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Collective natural resource management in agroecology

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1 Introduction

Water resource depletion, rangeland degradation, and biodiversity loss are just some of the trends undermining the sustainability of agricultural systems. The challenge of reversing these trends through agroecology initiatives is daunting because many of the natural resources involved are held in common among diverse stakeholders with differing goals and constraints. Like public goods, these "common pool" resources (CPRs) are accessible to all stakeholders, i.e. nonexcludable. However, their use or appropriation by one person can deplete the quantity, degrade quality, and otherwise create conflicts for others, i.e. subtractability. As such, they are a hybrid between a public and private good (Fig. 1). Due to their open access and rival or competitive character among users, congestion and exhaustion are possible, posing complex management challenges. Over-drafting and declining levels of the Ogallala aquifer, which crosses eight U.S. state boundaries, is a classic example of the risks.

Interest in more effective CPR management also has been spurred by recognition that unsustainable agricultural practices are exacting major impacts on other ecosystem services, including achieving a stable climate. Innovating

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		SUBTRACTABILITY	
		Low	*High*
EXCLUSION	*Difficult*	**Public goods** Useful knowledge Sunsets	**Common-pool resources** Libraries Irrigation systems
	Easy	**Toll or club goods** Journal subscriptions Day-care centers	**Private goods** Personal computers Doughnuts

Figure 1 Types of goods. Source: Hess & Ostrom (2007).

collective governance regimes for common resources has been identified as a key policy challenge for advancing agroecology (Barrios et al., 2020). Scientists have long recognized that CPR resources can suffer exploitation and diminished capacity, even exhaustion in some cases, prompting the infamous "tragedy of the commons" characterization (Hardin, 1968). However, the agroecology literature has given scant attention to the challenges posed by CPRs, especially the social science theory and evidence needed to inform effective management (Galt et al., 2024). Here we attempt to start filling that knowledge gap by examining CPRs that serve agriculture to inform the policy and practice of agroecological applications.

This chapter's central premise is that making progress toward sustainable agriculture through agroecological initiatives will require improved management of CPR vital to long-run production. Building off of Elinor Ostrom's Nobel Prize-winning scholarship (Ostrom, 2009), that progress will require substantial investments in human capacities and social institutions, training farmers to be natural resource champions and effective group facilitators, and investing in private and public institutions that can sustain CPR (Dentzman, 2022) Given diverse natural resource situations across regions, management approaches must be tailored to specific resource characteristics and socioecological conditions to be effective. Research has shown that voluntary, community-based approaches may be most feasible for common resources of moderate size for which local members incur lower costs of organization and can monitor resource use and implement effective enforcement (Chhatre and Agarawal, 2008; Ostrom, 2009).

Importantly, many of the successful bottom-up efforts in other sectors have been composed of private and public collaborations for polycentric governance of the commons (Ostrom, 2010). It is possible that new collective resource management models will emerge and scale up as agroecology-based efforts spread. Doing so could harness the power of farmers and the businesses on which they depend to improve not only the environmental capacity on which their operations depend, but also enhance the socioeconomic welfare of their communities. Bottom line: Understanding the potential and the limitations of participatory, democratic approaches in diverse socioecological settings is necessary to design and implement effective collective commons management for agriculture.

Lessons from theory and applications also suggest that a transdisciplinary (convergence) approach to collective natural resource management will improve the chances of success. The National Science Foundation and National Academy of Sciences have endorsed convergence frameworks for tackling complex sustainability challenges (NSF, 2024, NAS, 2014).

> A distinct characteristic of convergence research, in contrast to other forms of multidisciplinary research, is that from the inception, the convergence paradigm intentionally brings together intellectually diverse researchers and stakeholders to frame the research questions, adopt common frameworks for addressing them, and create and implement innovative scientific approaches for their solution.
>
> (NSF, 2024)

Early and continuing engagement of private and public stakeholders with natural and social scientists, therefore, is crucial to frame the problem and chart a productive path for agroecology-based initiatives. Implementing this more inclusive approach will require new research, education, and professional training programs that facilitate collaborative resource management systems (Shaw et al., 2023). Future research and education priorities to support the transformation to convergence approaches are identified in this chapter. Resources for applying CPR theory and management in food systems are given at the close.

2 Sustainability science and commons management

The concept of sustainable development was popularized in 1987 by the World Commission on Environment and Development (WCED) in its publication "Our Common Future":

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
>
> (Brundtland, 1987, p 1).

The goal of assuring non-declining well-being reflected the WCED's concern that current users were bequeathing lower quantities and qualities of natural resources for future generations. Many natural assets of high concern were common resources, such as exhaustible water resources and mineral stocks, assimilative atmospheric conditions, and biological populations.

The quest for a more sustainable agriculture and responsible resource management of the commons entered public discourse before the WCED report (Carson, 2000; Jackson, 1980; Rodale, 1983). Early discussions revolved around concerns with emergent farm models using larger and larger machinery complements to grow a limited number of major crops, e.g. corn, soybeans, wheat, and cotton, that relied heavily on off-farm chemical fertilizers and pesticides. These production operations were perceived as overly dependent on nonrenewable inputs, e.g. fossil fuels, and lacked enterprise diversity, e.g. animal husbandry, which expose farmers to financial and ecological risks. By concentrating on just a few major crops, for example, the farm operations were less resilient to invasive pest outbreaks and other environmental effects, e.g. climate disruption such as drought and floods. The negative impacts of larger farms on biodiversity were also a concern.

Although powerful in its simplicity, the WCED concept of sustainable development left a number of critical aspects and questions unaddressed, in particular the specific capacities and constructive approaches to achieve progress. Scholars in the natural and social sciences developed a wealth of literature on these needs. Clark and Harley (2020) synthesized the diverse approaches researchers have used to address the bold challenges of sustainable development. Their integrated analytical framework for sustainability science characterizes nature-society interactions as ". . . a globally interconnected, complex adaptive system in which heterogeneity, nonlinearity, and innovation play formative roles (Clark and Harley, 2020, p.331)." They identify six capacities that are crucial in advancing progress on sustainable development:

(1) Measure sustainable development.
(2) Promote equity.
(3) Adapt to shocks and surprises.
(4) Transform the system into more sustainable development pathways.
(5) Link knowledge with action.
(6) Devise governance arrangements that allow people to work together in exercising the other capacities.

(Clark and Harley, 2020, p.331)

An implication of this work is that the pursuit of sustainable agriculture under agroecological principles must move forward with all six capacities. Clark and Harley (2020, p. 338) explain that governance encompasses three major elements and relationships: (a) actors; (b) institutions; and (c) power. Barrios et al. (2020) in their review of agroecology principal components discuss each element in making progress on transitions to sustainable agriculture and food systems. The sixth capacity of building governance arrangements that facilitate people working together has direct relevance to forming bottom-up collective

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organizations to manage the resource commons for sustainable agricultural development.

3 Common pool resource theory

Common pool resources are natural or manmade resource systems from which users can extract resource units (RUs) without paying an access price or fee. The CPR stock is depletable and can be exhausted if the extracted flows exceed the regenerative capacity. As noted in the introduction, CPRs have two distinguishing characteristics: (1) their size or characteristics make it difficult and costly, though not impossible, to exclude potential users (i.e. nonexcludable); (2) their supply is subject to depletion (i.e. rivalry); one person's use precludes others from using the same RU. Unregulated surface and groundwater resources are quintessential examples for agriculture.

Appropriators of CPR resources, such as fishermen working ocean fisheries, have little or no incentive to conserve stocks for future use if others can consume them without paying the costs of degradation and replacement. To avoid a spiral of resource decline, some scientists originally argued that public coercion (regulation) is needed to ration use and correct for the lack of incentives and other barriers that stymie individual conservation efforts (e.g. Hardin, 1968).

