakeholder groups interviewed include farmers, land owners, local environmental research academics, irrigation managers, plant pest-and disease-control specialists, agricultural outreach agents, members of local environmental organizations, community leaders, international researchers familiar with this system, and representatives from agricultural industries, commodity organizations, and farmers' unions (Eichler et al., 2020). About two dozen local stakeholders participated in small group workshops or individual meetings in the Yaqui Valley, others participated in informal discussions during the International Maize and Wheat Improvement Center (CIMMYT[1]) Wheat Week research and extension activities. Workshops were organized through direct email contact with representatives of local agencies.

Goals and priorities vary among different stakeholders in the Yaqui Valley (Eichler et al., 2020). Most stakeholders recognize the importance of water and soil conditions in supporting farm production and the susceptibility of crops to droughts and higher night-time temperatures associated with climate change. Thus, goals for the DDRY include not only high agricultural production but also the conservation of non-renewable resources such as soil and water, which support profit and improve resilience. The priority social goal is quality of life, which consists of health, food security, employment, and household income. Crop diversity as well as native plant diversity was valued by some stakeholders.

Employing a rapid appraisal that only uses readily available information, indicators related to each of these goals were identified for soil quality, productivity, biodiversity, vulnerability to climate change, poverty, and economic implications of crop diversity (Eichler et al., 2020). Analyzing available data for each of these indicators suggests that land-management practices that conserve and improve nutrient- and water-use efficiency are important to achieving the Yaqui Valley stakeholders' goals (Lobell, Ortiz-Monasterio, Addams, & Asner, 2002; Luers, Lobell, Sklar, Addams, & Matson, 2003; Ortiz et al., 2008). Furthermore, monitoring these and other indicators is important to quantify the risks for soil compaction and salinization as well as health impacts associated with air pollution, dust, and agricultural chemicals. While laws and regulations exist for pesticide management, water and air quality, labor rights, etc., both enforcement and monitoring are inconsistent.

3.1.3. Lessons learned about agricultural systems in the Yaqui Valley

Our work builds upon the multiyear effort led by Stanford University and CIMMYT. Among the findings from that body of research are the following: sustainability is an ongoing process; a major barrier is the need to make decisions under uncertainty; broadening the agenda beyond economic goals to include social and environmental objectives is challenging; and knowledge must be paired with action (Matson, 2012). By working from a systematic *approach* to assess progress and build on prior work, we derive four additional lessons for the Yaqui Valley, namely (1) resource allocation has major impacts on productivity and socioeconomic and environmental conditions; (2) crop diversification can enhance resilience; (3) institutional transparency is a concern to stakeholders; and (4) sharing of information is necessary for improvements. Each of these lessons is discussed below.

[1] CIMMYT derives from the Spanish name, *Centro Internacional de Mejoramiento para Maíz y Trigo*, for the International Maize and Wheat Improvement Center.

Resource allocation affects crop productivity as well as socioeconomic and environmental conditions. Water availability in the face of climate change is a priority impacting productivity and profits. The impacts of agrochemical-use can reach the aquatic ecosystems and fisheries in the Gulf of California, and Beman and Luers (2012) point out that more efficient resource management can benefit both agriculture and the environment by increasing productivity and reducing runoff. At the same time, human health is a top social concern that is linked to pesticide use and handling. Furthermore, strong organizations and relatively recent national laws to engage stakeholders in prioritizing government investments in resource distribution provide opportunities to further develop multi-sectoral consensus around priority development goals for the valley and corresponding indicators of progress.

Diversification of crops, varieties, and cropping systems should be explored and implemented to enhance resilience to droughts, disease, pests, and other stresses. The variety of agricultural employment opportunities in the Yaqui Valley has now expanded from wheat production to include shrimping, nut production, and cultivation of maize, beans, and other crops that provide some economic fortitude. While wheat production is still the overwhelming driver of regional economy and water use, organic or other certification standards expand market opportunities of diversified crops.

Transparency of institutional and financial opportunities and transactions is a concern for stakeholders in the Yaqui Valley; yet the only information on this issue is of low resolution or difficult to interpret (Eichler et al., 2020). Hence the lack of openness regarding both data and funding resources for projects and new opportunities should be addressed in order to improve the sustainability of the landscape.