A group of social scientists subsequently questioned whether top-down regulation is always necessary or prudent to sustain CPR. They documented numerous situations around the globe in which communities of stakeholders had voluntarily collaborated in bottom-up community-based programs to avert overexploitation and avoid situations in which government programs perform poorly (Ostrom, 1990). This bottom-up approach holds special appeal in agriculture, where public regulation is an anathema to many U.S. farmland managers. The New England lobster fishermen's collective efforts to limit harvests and sustain populations is an example of successful bottom-up community action (Wilson, Yan and Wilson, 2007). At larger scales, certification systems, such as the Leadership in Energy and Environmental Design (LEED) program in green buildings and the International Federation of Organic Agriculture Movements (IFOAM), have flourished from privately led collective actions with public collaborations to address looming CPR sustainability issues, such as climate change. Such collective schemes are most likely to form under certain socioecological conditions as discussed (Ostrom, 2009).

The lack of control by government or private organizations to avoid CPR depletion and possible exhaustion can be rooted in various factors: cultural values of resource sharing, high administrative costs and/or infeasibility of technology to monitor use and users, weak governance institutions, or some combination of each. An example of government program failure is the continuing decline of the endangered northern spotted owl populations in the Pacific Northwest despite banning old growth timber harvests, important habitat for the owl (Franklin et al., 2021). An example of privatization to protect a commons resource is the advent of crop seed patents in the U.S. and other countries (Partelow et al., 2019). While such patents have enabled investment by private companies to develop new seeds, especially through genetic engineering, they have also curtailed seed saving and experimentation by farmers that traditionally augmented the pool and diversity of natural germplasm available for crop improvement. A quantitative study of 11 million patent documents from the U.S., Europe, and the International Patent Cooperation Treaty from 1976 to 2010 concluded that patent activity in a host of fields, including food, focused on approximately only 4% of taxonomically described species and 0.8–1% of predicted global species (Oldham, Hall, and Forero, 2013). The authors conclude that such a narrow focus on innovation and ownership of genetic resources will unlikely be in the long-term interest of humanity and that a broader spectrum of biodiversity needs to be opened up to address climate change and other global commons challenges.

Despite serious challenges, collective approaches can emerge to sustain commons resources. For example, indigenous Afro-alpine lands in Ethiopia have been managed by local communities to regulate the collection of firewood and grazing to assure appropriation of the resources is kept below levels that jeopardize the sustainability of ecosystem services (Ashenafi and Leader-Williams, 2005). Agrarian reforms to Ethiopia's land tenure and rights system in 1975 have exerted pressure on the community-based collective system, but it remains resilient:

> Nevertheless, the common property management system has shown sufficient resilience to withstand these changes and pressures, and is still functioning with defined user groups and byelaws to regulate resource use and manage the area.
> (Ashenafi and Leader-Williams, 2005, p.539)

Figure 2 shows recent pictures of the Afro-alpine landscape cover and challenging soil erosion conditions therein (Woldesenbet et al., 2020).

The combination of open access with a depletable supply sets up a prisoner's dilemma game in which users can either act only in their self-interest or cooperate to conserve the resource. Consider the simple case of two users who do not communicate before making resource use decisions. Assuming no communication and cooperation, if one decides to forgo resource use in a particular period to conserve the stock for more valuable future use, the other user, acting independently, could consume the saved RU and cancel the first user's forbearance. Logic and considerable scientific evidence show that communication and cooperation often lead to an outcome that is optimal

Figure 2 Field photos of the Afro-alpine. Source: Woldesenbet et al. (2020).

for both parties over not cooperating. For example, scientists have studied the mechanisms at work in natural selection among populations and found, "Contrary to common belief, our results reveal that cooperation can emerge among selfish individuals because of selfishness itself: if the final reward for being part of a society is sufficiently appealing, players spontaneously decide to cooperate (Bravetti and Padilla, 2018, p. 1)." Reinforcing this finding, Schlager (2002) notes "Contrary to the predictions of the bio-economic model, if given the opportunity to communicate, individuals attempt to devise rules and coordinate their actions to resolve appropriation externalities (pp. 805–806)."

3.1 *Examples of common pool resources vital to agricultural systems*

Diverse CPRs underpin agriculture, including those in climatological, ecological, social, and technological systems. Climatological conditions that provide adequate moisture, non-extreme temperatures, and other stable weather conditions are fundamental to sustaining crop and animal production. Crop pollination services often hinge on native bee populations as a keystone species and butterflies. Other biological commons resources include indigenous plant seed banks that may provide resilience to climate change impacts and other conservation services, e.g. resistance to harmful nonindigenous pests (Vernooy et al., 2017). Similarly, animal species gene pools can provide protection from disease infections and rising climate stress. Researchers have categorized weed gene pools susceptible to safe herbicide treatments as a valuable CPR for agriculture (Ervin et al., 2018). A final biological CPR category may be the soil biota that play instrumental roles in achieving soil quality conditions for crop productivity. Shared surface and groundwater resources used to support crop and animal agriculture are, of course, critical CPR for sustaining production, especially in areas where climate change leads to warmer and drier conditions.

Common pool resources are not confined to biological, atmospheric, hydrological, or physical resources. Social institutions also can be common resources if potential users have open access to their services without fees and are rival in terms of one person's use subtracting from the resource quantity or quality available to others, e.g. due to congestion. In the U.S., public and nonprofit private institutions have provided information, technology, and advisory services on managing agricultural systems for productivity and resource conservation to potential users without access fees. As long as the free services remain available to all without diminishment, then they are public goods (Fig. 1). Traditional examples of such socio-cultural common resources include the U.S. Extension Service, public agricultural research and education institutions and their libraries, government conservation services, and private philanthropic organizations, such as the Ellen MacArthur and Rockefeller foundations. However, if the consumption of those resources becomes congested or rival to some potential users because of insufficient capacity to deliver them, e.g. insufficient Extension Service personnel in a region, they become CPRs. Hess and Ostrom (2007) discuss novel collaborations that have emerged in science and education circles, e.g. open access journal articles, to ensure broad access to users. Note that private for-profit organizations are not included in this list as their advice and technical assistance services are generally excludable based on paying a price or access fee. However, some for-profit companies are providing free information and assistance to their

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suppliers to encourage their transition to agroecological systems because of customer interest in products with lower environmental and social footprints. An example is New Seasons food stores in Oregon and Washington that serve customers in the U.S. Pacific Northwest states (https://www.newseasonsmarket.com/purpose/regenerative-agriculture).

3.2 Managing and conserving common pool resources

Three general approaches can be used to manage CPR (Ervin and Frisvold, 2016):

1. Top-down government regulation.
2. Government or private financial schemes, e.g. subsidies or payments to sustain common resource stocks and flows.
3. Community-based collective programs.

This chapter focuses on the bottom-up community-based approach. However, one or more of the other approaches are often used to supplement or complement the collective effort to enable effective provisioning, e.g. government technical assistance, regulation or payments to increase CPR program participation for scale economies. For example, Maine lobster fishermen collaborated with government agencies to establish regulations that deterred overharvesting and enabled population recovery (Dietz et al, 2003). As emphasized earlier, the socially preferred and most effective approach depends on the socioecological conditions that surround the CPR, as selected cases reviewed attest (Ostrom, 2009).

Garrett Hardin in his seminal article on “tragedy of the commons” concerning the global overpopulation problem suggested “mutual coercion mutually agreed upon” as a potential approach for CPR management (Hardin, 1968, p. 1247). Many readers interpreted his argument as suggesting government regulation or privatization to avert resource degradation and exhaustion. It’s worth noting, however, that Hardin did not use the word “regulation” in his famous essay.

Elinor Ostrom, co-recipient of the 2009 Nobel Economics Prize, theorized that some CPR situations can avert the tragedy of CPR overuse without resorting to government regulation (Ostrom, 1990; Ostrom, 2009). Working with colleagues in the Workshop in Political Theory and Policy Analysis at Indiana University, social scientists used multiple methods to develop a general theory of CPR management (Ostrom, Gardner and Walker 1994). They empirically tested the theoretical propositions with case data from around the world to develop rules and implications for sustainable community-based resource management. As noted, generalizations about the implementation of

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such schemes are difficult as the most effective approach will depend on the socioecological conditions that govern access to and use of a particular CPR.

3.3 Pursuing collective bottom-up common pool resource approaches

Socioecological research has distilled key design principles for effective participatory democratic approaches to CPR management and the factors likely to stimulate stakeholder participation. Ostrom made two fundamental contributions to understanding the potential and limitations of collective community-based CPR management. In the first body of work, she analyzed the long enduring mountain commons systems in Switzerland and Japan and irrigation commons systems of Spain and the Philippines to identify eight design "principles" that characterize stable local systems (Ostrom 1990; Ostrom et al 2012). Summarized here, Ervin and Frisvold (2016, pp. 614–615) explain how each principle can be critical to building successful community-based collective (CBC) programs for pesticide resistance management.

1 Establish clearly defined boundaries. Implementing this principle requires the definition of two types of boundaries: (1) the geographic area to be governed by the CPR effort, and (2) the parties within the boundary who must be engaged (Cox et al., 2010). If the boundaries cannot be identified with acceptable confidence, then sufficient participation and assurance may not be achieved, and the CBC approach will be problematic.
2 Develop congruence between the appropriation and provision rules for the CPR that are adapted to local conditions. This principle also has two dimensions: the first is that appropriation and provision rules conform to local social and environmental conditions, and the second that appropriation and provision rules are in alignment (Cox et al., 2010). Following the first utilizes the local knowledge and experience of farmers who understand the biophysical and social intricacies of community resource management.
3 The second dimension involves achieving proportionality between the inputs of labor, material, or money provided and the benefits they receive from participation in the CBC action.
4 Implement collective-choice arrangements that allow most resource users to participate in the decision-making process. Following this principle empowers resource users to participate in the CPR decision process and takes advantage of the local knowledge of the special resource and social conditions. In general, their knowledge and experience provide lower-cost information to administer the system

of controlling resource access. While this principle is good in concept, the intent can be thwarted by an uneven distribution of local power or external actors who perceive gains from promoting particular practices.

5 Conduct effective monitoring by those who are part of or accountable to the CPR appropriators. This principle has two components: (1) monitors must be appointed by the CBC effort, and (2) monitors must be part of the community and accountable to the full set of appropriators (Cox et al., 2010). Following this principle makes monitoring an integral part of managing the CPR and engages those who have extensive knowledge of the resource situation, higher efficacy, and generally lower costs than if by an external party (e.g. local, state, or federal agency). Monitors should benefit (either by improved resource condition or other rewards) if they perform satisfactorily (i.e. monitoring is incentive-compatible). Finally, the monitoring system performs two key functions: (1) identify resource appropriators not in compliance, and (2) collect information on the condition of the CPR.

6 Institute a scale of graduated sanctions for CPR appropriators who violate community rules. This principle of imposing sanctions on resource appropriators who do not comply with the rules on CPR use is critical to success. Without a credible threat of the sanctions, experience shows that some portion of the appropriators will not comply (Ostrom et al., 2012). Social cohesion of the group is insufficient. Sanctions for noncompliance should be visible and significant, inducing a higher level of program participation. Imposing graduated penalties sends a signal to resource appropriators that larger departures impose proportionately higher costs on other resource users. The body responsible for administering the sanctions can be within the private community-based organization or codified in legislation and administered by a public agency.

7 Create mechanisms of conflict resolution that are inexpensive and easily accessible. Conflicts between CPR appropriators are inevitable. Access to cheap and easy conflict resolution procedures at the local level enhances the probability of decentralized solutions to CPR management problems, rather than elevating dispute resolution to higher and more distant bodies. The specific form and level of the conflict-resolution mechanism depend on the socioecological conditions of the CPR.

8 Higher level authorities recognize self-determination of the community. To implement effective community-based efforts for managing CPR issues, local and state laws must grant the rights to private nongovernmental organizations to be free from challenge by external parties. This certainty is necessary to foster long-term planning and vests the community participants with ownership of the issue. It also conveys

tenure security to the resource appropriators, a condition that promotes long-term investment from a longer planning horizon.

9 For larger CPRs, organization in the form of multiple layers of nested (polycentric) enterprises could be required (Ostrom, 2010). When CPR issues are large enough to span multiple jurisdictional boundaries, e.g. carbon capture and storage, single local CBC initiatives might be insufficient to exercise sufficient control over resource appropriation. This does not mean that local efforts would not be part of an effective solution. Rather, other entities at distant points or at higher levels of administration could be required to assure sufficient coordination and effective action to conserve the CPR. Such an approach can be thought of as nested or polycentric governance, and the nesting can run either in horizontal or vertical directions.

A visual picture of the roles and interactions of key principles arrows to governance requirements conveys the struggles and complexity of CPR management (Fig. 3).

Agrawal (2003) critiqued Ostrom's synthesis in that the implied cause-and-effect relationships are not as robust as the principles imply. He argued, for example, that smaller groups do not always form CBC programs that

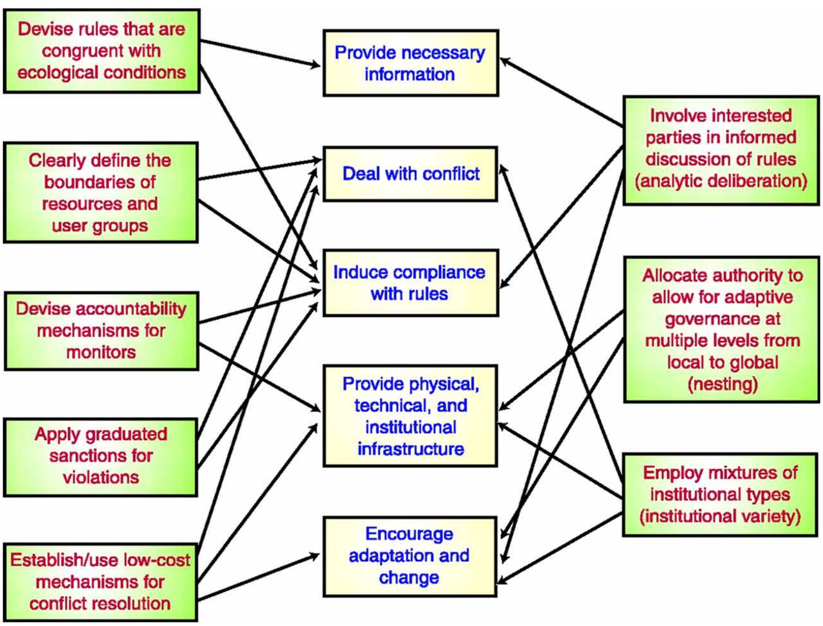

Figure 3 Roles of design principles (green) and governance requirements (yellow) in CPR management. Source: Dietz et al., 2003

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are more effective, even though transaction costs likely are lower. Further, increased group heterogeneity does not necessarily impede collaboration. He notes several cautions about using the principles: (1) monitoring and enforcement are still needed and possibly could be costly (institutional capacity and resources to monitor and enforce might be limited); (2) co-management with government entities might give local communities only very limited scope for decision and rule-making; (3) locally agreed-upon rules can be essentially nonbinding constraints and amount to insufficient action; (4) boundaries of resource management problems can be unclear; and (5) identifying noncompliance is difficult. Agrawal (2003, p.248) argues that Ostrom's and other analyses of successful commons management pay little attention to how resource features affect sustainable governance and incompletely address social, political-institutional, and physical environment influences.

Other scientists have found support for the principles by empirically analyzing CPR programs. Cox et al. (2010) assessed the performance of 91 programs to evaluate the statistical support for each principle. Their overarching finding was that each principle was well-supported empirically. They recommended, however, that three of the principles (1, 2, and 4) be split into two components to improve analytical power and insight. Although this meta-analysis provides a measure of confidence for using the principles to inform CPR programs in furthering agroecological food systems and sustainability, careful analysis is necessary to assure their application will be successful. Cox et al. (2010) conclude that three main critiques of the principles are valid: (1) they are incomplete; (2) they might not apply to a wide range of cases beyond those used to develop the principles; and (3) the principles do not capture the heterogeneity and messiness of environmentally and socially embedded CPR situations.