Efforts should focus on making information available to farmers, farm programs, and agencies so that agricultural practices can be improved. Improvements are warranted in practices related to cropping systems intensification – including crop rotation, use of chemicals, and irrigation. Technical assistance is needed at many levels. New practices are slow to be adopted, for early adopters must demonstrate benefits before others will follow, and the common practice of annual land renting does not incentivize adoption of practices that require several years to accrue benefits. CIMMYT makes important contributions to technology development, training, and outreach for maize and wheat systems and could contribute to national efforts to reestablish an extension service. Although farming and fishing organizations exist, their focus is on government support for business rather than on integrated sustainable production systems.

Fostering interactions among stakeholder groups can generate benefits if all parties have access to the same information and understand its relevance and significance. Identifying both common and conflicting goals among stakeholders points to opportunities for cooperation and areas where more discussion and time for resolution are needed. Access to trustworthy sources of information and constructive private-public partnerships are ingredients for advancing common development goals through multi-sectoral cooperation.

3.2. Small, low-input, family farms in the Western Highlands of Guatemala

3.2.1. Background

In contrast to the Yaqui Valley in Mexico, the people in the Western Highlands of Guatemala experience poorer health, more widespread and severe poverty, malnutrition, and fewer job opportunities as a result of historical policies, discrimination, and evolving agricultural economies and practices [Inner City Funds (ICF) International, 2014; Isakson, 2014]. Nearly half of all households in the Western Highlands live in extreme poverty, and 68 % of children under 5 years of age suffer from chronic malnutrition (Government of Guatemala, 2017), with 77 % showing signs of moderate to severe stunting (ICF International Inc, 2014). Overall, 40 % of Guatemalan's live with notable food insecurity, and by March 2020, 15 % of the population was considered to be in crisis and emergency conditions (Government of Guatemala, 2020b).

For centuries, agriculture in the Western Highlands of Guatemala has been based on traditional *milpa* systems that consist of small agricultural plots of maize mixed with climbing beans, squash, and other crops (Fig. 4). Crop options are often limited by microclimates and cold temperatures at higher elevations. In *milpa* systems, maize typically provides the structure upon which beans climb, and beans both enrich the soils and diet of the local people. A mixture of other crops blanket soils, decreasing opportunities for weeds, erosion, and water losses through run-off and evaporation. Chemicals are rarely used in *milpa* systems, and labor exchanges among members of the communities are common. Minimal mechanization on the farms is a result of topography and size of fields as well as cultural practices, poverty, and isolation due to poor communications and road infrastructure.

Different from the *milpa* system, an increasing amount of land is being contracted or rented for non-traditional export crops (NTEC). NTEC are typically grown in monocultures for commercial sale, with inputs such as seeds, herbicides, fertilizers, and pesticides often included as part of the out-grower contract. Although margins are typically slim, growing NTEC under contract reduces financial risk to small farmers since the inputs required for a successful harvest are provided by the buyer. Non-contract cash crops, such as potatoes (*Solanum tuberosum*), are risky for small farmers because there are few marketing options, prices for inputs and produce fluctuate widely, and there is great dependence on middlemen, who can take advantage of rural producers.

Mayans have cultivated steep Highland slopes for centuries and have largely retained traditional attire, crafts, markets, and customs. The region is characterized by alpine lakes and 34 volcanoes rising up to 4220 m, with farming communities being in a wide range of agroecological conditions and varying in elevation from 1800 to 3200 m. The rich volcanic soils are of sandy loam texture with the major biophysical constraints to yield being low available phosphorus (P) and low ratio of magnesium (Mg) to exchangeable potassium (K) (Matsumoto, Cifuentes, & Masunaga, 2013). The temperate climate can support a diversity of vegetables, but the rainy season is becoming less predictable.