In a subsequent body of work, Ostrom identified ten factors that significantly affect the likelihood of CPR stakeholders to self-organize for collective action (Ostrom 2009). Ervin and Frisvold (2016) relate these factors to possible community-based herbicide resistance management programs.

1 Size of the CPR system. Very large systems are unlikely to self-organize because of the high cost of defining boundaries, monitoring, and assembling ecological knowledge. Small systems might not produce enough valuable services to induce action. For these reasons, moderately sized systems are most conducive to self-organization.
2 Productivity of resource system. There is an inverted U-shaped relationship between resource productivity and self-organization. If a resource is either abundant or already exhausted, users perceive few

incentives to pursue collective action for conservation. Some scarcity (value) is necessary to induce their efforts.

3 Predictability of system dynamics. CPR system dynamics must be understood so that the effects of management actions on the resource can be accurately predicted. Unpredictability can deter users from self-organization due to a lack of certainty about the dynamics of use patterns, depletion, and recovery.
4 Resource unit mobility. Self-organization is less likely for highly mobile resources, such as wildlife or water in an unregulated river, that range over great distances. More mobility requires covering a larger geographic area and more cost to administer the CPR management regime.
5 Number of users. Larger groups of CPR users have higher costs to organize, but also can assemble labor and other resources to cover administration, monitoring, and other costs. The effect of group size on self-organization depends on the particular socioecological system and is indeterminate a priori.
6 Leadership. When some CPR stakeholders have entrepreneurial skills and enjoy the respect of others, the likelihood of collective action increases. For example, the presence of local elders and college graduates in the system can exert positive effects.
7 Norms/social capital. Users of resource systems who share moral and ethical standards of group behavior, including the norms of reciprocity and trust, have lower transaction costs in reaching agreement and are more likely to self-organize and carry out effective monitoring.
8 Knowledge of the socioecological system. When users share common knowledge of the resource system – its vulnerabilities to excessive use, how their actions affect each other, and the rules used in other systems – they perceive lower costs of organizing. If knowledge of regenerating the resource system is lacking, degradation risks rise.
9 Importance of the CPR to users. If the resource plays a significant role in the welfare of users, they are more likely to perceive that the gains from collective action to conserve the resource will outweigh the costs of organizing and maintaining.
10 Collective choice (governance) rules. If users have full authority and autonomy to take collective action to develop and enforce rules, they face lower transaction costs of organizing and less expense in implementing controls to defend the resource from external parties.

Ostrom (2009) emphasizes that the relative strength of an individual factor on the likelihood of self-organization depends on the values of other variables.

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The interaction effects between variables are often nonlinear and difficult to tease apart as Clark and Harley (2020) argue. These observations reinforce that bottom-up collective efforts to manage CPR depend upon the particular socioecological situation in which the stakeholders reside and will likely require adaptive management to iterate to an effective and sustainable program (Dentzman, Espig and Graham, 2025; Ervin and Jussaume, 2014).

Ostrom's CPR theory contributions and design principles have been adopted by rural development institutions ranging from the United Nations and World Bank to numerous NGOs. However, the promise of the bottom-up community-based projects has not always been matched by results on the ground. Saunders (2014) offered a critical appraisal of CPR theory and conditions that have limited its impacts:

> The paper argues that the individual 'rational resource user', encapsulated in the CPR design principles, struggles to provide clear direction for meaningful consideration of local norms, values and interests in commons projects. The focus of CPR theory on efficiency and functionality results in a tendency in commons projects to overlook how local conditions are forged through relations at multiple scales. Commonly politically complex and changing relations are reduced to institutional design problems based on deriving the incentives and disincentives of 'rational resource users'. The corollary is that CPR theory oversimplifies the project context that it is seeking to change because it offers little or no direction to deal with the social embeddedness of resource use or implications of different stratifications.
>
> (Saunders, 2014, p. 636)

This caution and Agrawal's (2003) arguments re-emphasize the importance of understanding the detailed socioecological conditions that impinge on the CPR situation before attempting an application. In a similar vein, Dentzman, Espig and Graham (2025) stress that the crux of pesticide resistance management is context; variations in socioecological conditions matter. Bergmann et al. (2024) note the difficulties experienced in implementing sustainable community-based herbicide resistance programs. The authors argue that other approaches such as the co-production of knowledge between scientists and stakeholders and participatory action research may help gain an improved understanding of the commons resource to be governed.

4 Collective natural resource management: case studies in agriculture

Case studies of commons-based management projects are notable for their sheer number and diversity. Smaller-scale projects, addressing both resource conservation goals and economic development, have been popular in developing countries (Saunders, 2014). Many other case studies have dealt with fishery and forestry commons. Three studies related to agriculture are summarized to demonstrate such diversity in applications as well as factors affecting their advantages and limitations.

4.1 Irrigation systems

Ostrom and colleagues in the workshop in Political Theory and Policy Analysis at Indiana University conducted a meta-analysis of 47 bottom-up CPR cases comparing collectively managed and government-installed irrigation systems. Tang (1994) reported that while 72% of irrigator-owned systems performed well, only 43% of government-owned systems did. The significant difference was attributed to irrigator-owned systems having water allocation rules and maintenance systems better crafted to the specific environmental conditions (e.g. rainfall amounts/distribution, topography) and social context (e.g. crops grown, labor requirements, benefits to individual farmers) of each irrigation system, whereas those that performed poorly had rules that did not reflect the particular situation or no rules were adopted (Tang, 1994). Specifically, the farmer-owned irrigation systems were more likely to have a variety of access and allocation rules informed by variation within the watershed whereas the low-performing government-owned systems were more likely to use a single rule, regardless of the socioecological conditions, or no rule to limit access and to allocate water (Tang, 1994, p. 236). This finding supports the argument that compared to top-down management, community-based CPR management systems can more effectively tailor management rules to fit the specific socioecological system conditions.

A specific case study comparing these two types of irrigation systems in Nepali rice-growing watersheds illustrates the importance of specific socioecological context in CPR management (Fig. 4). The analysis found that farmer-managed irrigation systems performed significantly better than government-managed irrigation systems installed through a top-down process that did not engage farmers (Lam, 1996, 1998). This was a surprise because the farmer-managed systems used earthen dams and unlined irrigation ditches, which require more labor and are less efficient in retaining water (Fig. 5). In contrast, the government-installed dams and irrigation ditches were made of concrete, which lose less water during transport and require less labor to maintain.

In the farmer-managed systems, farmers had a deeper understanding of the irrigation system, significantly higher levels of mutual trust, greater water use efficiency, and higher crop production (Lam, 1996; Lam, 1998, pp. 126–133). This understanding is important because farmers near the headwaters have access to the water resource first, but managing the irrigation infrastructure at these higher elevations requires more labor. Meanwhile, if these farmers withdraw too much water, farmers located farther down the watershed may end up with limited access; however, the infrastructure in the lower part of the watershed

Figure 4 Farmer-managed irrigation systems in Nepal. Source: https://prachandashare.wordpress.com/2004/07/15/farmer-managed-irrigation-systems-in-nepal-challenges-and-responses-2/

Figure 5 Unlined irrigation ditches for Nepal rice growing; 9 April 2014 FMIST Nepal.

requires less labor to maintain. Better water management in farmer-managed watersheds was achieved through community governance agreements that recognized the interdependence of farmers with varying levels of access and labor requirements and included effective monitoring and sanctions for rule violations. This system of community governance and incentives for water stewardship contrasts with top-down, government-managed systems. Indeed, government-sponsored infrastructure projects in Nepal were more effective at improving production when farmers were engaged as collaborators and contributed to the design and management of the improved irrigation systems (Lam, 1996). Schalger (2002, p. 811) clarifies that governments can play a constructive role in CPR management, but structuring the roles, including support and collaboration with private stakeholders, requires careful consideration of the specific socioecological context of resource management in question.