The context for the Western Highlands of Guatemala is a complex mix of historical marginalization, political manipulation, conflict, rich soils, steep topography, cool climate, and diverse languages and ethnic identities. Mixed crop *milpa* systems supported Highland

Environmental conditions
- Steeply sloped, erodible, deep volcanic soils
- Formerly coniferous & mixed cloud forest, montane-alpine (elev. 2000 to >3000 m)
- Cultivated by Mayans for centuries

Climate
- Abundant rainfall
- Temperate seasons, high elevation, cool night
- Pests increasingly problematic
- Drought, flood, & hail

Agricultural practices
- Non-mechanized, traditional mixed 'milpa'
- Manure fertilizer, limited chemicals
- Milpa giving way to single corn crop or contract specialty crops (e.g. *Brassica oleracea*)
- Average field size: 0.4 ha

Economics
- Majority operate below subsistence level
- Limited market & employment opportunities

Social system
- Tradition of communal cooperation
- High out-migration from rural areas
- Unmet basic needs, malnutrition, stunting

Fig. 4. Characteristics of small, low-input, family farms in the Western Highlands of Guatemala (based on DeYoung et al., 2017 and Kline et al., 2020).

subsistence farming for centuries, but the capacity for *milpa* to feed families has declined as household plots become smaller, work opportunities become sparse, bean diseases become more common, men seek employment elsewhere, women often become the primary farmers, the diversity of plantings declines, nutrition declines, weather patterns becomes more erratic, and poverty is exacerbated (Kline, Ramirez, Sum, López Ridaura, & Dale, 2020). This bleak situation has forced many to leave the Highlands (Carte et al., 2019), and others who remain must rely increasing on external remittances or social assistance programs (Keller & Rouse, 2016; World Bank, 2020).

Climate change is increasingly cited as a contributor to crop failures, which exacerbate poverty and malnutrition in rural Guatemala (Castellanos, 2019). Nationally, nearly half of all children under 5 suffer from chronic malnutrition, but the rates exceed 75 % in rural Highland communities (Government of Guatemala, 2015). Increasing problems due to new pests, drought, flood, hail, and other extreme weather events are attributed to changing weather patterns and climate, making rainfall patterns less predictable, with prolonged dry spells punctuated by intense rainstorms (Castellanos, 2019).

Dismal food security associated with social inequities, high poverty, and changing weather in the Guatemalan Highlands is now accentuated by additional social and economic disruptions. The COVID-19 economic restrictions and United States (US) immigration policies have drastically reduced options for off-farm employment and foreign remittances, which have been key traditional coping mechanisms in times of household stress [US Agency for International Development Famine Early Warning Systems Network (USAID FEWS NET), 2020]. The Guatemalan Ministry of Health (Government of Guatemala, 2020a) reported an increase of 22 % in severe malnutrition among children under 5 years of age in 2019, compared to 2018, and noted that rates of extreme poverty were also on the rise. A 2019 survey conducted by the World Food Programme (WFP)also found that food insecurity was increasing, with 30 % of households in rural areas throughout Guatemala classified as food insecure, and 81 % nutritionally deficient (WFP 2020). A more recent survey estimated that 1 million Guatemalans were facing critical food insecurity by March 2020, and that number was expected to exceed 1.3 million, or about one-fifth of the national population, by July 2020 (Government of Guatemala, 2020b). By April 2020, reported cases of acute malnutrition were more than triple the average rate for April reported in the prior five years (USAID FEWS NET Guatemala, 2020).

Declines in farm output and increasing malnutrition in the Highlands are also abetted by the shrinking size of average small farm operations. As inherited land is subdivided among children, family plots have fallen to under a quarter hectare in size across many Highland communities, meaning less available food per household (DeYoung et al., 2017; Lopez-Ridaura et al., 2019). To meet basic needs, more than half of farm households in the Highlands must rely on other sources of food, off-farm income, or remittances from family members working in the US (Lopez-Ridaura et al., 2019). As men move elsewhere, more of the farm work becomes the responsibility of women (World Bank, 2019), who must attend to fields in addition to innumerous other duties to support their families. Hence, more plots are being simplified to grow only maize and the proportion of maize consumed increases as household income declines (ICF International Inc, 2014).