4.2 Pest management

Pest control is another agricultural activity that has experienced CPR challenges and opportunities. The pool of genes in a pest population susceptible to treatments, chemical, e.g. herbicide, or non-chemical, e.g. mechanical, can be viewed as a CPR (Ervin et al., 2018; Gould et al 2018; Hennessy and Jia, 2024). Bergmann et al (2024, p.119) clarify that the CPR in this case, i.e. susceptible weed gene pool, is a function of both human actions, such as herbicide applications, and natural biological processes. If pests are mobile across landscapes, the pest gene pool resultant from natural processes and treatments is available to all appropriators in a region and effectively nonexcludable. Further, the RU of concern such as the evolution of resistance in the gene pool from increased treatment and selection pressure is rival. That is, once resistant pests develop in a population due to treatment pressure or natural pest population dynamics, they deplete the proportion (pool) of the pest genetic material that is susceptible to effective treatment (Ervin and Frisvold, 2016).

Community-based pest resistance control programs are still experimental. An early study in the Pacific Northwest, Dentzman and Burke (2021), used focus groups and survey data to analyze how farm operators view tillage as a treatment to offset the loss of effective herbicides due to resistance. They concluded that many farmers view tillage as an emergency fail-safe mechanism to manage weeds, that tillage use can be partly explained by the operator’s experience with and dedication to tillage, and that community management has the potential to provide the support and resources necessary to prevent a large-scale increase in tillage to manage the evolution. Whether the last finding foretells an effective CPR program remains an open question and awaits future collective action by the communities of growers. Multidimensional ecological strategies can alleviate heavy dependence on tillage intensification to battle resistance, but socioeconomic barriers often stymie their application (Liebman and Gallandt, 1997).

A complex case supporting the potential of hybrid CPR management comes from a pest eradication program in the U.S. southwestern states of California, Arizona, New Mexico, and Texas (Shaw et al., 2023, pp. 11–15). The pink bollworm infected the cotton crop in that region and caused substantial economic losses in terms of reduced yields and treatment costs by growers over much of the twentieth century. Heavy applications of insecticides, e.g. chlorinated hydrocarbons and synthetic pyrethroids, by growers led to the evolution of resistance in pink bollworm populations. Pink bollworms are highly mobile insects and make farm-by-farm and localized control ineffective. Due to the evolution of resistance and the wide geographic incidence of the bollworm, areawide control programs were a preferred approach.

After experiencing significant losses from bollworm infestations in cotton crops, growers began coordinating their actions to address the pest and resistance issues in the early 1990s. What emerged was a multipronged and coordinated effort with significant roles for the grower working groups, state and federal government agencies, universities, and other entities to address this damaging pest. Bt cotton was commercialized in 1996 and was very effective in controlling pink bollworms. A Bt cotton working group collaborated with the U.S. Environmental Protection Agency and university scientists to design Bt cotton refuges to assure that serious areawide resistance did not evolve. This elaborate and mostly voluntary collaboration of private groups, public agencies, and scientists led to the eradication of the pink bollworm in 2018. Four factors were key to the success of the eradication efforts (Shaw et al., 2023, pp. 14–15):

- The pink bollworm was controlled with a diverse array of chemical and non-chemical tactics.
- The diverse tactics were applied in a socially organized, collective fashion with multiple decision-making bodies operating across vertical and horizontal networks.
- The control program relied on incrementalism, as programs expanded geographically and in complexity with strong scientific support by land-grant universities and Cooperative Extension, which aided buy-in by federal agencies.
- Successful completion required long timeframes with continued commitment by key stakeholders.

4.3 Circular food and energy systems

Schulte et al. (2021) explore how systemic approaches to food and energy production can address a suite of agroecological goals ranging from CPR management in biodiversity and climate resiliency to economic prosperity and job creation. One case study, the Italian Biogas Consortium, engages more than 700 Italian farmers and associated companies in circular production processes involving crops, livestock, and biogas in ways that also enhance air and water quality and biodiversity (Shulte et al., 2021, p. 386).

The Biogas Consortium lists the following motivations:

- . . . produce additional carbon via agricultural ecological intensification and revegetation of set aside land.
- . . . transform the additional carbon production into a material to enhance soil fertility and store more organic carbon in the soil, thereby decoupling organic fertilization by livestock industry growth.
- . . . diversify agricultural output in the food, feed, and energy and biomaterials markets. In this way, such services and products will attract more and more investments in agriculture and in organic soil fertilization via digestate. This will lead to an increased food and feed production, an increase in renewable bioenergy, and especially an increase in Soil Carbon Sequestration.
- . . . Biogasdoneright® thus becomes a key tool to accomplish widespread low cost and sustainable Bioenergy with Carbon Capture and Storage (BECCS) as IPCC recommended (Biogasdoneright, 2025, p. 26)

The development of these biogas models promoting ecological intensification has been voluntary and farmer-led. However, the consortium also engages with a broad group of stakeholders, including academic scientists, industry partners, and other institutions to inform their efforts. As such, it is an example of bottom-up collective action to address a broad range of resources and objectives. For example, participating farms employ diverse and intense rotations of crops which enhance the cycling of carbon, water, and nutrients while providing food products and inputs for anaerobic digesters to produce biogas and electricity. Residue from crops, cattle manure, and nearby industries produce soil amendments while avoiding the release of greenhouse gas emissions.

Their focus extends beyond CPR management to social and economic development by creating new jobs and the valorization of the territory (Biogas World, 2025). Two catalysts led to the creation of the consortium: (1) an existential challenge to the livelihoods of these farmers and (2) a change in national energy policy to stimulate more renewable energy, which provided guaranteed markets for farm-produced electricity through price incentives (feed-in tariffs). The consortium itself provides a range of services to the farmers, including technical assistance, field trials, and research collaboration with universities and consulting firms. Shulte et al. (2021) note that the Italian consortium model might be an adaptable policy framework in the developed world. Applications of the model in less-developed countries will be more challenging, likely requiring institutions that provide necessary capital to implement bioenergy coupled with ecologically intensive agriculture operations suitable for local social and economic conditions, and strategic actions that increase the wealth of rural communities while reducing unequal wealth distribution (Shulte et al., 2021, p.387).

5 Certification initiatives

The higher costs of bottom-up collective efforts to address national and global CPR challenges, e.g. climate change, make collective action at relevant scales less likely to materialize (Ostrom, 2009). Nonetheless, it's encouraging to see voluntary national and international certification programs growing, several in agriculture, that may help facilitate CPR collective management. Depending upon their purpose and structure, the certification system may embody one or more of the following design "principles" for sustainable CPR management (Ostrom, 1990, 2012):

1. Implement collective-choice arrangements that allow most resource appropriators to participate in the decision-making process.
2. Conduct effective monitoring of practices affecting CPR appropriation.
3. Institute graduated sanctions for resource appropriators who violate rules.
4. Create mechanisms of conflict resolution.
5. Higher level authorities recognize self-determination of the collective.
6. Organization may be in the form of multiple layers of nested (polycentric) enterprises.

Brief discussions of three certification efforts illustrate their potential and challenges for commons resource management. These experiences show that certification systems can engage public and private entities to help fill gaps in CPR governance. While voluntary certification often lacks the force of public regulation, e.g. fines, to secure compliance with CPR appropriation rules, public bodies may opt to adopt a certification program in their own policies. More often, it relies on shifts in managers' environmental values through education and training, market rewards from consumers and investors, and reduced regulatory risks. Business sustainability scholarship has found significant environmental practice responses to these tripartite forces (e.g. Ervin et al. 2012). In short, market rewards and the threat of government regulation can advance voluntary collective natural resource management.

5.1 High-performance green buildings

The built environment is responsible for nearly 40 percent of global carbon emissions, as generated during the construction and operation of buildings along with the manufacture of building materials. A leading example of the power and reach of bottom-up certification systems for addressing such global challenges as climate change is the green building market. The U.S. Green Building Council (USGBC) was formed in 1993 to convene disparate segments of the sprawling building sector (including universities, governmental bodies, and nonprofit organizations) to help stimulate practices that resulted in better and more resource-efficient buildings. To that end, USGBC members created the LEED$_{TM}$ certification system, a tiered system of requirements and optional credits that must be verified by third-party reviewers in order for a building to earn LEED certification status. Since then, the USGBC has certified over 197,000 building projects in 186 countries (https://www.usgbc.org/resources/usgbc-impact-report). A recent assessment of the impacts attributed to LEED over that period showed diverse environmental, economic, and human health effects (USGBC, 2024)

The USGBC draws on the deep expertise of its members serving on technical committees to periodically update LEED so that it continues to represent best practices and emerging challenges. Members recently voted to approve LEED 5.0 with its growing emphasis on climate change while also addressing performance objectives for energy, water, materials, landscape, and indoor health environment.

The USGBC model reflects one version of bottoms-up collective action and tools such as certification and education to help address CPR challenges. The overall model has met with success. Today, 74 Green Buiding Councils operate around the world, employing either LEED or comparable certification systems adapted to local needs and conditions.

5.2 International organic agriculture

Organics International, formerly IFOAM, the International Federation of Organic Agriculture Movements, is a membership organization of over 100 countries and territories working to '…bring true sustainability to agriculture across the globe'. Global organic agricultural production and sales continue to grow (IFOAM 2025). Global farming area devoted to organic production approached 100 million hectares in 2023 and is operated by 4.3 million farmers.

Global sales of organic products reached 136 billion euros in 2023, led by the U.S. with 59 billion euros in sales followed by Germany (16.1 billion euros) and China (12.6 billion euros).

One of Organics International's programs to assist the production and marketing of organic products is working to improve organic standards and verification (certification) (https://www.ifoam.bio/our-work/how/standards-certification). That program provides advice to policymakers, national organic movements, nongovernmental organizations, and others to develop sustainable and credible organic sectors. They also maintain an Organic Guarantee System, a global nonprofit independent evaluation program to understand which organic labels are trustworthy by producers, processors, retailers, and customers. They support and promote guarantee systems that facilitate market access for small producers such as Participatory Guarantee Systems (PGS) and Group certification. Their Internal Control System (ICS) for smallholder group certification makes it easier for organic smallholders to access third-party certification and organic markets.

It's important to note that while both the international organic agriculture and regenerative agriculture movements rely on certification systems, they generally have different emphases, objectives, and standards. Robert Rodale coined the concept of 'regenerative organic agriculture' in the 1980s to differentiate organic farming that goes beyond sustainable (Rodale Institute, 2014). In his formulation, the organic and regenerative concepts were complementary and additive. However, some regenerative certification systems, as reviewed in the next section, may not be complementary to the Organics International four principles of Health, Ecology, Fairness, and Care (https://www.ifoam.bio/why-organic/shaping-agriculture/four-principles-organic). In effect, they are competing visions of what constitutes progress on sustainable agriculture. To address these differences, Organics International recently posted 'Elevating Truly Regenerative Agriculture – Statement from the Organic Movement**'** that cautions against possible misuse and greenwashing in some regenerative agriculture schemes (https://www.ifoam.bio/news/elevating-truly-regenerative-agriculture). As noted, this sort of competition in visions and certification systems is not uncommon and will eventually be resolved by market and policy forces.

5.3 Regenerative agriculture

Multiple certification programs for regenerative agriculture have emerged of late. Two examples are:

1 Regenified for agriculture and forest operations (https://regenified.com/about-us/#verification-standard-container).

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2 Certified Regenerative (https://agreenerworld.org/certifications/certified-regenerative/) run by A Greener World (AGW)

Multiple certification efforts are not uncommon in immature markets and institutions. For example, the U.S. organic certification label was created in response to a wide array of stakeholders, e.g. producers, input suppliers, retailers, wanting a consistent national standard to unify a disparate array of local and regional programs (Youngberg and DeMuth, 2013).

Regenerative agriculture programs focus on restoring depleted ecological resource stocks. Regenified (2024), for example, states 'regenerative agriculture is farming and ranching in synchrony with nature to repair, rebuild, revitalize and restore ecosystem function starting with all life in the soil and moving to all life above the soil . . . serving as a catalyst for building soil organic matter, cycling nutrients, enhancing water infiltration and retention, while fostering healthy ecosystems'. Their focus is on progress in achieving outcomes consistent with regenerative principles, e.g. increases in soil organic content, biodiversity, and carbon sequestration. The program provisions help farmers transition their operations through education, technical assistance, graduated levels of performance requirements, and the opportunity to reap market premiums and government incentives for their products. Certified Regenerative, for example, is collaborating with the Rural Advancement Foundation International and Soil Health Institute, under a 3-year U.S. Department of Agriculture initiative, to 'increase regenerative farming practices accessibility and expand markets for small and underserved producers' offering an array of incentive payments and technical assistance.

Given that environmental challenges are large and increasingly interconnected, it's not surprising that regenerative agriculture's holistic approach has garnered action by influential think tanks and business associations in developed and developing countries (Macarthur Foundation, 2025; Rockefeller Foundation, 2024; World Economic Forum, 2024). As public interest grows, certification programs will likely continue to proliferate and become market tools for expanding the demand for regenerative-based agricultural practices. Likewise, we will likely see increased efforts, perhaps including government involvement, to assure transparency and independent verification of regenerative practices like AGW's certification programs to prevent 'greenwashing' claims.

A key objective of a regenerative agricultural system is the capacity to survive natural and social system shocks and bounce back to original or higher levels (Shulte et al., 2021). This resilience characteristic is essential to the regeneration of CPR in agricultural systems as extreme natural events, e.g. high temperatures, drought, precipitation, and fires, increase in frequency. A principal thrust in achieving that resilience must be managing common

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resources in ways that preserve and enhance their capacity to tolerate such shocks and restore system functioning:

> Policies that encourage shifts beyond 'sustainable' towards 'regenerative' food and energy systems are needed to support food production over the long-term while addressing climate change and other forms of environmental degradation. Regenerative systems capture and store carbon while also producing food and energy, supporting rural communities and improving the environment. Regenerative agriculture is imperative for addressing the persistent challenge of food insecurity, as several of its key drivers – poverty, war and conflict, and natural disasters – are expected to worsen with climate change.
>
> (Schulte et al., 2022, p. 387)

Despite their primary focus on the natural crises of climate change, soil degradation, and biodiversity loss, many regenerative initiatives lack key social dimensions. Some mention the importance of serving supply chains, the processing sector, and local communities. Others, like Certified Regenerative, do include sections addressing social factors including wages and benefits, workplace fairness practices, and safety measures (https://agreenerworld.org/certifications/certified-regenerative/certified-regenerative-standards/). To wit, their certification system states 'Principle 10.0: Humans are an integral part of farming and sustainability: Certified Regenerative holdings must be managed in a socially responsible way', and several sub-principles elaborate on the various aspects of responsibility to the humans involved in and impacted by their certification system. Human and social values, responsible governance, culture and food traditions, and a circular and solidarity economy are salient social elements in an agroecological framework (Barrios et al., 2020). These factors will no doubt influence the evolutionary path of regenerative agriculture.

6 Conclusion and lessons

This review of collective resource management theory and practice suggests four overarching lessons in using an agroecology framework to advance sustainable food systems. Priority research and education activities become apparent in articulating those lessons:

6.1 Collective resource management can be efficacious if targeted to socioecological situations with high potential for continuing stakeholder participation

Ostrom's theoretical and empirical research (1990, 2009) identify ten factors that significantly affect the likelihood of stakeholders to participate in CPR management programs based on cases from around the world. New studies are necessary to add contemporary evidence about the continuing relevance of those factors and possible new influential factors. Ecological and social drivers and constraints, e.g. climate change, farm structure, have changed significantly since the original case studies. New qualitative and quantitative studies are needed to affirm the importance of previous research and test for significant variables. As urged by the National Science Foundation and the National Academy of Sciences, those studies should be cast in convergence (transdisciplinary) frameworks with natural and social science disciplines and the active engagement of private and public stakeholders. A high educational priority is for universities and other research organizations to develop curricula that train undergraduate and graduate students in convergence (transdisciplinary) theory and applications, and the necessary changes in laboratories informed by convergence approaches on and off campus.