3.2.2. Application of approach to the Western Highlands of Guatemala

Our efforts to apply the assessment *approach* to the Western Highlands of Guatemala have focused on identifying the context, stakeholders, and major concerns. This information has been useful to specify goals and potential indicators for the region as well as next steps in the assessment. A summary of that work is provided here.

Major stakeholders in agricultural communities of the Western Highlands include farmers and their families, truckers, buyers, nongovernmental organizations (NGOs), government agencies, researchers, and representatives of the many bilateral and multilateral development assistance programs active in the region. Key stakeholders in the region are custom authorities, who are in charge of safeguarding the cultural and social customs and enforce natural resource management regulation. Crop merchants focus on specialty crops that are produced in monocultures, not *milpa* systems, and sold in local or national and international markets. Farm families commonly include relatives who are working in lowland coffee plantations or cities and those who have migrated to the US in search of employment. NGOs in the region actively support improvements in health, nutrition, education, economic, and social conditions; access to clean water; and agricultural practices. Government agencies monitor conditions and support improvements to social and economic conditions and to agricultural practices. Research scientists at universities and centers such as the Agricultural Science and Technology Institute (ICTA) are seeking ways to improve nutrition and health of the people by developing hybrid crop varieties suitable for this region and a large pallet of crop and livestock management improvements to increase productivity and resilience of agricultural production and conserve natural resources. Development agencies have long supported programs to promote child survival, improved nutrition, and social and economic development as well as the conservation of natural resources such as forests, soils, and water. Recent international aid has focused on social justice, education, and development of agricultural-export industries that promote non-traditional export crops (NTEC) for commercial farms growing monocultures rather than on the distinct needs of small, subsistence farmers.

Key goals for the Western Highlands are improvements in nutrition, poverty reduction, and secure, gainful employment as well as conservation of natural resources (forests, soils, and water). However even though Guatemala has committed to the United Nations' Sustainable Development Goals (SDGs), including targets to eradicate poverty and hunger by 2030 (United Nations, 2020), little progress has been made (United Nations, 2019). Supporting more sustainable agricultural landscapes in the Highlands is one part of achieving those goals (Kline et al., 2020).

Indicators appropriate for the Western Highlands include measures already endorsed by the Government of Guatemala (2015) and NGOs, such as Advancing Local Development through Empowerment and Action (ALDEA) (https://aledeaguatemala.org). These measures include monitoring the health of children; the communities' use of new hygiene techniques; knowledge of family planning, upkeep and proper usage of new infrastructure (e.g. water system, gray water filters, stoves, latrines); and the progress of women's and young people's involvement in community planning and decision-making. It is useful to also assess progress toward more sustainable agricultural intensification strategies, by monitoring land management and productivity, including the proportion of land and farmers employing diverse-crop *milpa* systems and improved, disease-resistant crop varieties, rather than monocultures of maize or NTEC.

3.2.3. Lessons learned about agricultural systems of the Western Highlands

A key lesson for the Highlands is that investments are needed to engage with *milpa* farmers to identify and implement improvements that are appropriate for their situation. Agricultural landscapes can be managed to better meet community needs depending on the availability of knowledge (e.g., how to optimize systems with mixed crops, agroforestry, small animal husbandry, etc.) and resources including improved seeds (with selection, reproduction, and distribution suited to local micro-climates), technical assistance, market intelligence, weather warning systems, and pest management. An adaptive management strategy requires long-term commitment to target and build the capacity of agricultural households managing small farm plots and to identify and apply appropriate practices in response to new circumstances and information. In this paradigm, agronomists, ecologists, sociologists, and economists work with local institutions, farmers, and community organizations to determine, test, and deploy innovations.

Building local capacity to revitalize, adapt, and strengthen *milpa* systems that provide sustenance with minimal demands on land and capital and using traditional knowledge and culture offers a lifeline for a majority of the poorest segments of agricultural Highland communities (Kline et al., 2020). Participation in programs to improve *milpa* systems enhances household food security and facilitates participation in other programs such as water purification and conservation, soil conservation, family poultry production, forest management, and cash crop production and commercialization. More investments that target yields and diversity of small farms are needed and should form a cornerstone for progress toward sustainable agricultural systems in the Highlands. Such capacity building could also be a strategic intervention to reduce migration from the region, as the Western Highlands of Guatemala are a major source of migration to US (Jordon, 2019; Strochlic, 2019).

While improvements to agricultural landscapes by development and adoption of more sustainable agricultural production systems, including *milpa*, can provide a foundation, other investments need to be added to successfully address the challenges of malnutrition and poverty in the Highlands. Institutions that provide health, education, security, democratic representation, communications, training, and other services must be strengthened to better serve the rural communities, support non-agricultural employment, and improve infrastructure that facilitate access to markets (Kline et al., 2020).

4. Key lessons regarding the approach

Initial steps toward applying the landscape assessment *approach* to farm systems in Mexico and Guatemala reveal attributes that are required for success and the means to achieve those attributes (Fig. 5). Our experiences applying this *approach* suggest that the success of efforts to support more sustainable landscapes depends on the conditions described below.

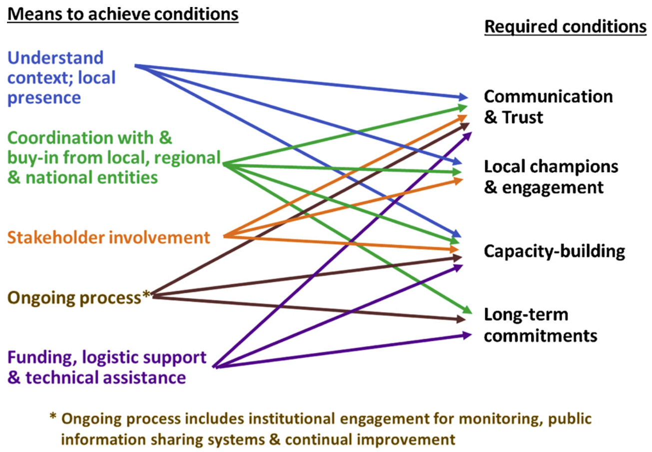

Fig. 5. The relationship between attributes that are required for success in applying the assessment approach and means to achieve those attributes.

4.1. *Local champions*

Having local champions for a project is critical to the success of the effort. These champions are people or institutions who are based in or close to the community; know the constraints and opportunities of the local situation; have a good working relationship with local people; and have the capacity to work with other local, regional, and national organizations. What is most important is a passion and commitment to achieve common goals for community improvement. Effective champions can be enabled through introductions (networking), training, and assistance to fill skill gaps and assure that they understand and can apply the *approach*.

4.2. *Transparency and trust*

Implementation of the *approach* must be in concert with local people and organizations as well as with regional and national policies and programs. Local contacts are necessary to build trust and to adapt the components of the *approach* to local circumstances including customs, crops, edaphic and climate conditions, markets, and available equipment and transportation. Coordination with regional and national policies and programs can provide additional staff and resources for project activities, integration with planning and options for continuation over a longer-term, opportunities to expand impacts via replication, and support for inclusion in ongoing monitoring and reporting on impacts. Effective engagement of people and organizations with wide-ranging interests is not a trivial endeavor and requires resources and skilled facilitation. Such outreach initiatives could benefit from the preparation of guidance on best practices for stakeholder engagement (Djenontin & Meadow, 2018; Fazey, 2004).

4.3. *Stakeholder engagement*

Identification and engagement of stakeholders are critical early steps in the *approach*. Therefore, stakeholder groups must be identified to include groups that are sometimes not a part of assessments, such as women, youths, indigenous people, absentee landowners, and people, organizations and places that perceive secondary effects. Special efforts are required to reach disenfranchised groups. For example, it may be necessary to provide transportation to attend meetings or to arrange additional meeting places and times that allow facilitators to meet with people and groups on their own turf.

4.4. *Iterative process*

Application of the *approach* is not meant to be a one-time effort but rather an ongoing process. Ideally, the iterative effort should be conducted with the aim of supporting adaptive management. That is, the components of the *approach*, including indicators and targets, are treated as hypotheses; information on changes over time is collected and evaluated as a means to measure progress toward sustainable landscapes; and changes in management practices and indicators are regularly and systematically reevaluated and adapted, as necessary, to optimize outcomes.