6.2 A universal template for implementing collective common pool resource management does not exist; program structure depends on the specific socioecological context

The implementation of a collective natural resource management program under an agroecology framework should begin with a baseline of salient social and ecological conditions. The process of designing and collecting this qualitative and quantitative information base makes for an excellent exercise with CPR stakeholders, students, and scientists who will be involved in the collective resource management. Armed with this transdisciplinary information, the program development can identify impactful stakeholders, including trusted leaders, for crucial roles to overcome a host of barriers to the program launch and sustained operation.

6.3 Collective natural resource management is a lengthy and non-linear process. Adaptive management will be necessary to adjust program operations for sustained progress

The pink bollworm eradication program took decades to succeed. Parties and institutions changed as new technologies were discovered, e.g. Bt cotton, and key stakeholders emerged. These adjustments suggest that building the social capital and institutions to sustain an effective CPR management program must be a long-term endeavor. Proven leadership, funding to support program operations and adjustments due to unexpected ecological and social developments make long-term social and financial commitments paramount.

6.4 Comprehensive stakeholder involvement from the outset is crucial to the science and practice of collective common pool resource management

As noted throughout this chapter, voluntary commons-based models and their potential to succeed vary widely depending on the nature of the resources and other local, social, and political factors. A basic tenet of Ostrom's CPR theory is the importance of engaging stakeholders from the onset to fully understand the socioecological conditions shaping the resource trajectory. This was prescient to the strong endorsements of convergence research by the National Science Foundation and the National Academies of Science, Engineering and Medicine to tackle wickedly complex sustainability challenges (NASEM, 2019; NSF, 2024). The wisdom of broad stakeholder engagement in research and policy has been argued in studies of ecosystem service valuation (Ruckelshaus et al., 2013), in pesticide resistance management (Shaw et al., 2023), and in collaborative governance more generally (Ansell and Gash, 2007). Aside from its crucial role in integrating experiential knowledge, it builds trust and reciprocity among appropriators. Furthermore, international development institutions are embracing the integration of experiential knowledge through inclusive stakeholder engagement in their programmatic efforts. As just one example, the Ellen MacArthur Foundation has launched a multi-stakeholder initiative of citizens, businesses, public bodies, communities, and others to discover ways to shift the global food system onto a healthier trajectory, including agro-ecological and regenerative food production components (https://www.ellenmacarthurfoundation.org/cities-and-a-circular-economy-for-food/overview) (e.g. MacArthur Foundation, 2025).

7 Where to look for further information

- Ostrom Workshop at Indiana University – https://ostromworkshop.indiana.edu/
- Digital Library of the Commons Repository – https://dlc.dlib.indiana.edu/dlc/home
- International Journal of the Commons – https://thecommonsjournal.org
- National Science Foundation (convergence research) – https://new.nsf.gov/funding/learn/research-types/learn-about-convergence-research
- National Academies of Science, Engineering and Medicine: *Fostering the Culture of Convergence in Research: Proceedings of a Workshop*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25271

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10 References

Ansell, C. and Gash, A. (2007) 'Collaborative governance in theory and practice,' *Journal of Public Administration Research and Theory*, 18(4), pp. 543–571. https://doi.org/10.1093/jopart/mum032.

Agrawal, A. (2003) 'Sustainable governance of common-pool resources: context, methods, and politics,' *Annual Review of Anthropology*, 32(1), pp. 243–262. https://doi.org/10.1146/annurev.anthro.32.061002.093112.

Ashenafi, Z.T. and Leader-Williams, N. (2005) 'Indigenous common property resource management in the central Highlands of Ethiopia,' *Human Ecology*, 33(4), pp. 539–563. https://doi.org/10.1007/s10745-005-5159-9.

Barrios, E. et al. (2020) 'The 10 elements of agroecology: enabling transitions towards sustainable agriculture and food systems through visual narratives,' *Ecosystems and People*, 16(1), pp. 230–247. https://doi.org/10.1080/26395916.2020.1808705.

Bergmann, N.T., et al. (2024) 'Herbicide-resistance management: a common pool resource problem?,' *Weed Science*, 72(2), pp. 117–124. https://doi.org/10.1017/wsc.2024.12.

Biogasdoneright (2025) Anaerobic digestion and soil carbon sequestration, a sustainable low cost, reliable and win-win BECCS solution. https://www.consorziobiogas.it/wp-content/uploads/2017/05/Biogasdoneright-No-VEC-Web.pdf (Accessed February 18, 2025)

Biogass World. https://biogasworld.com/companies/italian-biogas-consortium/ (Accessed February 18, 2025).

Bravetti,A., Padilla, P. (2018) An optimal strategy to solve the Prisoner's Dilemma. SciRep 8, 1948. https://doi.org/10.1038/s41598-018-20426-w.

Brundtland, G.H. (1987). *Our Common Future: Report of the World Commission on Environment and Development*. Geneva, UN-Document A/42/427.

Certified Regenerative. 2025. https://agreenerworld.org/about/ (Accessed February 15, 2025)

Certified Regenerative. 2025. https://agreenerworld.org/about/ (Accessed February 15, 2025)

Chhatre, A. and Agrawal, A. (2008) 'Forest commons and local enforcement,' *Proceedings of the National Academy of Sciences*, 105(36), pp. 13286–13291. https://doi.org/10.1073/pnas.0803399105.

Clark, W.C. and Harley, A.G. (2020) 'Sustainability science: toward a synthesis,' *Annual Review of Environment and Resources*, 45(1), pp. 331–386. https://doi.org/10.1146/annurev-environ-012420-043621.

Cox, M., et al. (2010) 'A review of design principles for community-based natural resource management', *Ecology and Society*, 15(4), pp. 4–38. http://www.jstor.org/stable/26268233. (Accessed February 1–6, 2025)

Dentzman, K. (2021) 'Community management of Herbicide-resistant weeds in the Pacific Northwest,' *Crops & Soils*, 54(2), pp. 8–13. https://doi.org/10.1002/crso.20107.

Dentzman, K. (2022). 'Governance of emerging pests and pathogens in production landscapes: pesticide resistance and collaborative governance', *Current Opinion in Environmental Sustainability*, 58, 1–8. https://doi.org/10.1016/j.cosust.2022.101220.

Dentzman, K. and Burke, I.C. (2021) 'Herbicide resistance, tillage, and community management in the Pacific Northwest,' *Sustainability*, 13(4), p. 1937. https://doi.org/10.3390/su13041937.

Dentzman, K., et al. (2025) 'Challenges and opportunities for embedding social science in pesticide resistance research and outreach,' *Pest Management Science* [Preprint]. https://doi.org/10.1002/ps.8687.

Dietz, T., et al. (2003) 'The struggle to govern the commons,' *Science*, 302(5652), pp. 1907–1912. https://doi.org/10.1126/science.1091015.

Ervin, D. et al. (2012) 'Motivations and barriers to corporate environmental management,' *Business Strategy and the Environment*, 22(6), pp. 390–409. https://doi.org/10.1002/bse.1752.

Ervin, D.E. et al. (2018) 'Farmer attitudes toward cooperative approaches to herbicide resistance management: a common pool ecosystem service challenge,' *Ecological Economics*, 157, pp. 237–245. https://doi.org/10.1016/j.ecolecon.2018.11.023.

Ervin, D.E. and Frisvold, G.B. (2016) 'Community-based approaches to herbicide-resistant weed management: lessons from science and practice,' *Weed Science*, 64(SP1), pp. 609–626. https://doi.org/10.1614/ws-d-15-00122.1.