4.5. *Continual approvement*

Ideally, sources of future funding and logistic support for ongoing implementation of the *approach* should be in place. This support is ultimately achieved by building capacities of local community members and other stakeholders, so that they can apply, learn from, and continually improve resource management practices and the *approach* over time. Since this effort takes time, it is valuable to build alliances so that the *approach* is supported from the policy-making level down to the implementation level within government and non-government organizations. Whenever possible, these alliances should be reflected in staffing, technical implementation, and funding.

Local universities, extension agencies, municipalities, and community leaders play a crucial role in building local capacities for sustainability assessment and landscape analysis, planning, and implementation. Without some assurance that the evaluation and implementation of the process will continue over time, there is little confidence that this *approach* will lead to continual improvement, a cornerstone of sustainability.

5. Discussion

Much has been learned from working toward applying the *approach* to the two case studies. The applications show the importance of local champions, stakeholder engagement, transparency and trust, effective communication, timely monitoring, a long-term commitment, and continual improvement. Iterative application of the assessment *approach* builds capacity and promotes continual improvements in management practices, thus enabling timely responses to changing conditions while progressing toward locally defined goals for sustainable agricultural landscapes. Application of the *approach* to a new and different system would helpful to confirm or refute these results. However more work should also be done to complete application of the assessment approach to the two case studies.

5.1. Next steps and recommendations for applying approach to the Yaqui Valley

Planned next steps include follow-up with stakeholders regarding the selected indicators, what has been found to date, and possible revision of goals and indicators. Developing a collective understanding of the major forces influencing the agriculture landscape is an initial step in deploying a framework for assessing progress in any system. Our team and prior research have made major advancements in that regard. However, working toward more beneficial outcomes is an iterative process and requires ongoing efforts to engage local leaders and other stakeholders in identifying problems and solutions.

Furthermore, it is important to seek out additional information on those indicators for which data are not readily available. Indicators deemed important by stakeholders for which information is not readily available are water quality and quantity, climate impacts, air quality, human health, energy security, external trade, profits, fossil energy dependence, and conservation of nonrenewable resources (Eichler et al., 2020). It is critical to understand how these conditions affect poverty and nutrition. While some of this information is gathered and used by those agencies that collect the data, it is not readily accessible to stakeholders.

Implementing a more comprehensive monitoring program will require engagement of government agencies, NGOs, and others. While researchers can provide advice on useful steps, the leadership of data collection activities is most often done by government programs even though NGOs have taken on this role in some countries. Such a program involves collecting information as well as distributing it to all parties so that it can inform better management practices.

The future of the Yaqui Valley and its sustainability is uncertain and will depend on, among other external forces, the capacity of local stakeholders to tackle concerns related to the environmental impact of agricultural activities while maintaining high levels of productivity and profitability for farmers in the region. More rational use of inputs (e.g., fertilizers) and diversification of agricultural production might confer higher sustainability and resilience to the agricultural sector in the region. The *approach* presented here and the indicators selected for this region can serve as the basis for monitoring progress towards desired future states.

5.2. Next steps and recommendations for applying the approach to the Western Highlands of Guatemala

A critical next step for the Highlands is developing support for agricultural extension programs, local seed banks, cooperatives, and community-based entrepreneurs to generate, reproduce, and disseminate appropriate natural resource management practices for transitioning towards more sustainable landscapes. According to Hellin, Ratner, Meinzen-Dick, and Lopez-Ridaura (2018), grassroots efforts in collective action have shown efficacy for conflict prevention and improved social-ecological resilience in the western Highlands. These collective actions need to link local stakeholder dynamics with broader institutional and governance context to be successful.