Ervin, D.E.and Jussaume R.A. (2014) Integrating Social Science into Managing Herbicide-ResistantWeeds and Associated Environmental Impacts. *Weed Science*. 62(2):403-414. doi:10.1614/WS-D-13-00085.1

Franklin, A.B. et al. (2021) 'Range-wide declines of northern spotted owl populations in the Pacific Northwest: a meta-analysis,' *Biological Conservation*, 259, p. 109168. https://doi.org/10.1016/j.biocon.2021.109168.

Galt, R.E. et al. (2024) 'Agroecology and the social sciences: a half-century systematic review,' *Agricultural Systems*, 216, p. 103881. https://doi.org/10.1016/j.agsy.2024.103881.

Giller, K.E. et al. (2021) 'Regenerative agriculture: an agronomic perspective,' *Outlook on Agriculture*, 50(1), pp. 13–25. https://doi.org/10.1177/0030727021998063.

Gould, F., et al. (2018) 'Wicked evolution: can we address the sociobiological dilemma of pesticide resistance?,' *Science*, 360, pp. 728–732. https://doi.org/10.1126/science.aar3780.

Hardin, G. (1968) 'The tragedy of the commons,' *Science*, 162(3859), pp. 1243–1248. https://doi.org/10.1126/science.162.3859.1243

Hennessy, D.A. and Jia, Y. (2024) 'Pest susceptibility commons in agriculture,' *Agricultural Policy Review*, Winter 2024. Center for Agricultural and Rural Development, Iowa

State University. Available at: https://agpolicyreview.card.iastate.edu/winter-2024/pest-susceptibility-commons-agriculture.

Hess, C. and E. Ostrom (Eds) (2007) *Understanding Knowledge as a Commons The MIT Press eBooks*. https://doi.org/10.7551/mitpress/6980.001.0001.

International Federation of Organic Agriculture Movements (IFOAM) (2025) https://www.ifoam.bio/news/global-organic-area-continues-grow-2025.

Jackson, W. (1980) *New Roots for Agriculture*. San Francisco: Friends of the Earth.

Lam, W.F. (1996) Improving the performance of small-scale irrigation systems: the effects of technological investments and governance structure on irrigation performance in Nepal. *World Development*, 24, pp. 1301–1315.

Lam, W.F. (1998) *Governing Irrigation Systems in Nepal: Institutions, Infrastructure and Collective Action*. San Francisco: ICS Press.

Liebman, M. and Gallandt, E. (1997) 'Many little hammers: ecological management of crop-weed interactions.' In Jackson, L.E. (Ed.), *Ecology and Agriculture*. Washington, DC: Academic Press.

MacArthur Foundation (2025). Regenerative Agriculture. https://www.ellenmacarthurfoundation.org/articles/regenerativeagriculture#:~:text=Such%20a%20path%20could%20not,is%20called%20'regenerative%20agriculture. (Accessed February 16, 2025)

National Academies of Sciences, Engineering, and Medicine (NASEM) (2019) *Fostering the Culture of Convergence in Research: Proceedings of a Workshop*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25271.

National Academies of Science and Engineering (2014) *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond*. Washington, DC: The National Academies Press. https://doi.org/10.17226/18722.

National Science Foundation (2024) Growing Convergence Research. https://new.nsf.gov/funding/opportunities/growing-convergence-research-gcr

Oldham, P., et al. (2013) 'Biological diversity in the patent system,' *PLoS One*, 8(11), p. e78737. https://doi.org/10.1371/journal.pone.0078737.

Ostrom, E. (1990; reissued 2015) *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781316423936.

Ostrom, E. (2009) 'A general framework for analyzing sustainability of social-ecological systems,' *Science*, 325(5939), pp. 419–422. https://doi.org/10.1126/science.1172133.

Ostrom, E. (2010) 'Beyond markets and states: polycentric governance of complex economic systems,' *American Economic Review*, 100(3), pp. 641–672. https://doi.org/10.1257/aer.100.3.641.

Ostrom, E., et al. (1994) *Rules, Games, and Common-Pool Resources*. Ann Arbor: University of Michigan Press.

Ostrom, E., et al. (2012) *The Future of the Commons: Beyond Market Failure and Government Regulation*. London, UK: Institute for Economic Affairs. 104 p.

Partelow, S. et al. (2019) 'Privatizing the commons: new approaches need broader evaluative criteria for sustainability,' *International Journal of the Commons*, 13(1), p. 747. https://doi.org/10.18352/ijc.938.

Regenified (2024) Regenerative agriculture certification. https://regenified.com. (Accessed February 16, 2025)

Rockefeller Foundation (2024) Financing for regenerative agriculture. https://www.rockefellerfoundation.org/wp-content/uploads/2024/06/Financing-for-Regenerative-Agriculture-Final.pdf. (Accessed February 16, 2025)

Rodale Institute (2014) *Regenerative Organic Agriculture and Climate Change: A Down-to-Earth Solution to Global Warming*. Kutztown, PA: Rodale Institute. https://rodaleinstitute.org/why-organic/organic-basics/regenerative-organic-agriculture/. ((Accessed February 16, 2025)

Rodale, R. (1983). 'Breaking new ground: the search for a sustainable agriculture,' *Futurist*, 17(1), pp. 15–20.

Ruckelshaus, M., et al. (2013) 'Notes from the field: lessons learned from using ecosystem service approaches to inform real-world decisions,' *Ecological Economics*, 115, pp. 11–21. https://doi.org/10.1016/j.ecolecon.2013.07.009.

Saunders, F.P. (2014) 'The promise of common pool resource theory and the reality of commons projects,' *International Journal of the Commons*, 8(2), p. 636. https://doi.org/10.18352/ijc.477.

Schalger, E. (2002) 'Rationality, cooperation and common pool resources,' *American Behavioral Scientist*, 45(5), 801–819. https://doi.org/10.1177/0002764202045005004.

Schulte, L.A., et al. (2021) 'Meeting global challenges with regenerative agriculture producing food and energy,' *Nature Sustainability*, 5(5), pp. 384–388. https://doi.org/10.1038/s41893-021-00827-y.

Shaw, D.R., et al. (2023) 'Changing the paradigm for pesticide resistance management,' *Pest Management Science*, 79(12), pp. 4726–4730. https://doi.org/10.1002/ps.7709.

Tang, Y.S. (1994) 'Institutions and performance in irrigation systems.' In E. Ostrom, et al. (Eds.), *Rules, Games and Common-Pool Resources* (pp. 225–246). Ann Arbor: University of Michigan Press.

U.S. Green Boulding Council (USGBC) (2024) USGBC impact report. https://www.usgbc.org/resources/usgbc-impact-report (Accessed April 12, 2025)

Vernooy, R., et al. (2017) 'The roles of community seed banks in climate change adaption,' *Development in Practice*, 27(3), pp. 316–327. https://doi.org/10.1080/09614524.2017.1294653.

Wilson, J., et al. (2007) 'The precursors of governance in the Maine lobster fishery,' *Proceedings of the National Academy of Sciences*, 104(39), pp. 15212–15217. https://doi.org/10.1073/pnas.0702241104.

Woldesenbet, A.B., et al. (2020) 'Enset-based land use land cover change detection and its impact on soil erosion in Meki river watershed, Western Lake Ziway Sub-Basin, Central Rift Valley of Ethiopia,' *Environmental Systems Research*, 9(1). https://doi.org/10.1186/s40068-020-00198-x.

World Economic Forum. (2024) What is regenerative agriculture? https://www.weforum.org/agenda/2022/10/what-is-regenerative-agriculture/ (Accessed February 16, 2025)

Youngberg, G. and DeMuth, S.P. (2013) 'Organic agriculture in the United States: a 30-year retrospective,' *Renewable Agriculture and Food Systems*, 28(4), pp. 294–328. https://doi.org/10.1017/s1742170513000173.