Training and technical assistance programs need to be tailored to integrate with and support local traditions. For example, training and distribution of more resilient maize and bean seeds, adapted to local micro-climates and milpa systems, should build on existing extension programs and social networks in which families cooperate with neighbors in planting and harvesting. Basic infrastructure and extension agents, including women, who speak local Mayan dialects are needed to help apply new knowledge for increasing mixed-crop and crop-livestock system productivity while reducing risks, costs, and erosion of soil. Advancements in mixed cropping can build on traditional practices to improve *milpa* systems, nutrition, and employment options (DeYoung et al., 2017; International Maize and Wheat Improvement Center (CIMMYT) (2019)). For examples, (1) disease-resistant varieties of climbing beans have recently been developed that are suitable for small plots and cultural tastes in the Highlands (Moscoso, Agreda, Suchini, & Aguilar, 2019) and (2) research has shown how insect pests, such as the bean pod weevil (*Apion godmani*), can be managed with timely implementation of control measures. However, the seeds and skills required for successful adoption of these advances are not yet widely disseminated. Assistance programs in the Western Highlands could take advantage of these and other opportunities to better address the needs of small, low-input, family farms. Given the customs and valuable cultural heritage in the region, traditional indigenous practices must be understood and respected in order to succeed in adapting agricultural practices to improve environmental, social, and economic conditions.

Engagement with the local community in developing and implementing the next steps is critical. Proposed goals and indicators should be reviewed by local leaders, and their insights used to development improvements in agriculture practices and monitoring systems. Information about key indicators should be shared with stakeholders and values and trends should be communicated in a way that has meaning. The nongovernmental organization ALDEA had made progress in this regard by employing local promoters, women from the village selected by fellow community members to learn and convey knowledge of how practices can be improved.

The future of the western Highlands with regards to its agricultural production and natural resource management is critical for the development of the whole region as most people maintain their livelihood through small scale, mainly subsistence, agriculture. Different possible pathways for agricultural development can be envisaged and explored through the indicators identified with the *approach* presented here. Because of the limited land availability, a shift of agricultural production towards non-traditional export crops can be envisaged. Alternatively, strengthening the local maize-based systems and building upon traditional knowledge to fulfill basic needs of farm household and seeking alternative sources of income can also be a future reality. The *approach* presented here could be used to explore these alternative future scenarios and support local stakeholders in deciding the pathway they want to collectively follow considering the sustainability of the resource base (e.g., preventing soil erosion and deforestation) as well as the social and cultural values that characterizes the identity of the region.

6. Conclusion

Attempting to apply the assessment *approach* to two contrasting agricultural landscapes in northwestern Mexico and the Western Highlands of Guatemala reveals both difficulties and benefits. Collecting reliable data on practical indicators and effectively communicating implications of data analysis to guide decisions over time are major challenges to implementing the *approach* and require long-term commitments of time and resources. Much time and effort are required to build trust, engage diverse stakeholders, apply the *approach*, communicate what has been learned and what additional information is required, and use that information to build capacity to improve conditions. All of the components are needed to address the challenges of alleviating poverty, improving human health, and addressing climate change. Our modest attempt to apply the assessment *approach* to the two case studies show that it was not possible to systematically move through all the steps within our limited time and budget. We found that identifying practical indicators is relatively easy compared to monitoring, measuring change, interpreting, and communicating results to guide behaviors. However rapid appraisal is a useful way to quantify trends based on existing data, identify data gaps, and prioritize protocols for gathering data that can inform key indicators (Eichler et al., 2020). Reality is a special case, and application of the *approach* can encounter unforeseen obstacles such as sudden project terminations, travel prohibitions, or security concerns.

Nevertheless, the experience of attempting to apply the *approach* is useful. Setting goals, selecting indicators, active monitoring, evaluation, and identification of opportunities to improve resource management practices are all steps that can produce new insights and, sometimes, unexpected results. Advances can inform several of the steps in the assessment process, and new information may require revision of goals, selected indicators, and practices. Hence flexibility while remaining true to an iterative process are required. In the same sense that sustainability is aspirational, best practices are as well. Employing a process that helps stakeholders identify and seek improvements in practices that impact their lives puts the tools in the hands of those who can best apply them to improve outcomes to address the specific needs and opportunities presented by their agricultural landscape. Such a perspective is important in these agricultural landscapes where farm activities affect and are affected by human and environmental health, incomes, and climate change.

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